A FIRE TO BE LIGHTED: THE TRAINING OF AMERICAN ASTRONAUTS FROM 1959 TO THE PRESENT

A Dissertation

by

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ABSTRACT

This study examines the training of American astronauts from the selection of the original *Mercury* astronauts in 1959 to the present, as crews of six work aboard the International Space Station. It makes the primary argument that through all of those years, the training sequence has successfully adapted to the challenges of preparing astronauts for flight far more than it has failed. It will examine in more detail than any previous publication how training devices for the *Mercury*, *Gemini*, *Apollo*, *Skylab*, Space Shuttle, and International Space Station programs helped astronauts to make this statement true. This study will also make the argument that the successful training of astronauts helped prove the value of sending them into space. Sessions at a variety of locales, from electronic flight simulators, to neutral buoyancy pools, to virtual reality laboratories have given astronauts the mental and physical flexibility in space missions that only they possess. In other words, they are not automatons, but rather people who can develop their skills through training.

This study will demonstrate that when their missions began, those skills contributed to spectacular successes in space. Astronauts have returned a bevy of scientific data from their scientific experiments in Earth orbit and from their walks on the Moon during *Apollo* thanks to their trained eyes and minds. They have also serviced the Hubble Space Telescope and constructed an International Space Station that is longer than a football field thanks to their training. As the 21st century continues, astronauts will journey on bolder missions to near Earth asteroids, back to the Moon, and onto

Mars. The instructors who train them for those missions, whether belonging to a government or a company, will benefit from reading this study because they will gain a sense of what training methods have worked historically and understand the tremendously strong track record of human accomplishments in space given adequate training.

DEDICATION

To the crews of *Apollo 1*, *STS-51L Challenger*, and *STS-107 Columbia*

In memoriam:

Apollo 1: Gus Grissom, Ed White, Roger Chaffee

STS-51L Challenger: Dick Scobee, Mike Smith, Ellison Onizuka, Judy Resnik, Ron McNair, Greg Jarvis, Christa McAuliffe

STS-107 Columbia: Rick Husband, Willie McCool, David Brown, Kalpana Chawla, Mike Anderson, Laurel Clark, Ilan Ramon

ACKNOWLEDGMENTS

Working on this project has allowed me to fulfill my dream of contributing to the history of human spaceflight. I fell in love with the subject when I was in elementary school in Cedar Falls, Iowa, reading about the exploits of the *Apollo* astronauts who saw the Earth as no one had ever seen it before, revealed new knowledge about another heavenly body, and above all else made the greatest adventures in human history. Almost twenty years later, I still have not lost the sense of wonder that I felt back then. Whenever I think about Frank Borman reading from the Book of Genesis while orbiting the Moon, John Young making his joyful leap from the lunar surface to salute the American flag or pumping his fist after the first landing of Space Shuttle *Columbia*, the quiet dignity and faith of Rick Husband, or even Clay Anderson's wisecracks, I am reminded of why I enjoy reading and writing about human spaceflight. The technical aspects of spaceflight have always intrigued me, and I have indeed written about many of them in this work. But I enjoy human spaceflight most of all because it involves people. These people have brought their talents and personalities to a new frontier and helped to expand the horizons of the human race. More than anything else, I want to acknowledge the opportunity to write such a lengthy work on a topic I love. For the most part, it did not even feel like work.

My journey at Texas A&M University began in the fall of 2013, and in the four years since, I have accumulated a list of people to thank. Dr. Jonathan Coopersmith served as my advisor. As a fellow enthusiast of spaceflight history who teaches a course to undergraduates on the subject, he kept up with my progress and offered helpful suggestions across all of my years in College Station. Dr. Jason Parker, Dr. Adam Seipp, and Dr. Walter Kamphoefner also agreed to serve on my committee despite my interest area being outside their primary field. Each has proven very helpful as I have taken their seminars and gone through their preliminary exams. I have also enjoyed working with other professors for the seminars I took from 2013 to 2015 and my Teaching Assistantships from 2013 to 2017. I served as a TA for Dr. Robert Resch, Dr. Armando Alonzo (who also gave me the chance to work on a research project in Texas history during the summer of 2014), Dr. Katherine Unterman, Dr. Charles Brooks, Dr. Anthony Stranges, Dr. John Lenihan, and Dr. Trent MacNamara, all of whom did excellent jobs as professors and allowed me to perform my assistantship effectively. I also want to recognize Dr. Lorien Foote, with whom I worked during two seminars and currently serves as Graduate Program Director. She has been very supportive during my time in College Station, especially with Professional Development workshops for graduate students. In the History department office, Kelly Cook, Barbara Dawson, Mary Johnson, and Rita Walker supported me and all the graduate students with administrative details. Finally, I want to recognize the fellow graduate students who I have enjoyed meeting over the last four years: Regina Alvarez, Hillary Anderson, Daniel Bare, Ray Batchelor, Doug Bell, Brittany Bounds, Andrew Brown, Jeff Crean, Rachel Gunter, Brooke Linsenbardt, Shane Makowicki, Jared McBee, Robin Roe, Tyler Thompson, Erika Weidemann, and Matt Yokell. I wish all of them the best in their academic journeys.

In 2015, I met another person who I must recognize. Having just read Henry Cooper's book *Before Liftoff: The Making of a Space Shuttle Crew*, I had embarked on the goal of writing a dissertation about the training of astronauts. I knew I needed a committee member from a department outside History, so I looked at the website for the Texas A&M Aerospace Engineering Department and found that a former astronaut named Greg Chamitoff, who had flown twice to the International Space Station, was part of that department. I sent him an email and received an almost immediate response from him agreeing to be on my committee and help in any way possible with my work on astronaut training. When I spoke to Clay Anderson for this project and the subject turned to his fellow "Penguin" from the astronaut class of 1998, he told me, "Chamitoff is so damn smart, though. He pisses me off, and you can tell him that!" But in addition to finding out about his intelligence, I found him extremely helpful. He answered a list of 12 questions that I sent him about his experience in training for spaceflight, writing several pages in doing so. He also introduced me via email to several people, both astronauts and Johnson Space Center instructors, with whom I would not have otherwise had the chance to speak. I am very happy that I sent that email to Professor Chamitoff in 2015.

A long list of people who have also assisted me with this project deserve my thanks as well. Astronauts Clay Anderson, Greg Chamitoff, Eileen Collins, Susan Helms, Joe Kerwin, Stephen Robinson, and Jim Voss all answered questions, as did instructors Pete Beauregard, Andy Foster, Juan Garriga, Dick Koos, Lisa Martignetti, Lucia McCullough, Dianne Murphy, Marc Reagan, Vince Shafa, Mark Sonoda, and

Mike Sterling. I thank each of them for their devotion to making American human spaceflight as successful as it has been, as well as taking time out of their schedules to share their training insights with me. Mr. Koos, one of the original Simulation Supervisors who joined NASA in 1960, even invited me into his home during my summer 2016 trip to Davenport, Iowa and showed me his memorabilia. For this project, I also made four archival trips: to the Johnson Space Center History Collection at the University of Houston-Clear Lake, to the John Glenn Collection at the Ohio State University, to the Sally Ride and David Brown Collections at the Smithsonian National Air and Space Museum, and to the Rick Husband Collection at Texas Tech University. The archivists at all four locations helped me find what I needed and I believe all of the collections have strengthened my work.

Finally, I thank my family for their support during this project and my time in College Station. I moved into my apartment with the help of my mother Elaine and stepdad Bill Brown in 2013, and have stayed in their home in Cedar Falls, Iowa during summer and winter breaks ever since then. I have also had the chance to stay with my sister Anne Wilmoth, brother-in-law Steve Wilmoth, and nieces Penelope and Stevie Wilmoth in Iowa City. As my journey has taken me from Cedar Heights Elementary School, to Peet Junior High School, to Cedar Falls High School, to the University of Iowa for my Bachelor’s degree, to Auburn University for my Master’s degree, to one year of teaching at Mountain View College in Dallas, Texas, to Texas A&M University for my Ph.D., my family has stayed supportive at each step.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supported by a dissertation committee consisting of Dr. Jonathan Coopersmith (advisor), Dr. Jason Parker, Dr. Walter Kamphoefner, and Dr. Adam Seipp of the Department of History and Dr. Greg Chamitoff of the Department of Aerospace Engineering.

Several interview participants shared their recollections of astronaut training, as noted in the footnotes and references.

All other work for the dissertation was completed by the student independently.

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NOMENCLATURE

ACCESS: Assembly Concept for Construction of Erectable Space Structures

ALFA: Air Lubricated Free Attitude

ALSEP: *Apollo* Lunar Surface Experiments Package

AMU: Astronaut Maneuvering Unit

AOA: Abort Once Around

APU: Auxiliary Power Unit

ASCAN: Astronaut Candidate

ASCS: Automatic Stabilization and Control System

ASIS: Automatic Sensing and Implementation System

ATDA: Augmented Target Docking Adapter

ATM: *Apollo* Telescope Mount

ATO: Abort to Orbit

BS: Bachelor of Science

CAIB: *Columbia* Accident Investigation Board

CapCom: Capsule Communicator

CCT: Crew Compartment Trainer

CCTV: Closed-Circuit Television

CD-ROM: Compact Disc-Read Only Memory

CM: Command Module

CMP: Command Module Pilot

CMS: Command Module Simulator

COSTAR: Corrective Optics Space Telescope Axial Replacement

CSM: Command/Service Module

DCPS: Dynamic Crew Procedures System

DDP: Digital Data Processor

DM: Docking Module

DOD: Department of Defense

DOUG: Dynamic Onboard Ubiquitous Graphics

DT: Johnson Space Center Training Division

EASE: Experimental Assembly of Structures in EVA

EMU: Extravehicular Mobility Unit

ERA: Environmental Research Associates

ERBS: Earth Radiation Budget Satellite

ESS: Errant Satellite Simulator

ET: External Tank

EVA: Extravehicular Activity

FAA: Federal Aviation Administration

FCSD: Flight Crew Support Division

FEU: Functionally Equivalent Unit

FDF: Flight Data File

FSL: Flight Systems Laboratory

GCTC: Gagarin Cosmonaut Training Center

GDP: Gross Domestic Product

GEDA: Goodyear Electronic Differential Analyzer

GMS: Gemini Mission Simulator

GSSC: Ground Support Simulation Computer

HHMU: Hand Held Maneuvering Unit

HQ: Headquarters

IA: Instructor Astronaut

IBM: International Business Machines

ICBM: Intercontinental Ballistic Missile

ILC: International Latex Corporation

ISS: International Space Station

IUS: Inertial Upper Stage

IVA: Intravehicular Activity

JEM: Japanese Experiment Module

JSC: Johnson Space Center

KGB: Komitet Gosudarstvennoy Bezopasnosti

KSC: Kennedy Space Center

LDEF: Long Duration Exposure Facility

LES: Launch and Entry Suit

LRC: Langley Research Center

LLRF: Lunar Landing Research Facility

LLRV: Lunar Landing Research Vehicle

LLTV: Lunar Landing Training Vehicle

LM: Lunar Module

LMP: Lunar Module Pilot

LMS: Lunar Module Simulator

LRV: Lunar Roving Vehicle

MA: *Mercury-Atlas*

MASTIF: Multiple Axis Space Test Inertial Facility

MCC: Mission Control Center

MDF: Manipulator Development Facility

MDM: Multiplexer/Demultiplexer

MER: Mission Evaluation Room

MET: Modularized Equipment Transporter

MIT: Massachusetts Institute of Technology

MM: Millimeter

MMU: Manned Maneuvering Unit

MOCR: Mission Operations Control Room

MPT: *Mercury* Procedures Trainer

MR: *Mercury-Redstone*

MS: Mission Specialist

MSC: Manned Spacecraft Center

MSFC: Marshall Spaceflight Center

NACA: National Advisory Committee on Aeronautics

NASA: National Aeronautics and Space Administration

NBL: Neutral Buoyancy Laboratory

NEEMO: NASA Extreme Environment Mission Operations

NOAX: Non-Oxide Adhesive Experimental

NOLS: National Outdoor Leadership School

OBSS: Orbiter Boom Sensing System

OMS: Orbital Maneuvering System

OPF: Orbiter Processing Facility

ORFEUS-SPAS: Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite

PC: Personal Computer

PEAP: Personal Egress Air Packs

PI: Principal Investigator

PLATO: Programmed Logic for Automatic Teaching Operations

PLSS: Portable Life Support System

POCC: Payload Operations Control Center

PPS: Private Psychological Conference

PS: Payload Specialist

PSI: Per Square Inch

RAM: Random Access Memory

RAND: Research and Development

RCA: Radio Corporation of America

RCC: Reinforced Carbon Carbon

RCS: Reaction Control System

RFP: Request for Proposal

RMS: Remote Manipulator System

RPM: Rotations Per Minute

RPM: Rendezvous Pitch Maneuver

RTG: Radioisotope Thermoelectric Generator

RTLS: Return to Launch Site abort

SAFER: Simplified Aid for EVA Rescue

SBS: *Satellite Business Systems*

S/C: Spacecraft

SCA: Shuttle Carrier Aircraft

SCE: Signal Conditioning Equipment

SEAL: Sea, Air, and Land

SES: Systems Engineering Simulator

SFRM: Spaceflight Resource Management

SHIFT: *Spacehab* Intelligent Familiarization Trainer

SIM: Scientific Instrument Module

SIMFAC: Real-Time Simulation Facility

SimSup: Simulation Supervisor

SLS: Space Launch System

SMEAT: *Skylab* Medical Experiments Altitude Test

SMS: Shuttle Mission Simulator

SPAN: Spacecraft Analysis Room

SPAS: Shuttle Pallet Satellite

SPS: Service Propulsion System

SRB: Solid Rocket Booster

SSME: Space Shuttle Main Engine

SSR: Staff Support Room

SST: Single System Trainer

STA: Shuttle Training Aircraft

STA: Shuttle Tire Ablator

STG: Space Task Group

STIF: Space Telescope Imaging Spectograph

STL: Station Training Lead

STS: Space Transportation System

TAL: Transatlantic Abort

TDRS: Tracking and Data Relay Satellite

TDS: Translation and Docking Simulator

TFNG: Thirty-Five New Guys

TPS: Thermal Protection System

USA: United Space Alliance

USAF: United States Air Force

USGS: United States Geological Survey

USS: United States Ship

VAB: Vehicle Assembly Building

VHF: Very High Frequency

VIP: Very Important Person

VMS: Vertical Motion Simulator

VRL: Virtual Reality Laboratory

WETF: Weightless Environment Training Facility

WIF: Water Immersion Facility

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CHAPTER I

INTRODUCTION

Two astronauts standing in the Lunar Module (LM) heard the familiar voice of Capsule Communicator (CapCom) Charlie Duke: "*Eagle*, you are Go for powered descent." A few minutes later, *Eagle's* descent engine fired at an altitude of 50,000 feet and began the long braking maneuver that would culminate in the vehicle coming to a complete stop on the surface of the Moon. But the LM pilot and flight controller Steve Bales each found a critical glitch with *Eagle's* computer: a 1201 program alarm. Bales realized that this meant the computer was overloaded with tasks and going through software restarts. This suggested the computer would not have the capacity to guide the crew through the landing. Given that the powered descent sequence only took about twelve minutes, Bales knew he had little time to make a decision. He finally decided that he could not let the crew continue with a balky computer. He would have to tell Flight Director Gene Kranz the disappointing news that the Moon landing was scrubbed.

"Flight, Guidance," he said. "Something is wrong in the computer. I've got a bunch of computer alarms. Abort the landing…Abort!"

Kranz relayed the call to Duke, who told the astronauts. In seconds, they jettisoned the LM descent stage and ignited the ascent stage engine. The two astronauts were on their way back to a rendezvous with their crewmate in the Command Module. Their planned landing site in the Sea of Tranquility would remain untouched by human hands. With that decided, Dave Scott and Jim Irwin climbed out of the simulator. Both the astronauts and the flight controllers would need to participate in a debriefing session with lead Simulator Supervisor Dick Koos, who had just instituted the computer alarm into the landing sequence. Koos explained the severity of the problem, then offered his startling conclusion: “This was not an abort. You should have continued the landing.” According to Koos, Bales should have quickly understood that despite the overflow message, the computer still maintained the capacity to keep the LM guidance system and thrusters in operation while updating crew displays. He should have unflappably told Kranz, “We’re Go on that alarm.” Instead, he had called for an abort with undue haste.[1]

When Bales left the Mission Control Center (MCC) on that afternoon of July 5, 1969, he knew that Neil Armstrong and Buzz Aldrin were at their Cape Kennedy crew quarters that very moment. 400,000 Americans from government, industry, and academia had contributed to an *Apollo* program that had cost billions of dollars in taxpayer money, but in two weeks the success of *Apollo* would depend on Armstrong and Aldrin working in concert with the flight controllers of the Manned Spacecraft Center (MSC, later renamed the Johnson Space Center [JSC]). If a glitch arose in *Eagle’s* machinery, either an astronaut or a controller would need to know how to respond. If somebody made a wrong response during that twelve minute period, two possibilities beckoned. Armstrong and Aldrin might abort and return home with the knowledge that they had failed in their mission, only to find out later that the abort had been unnecessary. Or *Eagle* might crash, splatter Armstrong and Aldrin onto the Sea of

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[1] Gene Kranz, *Failure Is Not An Option: Mission Control From Mercury to Apollo 13 and Beyond* (New York: Simon & Schuster, 2000), 267-271.

Tranquility, and the world would mourn the first American astronauts lost in space.

Fifteen days later, the controllers learned a lesson about the value of the training process. The millions of people watching or listening to the landing sequence on July 20 had no idea about the training session of July 5. Even Armstrong and Aldrin were unaware. But when Aldrin called out during the descent, "Program alarm. It's a 1202," Bales, Duke, Kranz, and their colleagues in the MCC backroom all remembered the simulation.[2] After consulting with computer engineer Jack Garman in the backroom, Bales determined that the landing could continue. The decision saved the mission, but the controllers could not make the actual landing themselves. As *Eagle* passed through 2,000 feet, Duke quietly told Kranz, "I think we better be quiet from here on, Flight![3] The touchdown depended instead on Armstrong, too busy to speak to controllers because he was searching for a suitable landing site. The *Apollo 11* Commander had studied maps of the Moon containing the landmarks he would fly past. He had spent 383 hours in the LM simulator, a machine that mimicked every switch and readout of the real vehicle. He had also spent time flying the Lunar Landing Training Vehicle (LLTV), a vehicle featuring a single jet engine that could be adjusted to cancel five-sixths of the vehicle's weight, thus simulating flight in lunar gravity.[4] This late in the descent, his training took precedence over that of the flight controllers. He found a safe site amid a crater and boulder field, precisely controlling the LM's lateral motion and rate of descent, and finally spoke to the waiting world after his vehicle came to rest: "Houston,

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[2] Ibid, 288.

[3] Ibid, 290.

[4] James R. Hansen, *First Man: The Life of Neil A. Armstrong* (New York: Simon & Schuster, 2005), 321-465.

Tranquility Base here, the *Eagle* has landed."

Each of the men involved in this twelve-minute sequence was tremendously accomplished on his own merits. For instance, Bales had earned an engineering degree from Iowa State University and had spent several years working in the Flight Dynamics Branch during the *Gemini* and *Apollo* programs. His superiors trusted him enough to give him a flight controller assignment for *Gemini XI*, when he was only 23 years old.[5] Garman had earned an engineering degree from the University of Michigan and had also been hired at a young age to specialize in *Apollo* computers.[6] Armstrong occupied his own remarkable niche in the history of aviation even before *Apollo 11*, given his combat missions in Korea and groundbreaking flights aboard the X-15 aircraft. Yet prior to the mission, each of these men shared another title in addition to their glamorous jobs and achievements: student. This title owed to the reality that they needed to undergo training to assure themselves and the National Aeronautics and Space Administration (NASA) that they could carry out their mission successfully. As two scholars have written, "The success of any organization depends on appropriate use of human assets available in the organization. All other assets could only be supplementary to human assets…The organization has to concentrate necessarily on developing the ability, wisdom, and skills of its workforce."[7] The *Apollo* spacecraft, containing over a million parts between the Command/Service Module (CSM) and Lunar Module, was the most complex machine

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[5] Billy Watkins, *Apollo Moon Missions: The Unsung Heroes* (Westport: Praeger, 2006), 3-6.

[6] John R. Garman, Interviewed by Kevin M. Rusnak, March 27, 2001, Houston, Texas, http://www.jsc.nasa.gov/history/oral_ histories/GarmanJR/GarmanJR_3-27-01.pdf (accessed February 6, 2016).

[7] Chidambaram Vijayabanu and Ramachandran Amudha, "A Study on Efficiency of Employee Training: Review of Literature," *Business: Theory and Practice* Vol. 13, No. 3 (2012): 275.

ever devised. No one person could know each part in detail. This underscored the importance of a team of instructors determined to test human resources, the astronauts and flight controllers, under the most realistic simulated conditions possible. Nearly half a century after the triumph of *Apollo 11*, instructors from around the world still work closely with astronauts.

This dissertation will examine the training of American astronauts from the day the "Original Seven" *Mercury* astronauts reported for work in 1959 through the present, as crews of six live and work aboard the International Space Station (ISS). It will make the primary argument that from *Mercury* to the ISS, the training sequence has met the challenges of preparing astronauts for flight far more than it has failed. It will address several training inadequacies, but the plethora of oral and written evidence from nearly sixty years overwhelmingly indicates that the benefits have outweighed the drawbacks. This dissertation will demonstrate why this is true in more detail than any previous publication, by taking a program by program and a mission by mission approach to training. It will also make the argument that the successful training of astronauts has helped prove the value of sending them into space. Scientists, especially physicists and astronomers, have criticized the idea of sending humans into space since the *Mercury* era. These scientists have pointed out that robotic vehicles can return data from space at a lower cost than human vehicles, and with no risk to life.[8] But robotic vehicles lack the mental and physical flexibility that astronauts have brought into space through their

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[8] Roger D. Launius and Howard E. McCurdy, *Robots in Space: Technology, Evolution, and Interplanetary Travel* (Baltimore: The Johns Hopkins University Press, 2008), 17.

training. Astronauts have carried out tasks that would not have been possible on purely automated missions, from flying manual reentries into Earth's atmosphere, to making equipment repairs during Extravehicular Activities (EVAs), to exploring the Moon far more extensively than possible using only robotic technology. The decision to pursue human spaceflight has brought about all of these successes, and the reason they are successes is that astronauts have brought trained minds to space. This dissertation will therefore explore how training empowered humans to draw upon the skills that they uniquely possessed.

The idea that astronauts needed to train to contribute useful tasks on space missions did not simply happen inevitably. When the *Mercury* program began, the Space Task Group (STG) at NASA's Langley Research Center (LRC) in Virginia needed to make an organizational determination of what astronauts could contribute. In 1959, without any human spaceflight experience to draw upon, Robert Voas gave the "Original Seven" tasks that made them systems engineers, scientific observers, and even pilots of the vehicle's attitude.[9] This demonstrated the desire of the STG members to make astronauts much more than mere passengers while aboard a spacecraft, and to a much greater extent than the Soviet cosmonauts in training at the same time.[10]

What did this organizational determination portend for astronaut training? It meant that the construction of training technology would have to reflect the desire to

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[9] Robert B. Voas, "Astronaut Training," in *Mercury Project Summary* (Washington, D.C.: NASA SP-45, 1963), 173-175.

[10] Slava Gerovitch, *Soviet Space Mythologies: Public Images, Private Memories, and the Making of a Cultural Identity* (Pittsburgh: University of Pittsburgh Press, 2015), 98.

assign astronauts significant tasks. Although the software in the *Apollo* Lunar Module had the ability to guide the vehicle to a safe touchdown on the Moon, the Commander on all six moon landings took manual control during the final phase of descent.[11] Despite the prowess of the software aboard the Space Shuttle orbiters, the Commander on all missions took manual control during the last five minutes of the descent. Whether hovering above the lunar surface to search for a safe landing site or closing in on a shuttle runway on a glideslope seven times steeper than a commercial airliner, human judgment augmented onboard software.[12] The construction of the Lunar Landing Training Vehicle and Shuttle Training Aircraft (STA) for astronauts followed this determination to assign astronauts these functions. The determination to allow astronauts from the *Mercury* era through the Space Shuttle era the tasks of managing systems and maneuvering the vehicle, especially during emergencies, meant that crews would also need high fidelity simulators of their spacecraft cockpits. The determination to allow astronauts the task of repairing equipment such as the *Hubble Space Telescope* meant that crews would need an underwater facility to replicate EVAs. The determination to send astronauts to the Moon meant that crews would need geology instruction to take best advantage of the greater physical and mental flexibility they offered over robot explorers.

This dissertation will painstakingly examine the evidence that these devices succeeded in their task of helping astronauts become well prepared to meet the

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[11] David Mindell, *Digital Apollo* (Cambridge, MA: The MIT Press, 2008), 6.

[12] Stephen Clark, “How Does NASA Train Pilots to Land the Space Shuttle?” May 25, 2010, *Spaceflight Now*, http://www. spaceflightnow.com/shuttle/sts132/100525landing/ (accessed February 4, 2016).

challenges that their flights would present to them. The chapters will cover every program to date: *Mercury*, *Gemini*, *Apollo*, *Skylab*, *Apollo-Soyuz*, Space Shuttle, and ISS. The discussion of each program will begin with an assessment of the training devices used for it: what purpose the devices served and the astronauts' comments about them (the instructors valued the astronauts' opinions as users of spaceflight technology). The ultimate indication of the success of training would come with the astronauts' performances in flight. The discussion of each program will therefore move on to describe the spaceflights. Although well-known and written about extensively, the flights are still instructive when examined from a standpoint of how training aided the astronauts. The discussion of each program will then end by briefly describing what lessons the training experience can offer in understanding the history of spaceflight.

The training of astronauts has evolved both quantitatively and qualitatively over the nearly sixty years from the introduction of the *Mercury* astronauts to the present. In his training to become the first American to orbit Earth aboard *Friendship 7* in 1962, John Glenn spent 60 hours in a procedures trainer preparing for a flight about five hours long.[13] When Ed White trained to become the first American to make an EVA in 1965, he spent only 12 hours in an Air Bearing Facility and a handful of hours in a KC-135 aircraft preparing for his brief jaunt outside the *Gemini IV* cabin. Yet as the duration and complexity of the flights increased, training needed to keep pace. The training staff dramatically expanded as President John F. Kennedy made his commitment to send humans to the Moon by the end of the 1960s and the responsibility for supporting human

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[13] See Chapter 3 of this dissertation.

spaceflight moved to a lavishly funded new facility in Texas in 1962. By this point, a division at the new space center had become devoted to training personnel.[14] By the time the *Apollo 11* crew trained for the first Moon landing, Neil Armstrong and Buzz Aldrin spent close to 1,300 hours in training on a bevy of tasks Glenn could not have foreseen in 1962: from simulations in two spacecraft, to docking, to rendezvous, to a lunar landing, to geological exploration once outside the lander on the lunar surface.[15] Though the first few astronaut groups consisted entirely of pilots, who expressed initial reluctance in focusing on scientific tasks such as lunar geology training, this dissertation will argue that those who ultimately reached the Moon embraced their lunar geology training. The *Apollo* astronauts convincingly reframed the identity of the astronaut corps around prowess in scientific tasks as well as piloting tasks, and this would not have been possible without this commitment to geology training.[16]

Though later astronauts did not travel as far from Earth as the *Apollo* Moon crews, the training time and level of sophistication only increased. For instance, each member of the *STS-124* crew in 2008 spent about 1,940 hours in training, meaning they spent six hours in training for every hour spent in space. The 50 International Space Station expeditions since 2000 have proven to be the ultimate endurance test in training, because crews must spend 24-30 months in training, during which time they must learn the Russian language and make overseas visits to Russia, Europe, and Japan. This dissertation will demonstrate that these later crews benefited from a level of

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[14] See Chapters 3 and 4 of this dissertation.

[15] See Chapter 7 of this dissertation.

[16] See Chapters 6, 7 and 8 of this dissertation.

sophistication in training that increased thanks to advances in computers that could more accurately simulate the space environment and even provide a virtual reality experience beginning in 1993. The crews of Space Shuttle and International Space Station missions also benefited from a training experience that became more standardized over time, as training personnel and astronauts learned what priorities to emphasize after an increasing number of astronauts had been exposed to the experience. Astronauts even began to give formal training advice through an Instructor Astronaut program beginning in the Space Shuttle era. Today, astronauts must balance a schedule that includes flying from site to site, making speaking engagements, and serving in Astronaut Office management positions, but training continues to be the heaviest burden on their time.[17]

A scholar who does not specialize in the history of spaceflight might wonder why a work on astronaut training is relevant to the scholarly community at large. Astronaut training emerged in the post-World War II years, as the training of workers in the United States entered a new era. In her essay on the subject, Deborah Alpert Sleight explains the major developments. During the economic boom of the 1940s and 1950s, companies sought more efficient and less expensive methods of training workers. The most popular way of doing this became giving workers individualized instruction, meaning instructors gave workers programmed materials divided into small steps which the learner could easily understand. The instruction could be presented in book form, or inserted into a teaching machine, which two authors of a 1962 document described as, “devices that house, display, and present printed programmed instruction…Feedback is given when

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[17] See Chapters 12, 13, 14, and 15 of this dissertation.

the program is advanced through actuation of a lever, knob, or button, and the correct answer comes to view." By this point, organizations using individualized instruction methods had made serious strides in reducing learning time, producing a low error rate for learners, and improving learning through immediate feedback. With the development of Computer Based Training on mainframe computers in the 1970s came a more modern form of individualized instruction that utilized the speed and visual displays of these machines. By the last decades of the 20th century, Sleight explains that the United States had become a "knowledge society" in that "it emphasizes intellectual work more than manual work—the mind more than the hands." Given the high amount of knowledge needed to perform this work, instructors increasingly provided workers with job support tools to assist them. Job support tools provide workers with step by step instructions on how to perform a task and are designed for use on or just before a task.[18]

When the *Mercury* astronauts began training for spaceflight, their circumstances made them exceptional compared to the workers who Sleight focuses upon in her work. First, they were training for a task that had no person had ever done before. Training was not cut and dried at this point, because no person had yet experienced the sensations of riding a rocket into space, experiencing extended weightlessness, and hurtling back through Earth's atmosphere. The second chapter of this dissertation will explain how this resulted in *Mercury* instructors overtraining the astronauts and even exposing them

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[18] Deborah Alpert Sleight, "A Developmental History of Training in the United States and Europe," 1993, *Michigan State University*, https:/www./msu.edu/~sleightd/trainhst.html (accessed March 13, 2017)..

to training facilities deemed unnecessary for future programs, once instructors had better understood how spaceflight affected the human body. Second, astronauts belonged to a government organization rather than the companies in the private sector who Sleight mainly focuses upon. The prestige of the United States during the Cold War would be riding on their efforts, which placed a premium on the need to spend money for training facilities that would help ensure humans would not be the weak link in human spaceflight operations. Third, the instructors who would teach them would not actually take part in the task they were teaching; they would not fly in space themselves. Fourth, the training of astronauts focused on a small number of highly skilled people rather than the mass numbers of semi-skilled or unskilled workers that Sleight mentions in her history of training.[19]

But the instructors and astronauts from *Mercury* to the ISS were not completely isolated from the post-World War II developments mentioned by Sleight and the more than two dozen scholars that she cites. Instructors provided astronauts with individualized instruction by preparing copious written material on spacecraft systems for them. Although Sleight mentions the expense of individualized instruction as one of the drawbacks of this method, astronaut training began as a well funded institution given the national prestige at stake and has remained robustly funded ever since. As explained in the twelfth chapter of this dissertation, astronaut instructors favored Computer Based Training during the 1970s as a modern form of individualized instruction. Instructors quickly embraced this new training technology when it became available. Sleight also

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[19] Ibid.

mentions a specialized form of Computer Based Training called embedded training. This refers to "incorporating training functions, either in whole or in part, into an operational system." Embedded training was a development that emerged primarily in the military to prepare soldiers for tasks such as air-to-air engagement and air combat maneuvering. But training to operate spacecraft from *Mercury* to the ISS has also entailed astronauts using expensive simulators that have incorporated training functions into an operational system. Astronauts have made use of the job support tools that Sleight mentions as well. These include the checklists that they have brought with them on missions and, in recent years, the videos they watch aboard the ISS that provide them with training in the scientific experiments they have to perform.[20]

The training of astronauts has therefore fit into the pattern of late 20th century training developments in American society and can serve as a positive case study of an organization striving to successfully teach new skills. Each chapter of this dissertation will explore ways that training helped astronauts solve unexpected glitches, in addition to demonstrating that astronauts have taken a far more positive than negative view of the training devices they have used over the years. Each chapter will also show that training adapted to meet new challenges, from the *Mercury* era when the goal was simply to send humans into orbit aboard a phone booth sized cockpit, to the rendezvous and EVA of the *Gemini* era, to the geological exploration of the *Apollo* era, to the long duration missions of the *Skylab* and ISS eras, to the international cooperation of the Space Shuttle and ISS eras. Throughout these years, as these new challenges required astronauts to train to

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[20] Ibid.

develop new skills, an institutional culture developed where astronauts valued training and received encouragement if they felt they needed additional training. Shuttle Commander Eileen Collins explains that NASA adopted a philosophy of instituting malfunctions into simulations as a way of forcing astronauts into mistakes that would make them better prepared when on an actual mission.[21] Though this dissertation will focus on spaceflight, scholars must understand that organizations throughout the United States and the world, whether in the public or the private sector, must adapt to new challenges through creative approaches to training.

Several scholars have indeed written books about the need for organizations to become "learning organizations" that adapt to meet new challenges. For instance, Michael Marquardt wrote in 2011, "Unless an organization continuously adapts to the environment via speedy, effective learning, it will die."[22] Though Marquart's book focused on organizations in the private sector, other scholars have made the case for learning as an essential component of success in government organizations. "In today's highly globalized world, a persuasive argument can be made that the organizations that most need to adapt to changing times are the large organizations in national or local governments," wrote a Malaysian scholar in 2005. "Employees' skills…and an organizational learning culture are worth far more than government's physical assets."[23] The work on training and organizations illustrates that the study of astronaut training is

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[21] Eileen Collins, Phone Interview by Author, January 12, 2017.

[22] Michael J. Marquardt, *Building the Learning Organization: Achieving Strategic Advantage Through a Commitment to Learning* (Boston: Nicholas Brealey Pub., 2011), 1.

[23] Malek Shah Bin Mohd. Yusoff, "The Public Service as a Learning Organization: The Malaysian Experience," *International Review of Administrative Sciences* Vol. 71, No. 3 (2005): 463-466.

not an isolated field without any value to the larger scholarly community. The world in the 21st century is shifting more and more towards the "knowledge society" that Sleight describes, because as Marquart writes, "knowledge workers now outnumber industrial workers by 4 to 1."[24] These workers who must process vast quantities of information to perform their jobs cannot expect to succeed without training. Astronaut training is relevant because it reflects a widespread development throughout modern society: teaching complex tasks to workers whose jobs require knowledge and not simply physical labor.

This dissertation will make extensive use of primary sources, which abound for an undertaking as large, expensive, and exciting as human spaceflight. These primary sources have taken the form of entire books by astronauts and flight directors, material available online such as the JSC Oral History Project, and archived material such as the JSC History Collection at the University of Houston-Clear Lake, the John H. Glenn Archives at The Ohio State University, and the astronaut collections at the National Air and Space Museum, Texas Tech University, or Purdue University. A few secondary sources are also helpful in understanding astronaut training. The NASA History Office has produced detailed histories of the *Mercury*, *Gemini*, and *Apollo* programs that devote attention to preflight preparation. Journalist Henry S.F. Cooper broke new ground in his book on the training of Space Shuttle crewmembers for a 1984 mission, while historian David Mindell provided great insight in his book into the human-machine interaction in the *Apollo* program (this interaction shaped the design of the spacecraft and thus the

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[24] Marquardt, 11.

simulators intended to train humans). This dissertation will refer to these sources but break new ground by making new arguments and covering training methods more thoroughly than any previous publication.

This dissertation is organized chronologically. Astronaut training began with the era of the one-man *Mercury* spacecraft, the focus of the second and third chapters. Although no person had yet flown in space in 1959, NASA officials understood that the tasks of the first astronauts would most closely resemble the tasks of America's most qualified pilots. Instructors consequently drew upon techniques and equipment from the aviation industry in originating the training of the seven test pilots who became the *Mercury* astronauts. These chapters will therefore delve into the training of National Advisory Committee on Aeronautics (NACA) pilots prior to the *Mercury* program, then describe the astronauts' initial training runs aboard *Mercury* simulators in Virginia and Cape Canaveral. They will also describe the astronauts' detailed feedback on the training runs and the effectiveness of sending highly trained astronauts into space as indicated in the six successful piloted flights of the *Mercury* program.

The fourth and fifth chapters will examine new developments in the *Gemini* program that followed *Mercury*. Whereas *Mercury* astronauts could only fire thrusters to control their attitude, *Gemini* astronauts were able to change their orbits, rendezvous, and dock with other vehicles. The latter astronauts thus rehearsed their complex flight maneuvers with simulators containing digital computers equal to the task and even scene generators to give them a realistic view of space outside the simulator windows. The astronauts scheduled to make the first EVAs also underwent a detailed process of preparation aboard the KC-135 aircraft and in underwater facilities. These chapters will offer an assessment of the fidelity of these training methods. Not every training decision worked, especially concerning EVA, and so this chapter will identify lessons learned from *Gemini*. Yet these chapters will also recount the extensive evidence from the flights themselves that the training aided astronauts in demonstrating the unique skills they could bring to spaceflight.

The sixth, seventh, and eighth chapters will assess the *Apollo* program that sent Americans to the Moon. *Apollo* astronauts operated in the most complex simulators constructed to date, in order to train for procedures that were unprecedented and remain unequaled since the program ended. Crews needed to train for the powered descent sequence to the lunar surface, for instance, as well as the LM rendezvous and docking with the CSM that followed liftoff from the surface. They would even need to prepare for the period when they passed over the far side of the Moon and lost contact with flight controllers. Two of the three astronauts from each mission walked on the lunar surface, where they brought tools of exploration that robots could not match in part due to extensive training. The point of walking on the Moon was to capture the lunar geological environment as accurately as possible through words to scientists on Earth and collection of rock samples to return to Earth. Although the astronauts chosen to explore the lunar surface each had backgrounds in piloting rather than geology (except for *Apollo 17's* Harrison "Jack" Schmitt), each successfully developed an aptitude for geology after undergoing the training sequence. The attention within NASA to ensuring the astronauts were highly prepared for their tasks meant that *Apollo* remains a compelling example of what humans can accomplish rather than automatons.

The next chapters will focus on the flights which followed lunar exploration, which used *Apollo* hardware but sent crews to Earth orbit. The ninth and tenth chapters will discuss the challenges associated with training the nine men who lived aboard the space station *Skylab* in 1973 and 1974. Though these men would not travel as far away from Earth as their *Apollo* predecessors, they would spend up to 84 days in orbit and thus needed much more instruction in the operation of microgravity experiments. The crews received lectures from Principal Investigators on the theory behind each experiment, then a presentation on the equipment and procedures needed to operate them. This made for a more demanding training process than that experienced by any previous crew, but also the collection of compelling scientific data in orbit that demonstrated the potential of sending highly trained humans there. The eleventh chapter will then discuss the training effort for the first joint mission in the history of human spaceflight. Tom Stafford, Vance Brand, and Deke Slayton trained in the Soviet Union, while cosmonauts Alexei Leonov and Valery Kubasov trained in the United States prior to the 1975 *Apollo-Soyuz* mission. The Americans then became the last astronauts to fly aboard an *Apollo* spacecraft when they docked with the *Soyuz*. This chapter will demonstrate how their mission pioneered the concept of international training that guides American and Russian human spaceflight today.

The twelfth, thirteenth, and fourteenth chapters will assess America's longest human spaceflight program. The Space Shuttle era brought about a new challenge for astronaut training upon the approval of the vehicle in 1972, because the Commander needed to pilot the orbiter to a landing at the end of a mission rather than make a splashdown. The orbiter also carried a complement of additional astronauts, called Mission Specialists, who performed experiments, operated orbiter equipment, and made EVAs but did not pilot the vehicle. Payload Specialists from outside the space agency also flew on select missions. The twelfth chapter will provide a brief overview of the entire program, assessing the equipment and procedures designed to simulate shuttle flights for each of these astronaut types. The thirteenth and fourteenth chapters will then delve into the chronology of the program and the flight results that justified the training process. As the years passed and the program recovered from the 1986 *Challenger* disaster, new emergency procedures for which the astronauts needed to train took shape. Astronauts prepared to bail out of the orbiter using an escape pole and rely on survival equipment located in their Launch and Entry Suit. Simulation technology also progressed, as indicated by the use of virtual reality for the *STS-61* mission, the first to service the *Hubble Space Telescope* in 1993. The loss of the *STS-107* crew aboard the shuttle *Columbia* in 2003 brought the program to a second prolonged delay, but also spurred the adoption of new training methods oriented around safety. Instructors taught astronauts to operate an orbiter boom sensor system to allow them to search for damage to their Thermal Protection System, to make a pirouette maneuver that exposed the orbiter's underside before docking to the ISS, and even to repair tile damage if necessary. As they had since *Mercury*, NASA officials had made a determination of what astronauts could accomplish and devised sophisticated training methods in accordance with their ideas. As a result, astronauts demonstrated their talent in contributing to spaceflights.

The fifteenth chapter will examine the latest era of human spaceflight. In 1993, the administration of Bill Clinton reached an agreement to send American astronauts to the existing Russian space station *Mir* and then work with Russia on the new ISS. This meant that Americans would have to travel to Russia, overcome the language barrier in working with cosmonauts and instructors, and adjust to new methods of preparation. This chapter will assess how Americans and Russians overcame their differences during the Shuttle-*Mir* program that launched the first American into space from Russian soil in 1995 and concluded in 1998. It will then move on to the ISS, which has housed multinational crews continuously since November 2, 2000. When Americans began living aboard the ISS in stints of several months, the preparation process differed from the preparation for one to two week shuttle flights. The timeline for ISS crewmembers was relaxed, which affected simulator training. Staying aboard a station for several months also posed a psychological challenge for crewmembers, which affected the selection and training of crews. This chapter will therefore demonstrate that the ISS era has marked a major turning point in the history of astronaut training. Some of the tasks for which 1960s astronauts trained, such as piloting and geology, are no longer prevalent. ISS astronauts must instead train to operate experiments, perform hardware maintenance, and adapt psychologically to long duration flight. But once again, training has helped these astronauts to deliver scientific results that help to justify the human presence in space. This chapter will bring the saga of human spaceflight to the present day, as new spacecraft such as NASA's *Orion*, the SpaceX *Dragon*, and the Boeing

Starliner undergo development. No matter which of these spacecraft prove to be most successful, the astronauts and instructors working on them should understand what training approaches have worked best in the nearly sixty years since the *Mercury* astronauts reported for work.

CHAPTER II

MERCURY: "IT WAS ALL BRAND NEW"

Training for the historic act of sending the first Americans into space began at the southeast tip of the historic Virginia peninsula. Just north of Hampton, a town English settlers had visited shortly after their 1607 arrival in the New World, a group of engineers had worked attempting to solve the problems of high-speed flight for several decades. Shortly after the formation of the NACA in 1915, a selection board chose this site for a facility called the Langley Aeronautical Laboratory based on the temperate climate and location alongside a tidal river that would allow flying above both land and water.[1] In April 1959, seven young men named Scott Carpenter, Gordon Cooper, John Glenn, Virgil "Gus" Grissom, Wally Schirra, Alan Shepard, and Deke Slayton found themselves walking here amid an expanse of laboratories, wind tunnels, and airplane hangars. The men worked at seven desks inside a block-walled building that dated back to World War I.[2]

In a nearby building, engineers at a new organization called NASA (having replaced NACA less than one year earlier) gave speeches to busloads of visitors. "The Space Task Group has found the seven astronauts inspiring young men with whom to work," the engineers repeatedly stated. Since they would need the "detailed knowledge

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[1] James R. Hansen, *Engineer in Charge: A History of the Langley Aeronautical Laboratory, 1917-1958* (Washington, D.C.: NASA SP-4305, 1986), 11.

[2] Neal Thompson, *Light This Candle: The Life and Times of Alan Shepard, America's First Spaceman* (New York: Crown Publishers, 2004), 177.

and skills that a pilot of a pioneering orbital space capsule must possess," the seven were currently undergoing "an extensive program of training, indoctrination, and specialized education."[3] Yet at the time of these speeches, the facility housed only the most primitive of devices designed to mimic the *Mercury* spacecraft. A collection of analog computers sat alongside a replica instrument panel, which sat above a couch for the seven to sit.[4] What training devices would guide the astronauts in their quest to become the first humans to visit space, and what people would guide them in their efforts? Were the seven taking part in a stunt, which would only result in their returning to their respective military services in a few years, or was this the beginning of a new line of work? These questions remained to be answered in 1959, but already the *Mercury* astronauts could point to two inventions that had made simulations of complex flights possible: replica cockpits and analog computers.

The use of a flight simulator was not new by the time the seven *Mercury* astronauts reported for work. When military aviation blossomed during the 1910s, Americans and Europeans each understood the need to teach the skills of piloting to large groups of people. After World War I ended, the expansion of flights carrying freight, mail, and paying passengers further established this need. As New Yorker Edwin Link barnstormed the country and gave flying lessons during the 1920s, he wondered if a device designed to simulate flying could cut down on the cost of teaching the masses to

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[3] James R. Hansen, *Spaceflight Revolution: NASA Langley Research Center From Sputnik to Apollo* (Washington, D.C.: NASA SP-4308, 1995), 43.

[4] Charles C. Alexander, James M. Grimwood, and Loyd S. Swenson, *This New Ocean: A History of Project Mercury* (Washington, D.C.: NASA SP-4201, 1966), 240.

fly. His experience manufacturing air-driven pianos and church organs in his father's factory led him to a specific idea of how to do this: build an air-driven device that could simulate the motions of an aircraft. By 1929, he had developed the first modern flight simulator: a machine where a pilot could sit inside a replica cockpit, manipulate the control stick, and feel compressed air tilt the cockpit in a corresponding direction. The pilot would then look at a replica instrument panel, which would tell him the state of the aircraft. In Thomas Hughes's concept of a technological system, Link's invention marked the first step in the evolution of flight simulation that eventually influenced spaceflight. The U.S. Army Air Corps became Link's first customer, buying six of his simulators in the 1930s. Army officials realized that during flights in nighttime or bad weather, pilots would benefit from experience in instrument flying and that this experience did not have to come while in the air. The Link simulator could give this to them more cheaply and less dangerously, and thus over half a million Allied pilots undertook training in the numerous simulators purchased by the Army during World War II.[5] To return again to Hughes's theory, flight simulation as a technological system had now reached a second step because it had transferred from Link to a major institution.

Though the Link simulator only mimicked the motions of aircraft simply and inexactly, the invention provided a critical building block for spaceflight simulators in several ways. The Link was the first machine that demonstrated flight training did not have to take place while in actual flight, an advantage that would enormously benefit astronauts given the enormous cost of launching people into space. The Link could

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[5] David Allerton, *Principles of Flight Simulation* (Chichester, UK: John Wiley & Sons, Ltd., 2009), 1-3.

move, giving pilots a physical sensation of their actions when they pitched, rolled, and yawed the simulator. This meant that pilots could also become disoriented, just as astronauts later would aboard space simulators, but work on remaining calm and precisely monitoring their instruments. The Link allowed early pilots to practice emergency drills, which would become a linchpin of astronaut training. The Link also included an instructor sitting nearby, who would monitor the pilots' actions just as generations of instructors would later monitor astronauts' actions.[6] But this machine did not provide the precision to replicate the exact motions of aircraft. Flight simulation as a technological system had thus reached a third stage, in which a problem (what Hughes called a reverse salient) holds up the growth of the system. Especially after World War II, when military aviators might have to operate aircraft under grim conditions in the Cold War, researchers at the NACA High Speed Flight Station (based at California's Edwards Air Force Base) wanted to eliminate the problem by precisely simulating the motions of aircraft that could surpass Mach 1.

Fortunately, the analog computer allowed them to do this during the decade after Chuck Yeager became the first pilot to break the sound barrier in 1947. For centuries, humans have experimented with mechanical devices that gather data by measuring continuous changes in physical quantities, and then use this data to make calculations. But the development of the electronic analog computer in the twentieth century opened a new range of possibilities in simulating flight. Engineers could use these computers to model (hence the name analog) the equations guiding the six degrees of freedom along

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[6] Ibid.

which aircraft would move.[7] The United States Air Force (USAF) thus bought a set of Goodyear Electronic Differential Analyzer (GEDA) computers in 1952. "We were asked if we could simulate the F-100 on a GEDA," remembered Dick Banner, referring to the supersonic jet that would eventually become a crucial tool in the Vietnam War. In the mid-1950s, "to the best of my knowledge, we were the first at NACA, Edwards, to simulate aircraft motions on a computer." Major universities began offering classes in analog computation at this time as well.[8] Thus at the moment that Soviet and American engineers were preparing to launch the first artificial satellites into Earth orbit, and contemplating the launch of the first humans, a machine that would prove vital in conducting spaceflights and training for them entered engineers' toolkits.

The NACA managed to combine analog computers with replica cockpits beginning with simulations for the X-2 research aircraft. For the first time, engineers had combined the two critical building blocks to spaceflight simulators. The first replica cockpit in the Flight Simulation Lab consisted of a seat, an instrument panel, a hydraulic-powered control stick, and rudder pedals. When a pilot manipulated the stick, he provided the required inputs into the equations that the computer calculated to guide the mock aircraft. The pilot even saw visual displays out the window to heighten the fidelity of the simulation. The simulation engineers only gradually convinced the pilots they sought to train of the importance of their work. The older NACA pilots remained skeptical of the value of ground-based simulations during the mid to late 1950s. Yet the

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[7] Ibid, 4.

[8] Gene L. Waltman, *Black Magic and Gremlins: Analog Flight Simulations at NASA's Flight Research Center* (Washington, D.C.: NASA SP-4520, 2000), 1-7.

newer pilots "not only accepted the idea but in some cases insisted on the development of such simulators," according to simulation engineer Gene Waltman.[9]

Dick Day, one of the preeminent engineers at the High Speed Flight Station, understood the critical importance of analog computers. In his presentation at a 1959 meeting for the upcoming flights of the X-15 research aircraft, he said, "Prior to the general acceptance of the analog computer, essentially no ground-training devices were employed by NASA in guiding flight testing of research airplanes. Rather, gradual in-flight buildup to design conditions was depended upon. However, certain types of control problems are not amenable to this approach since they are characterized by abrupt and violent instabilities." Thus the speed of computers became critical in modeling the behavior of aircraft and thereby understanding the motions that could threaten the vehicle and its pilot.[10] The tragic death of Mel Apt aboard the X-2 aircraft in 1956, after he lost control of the vehicle due to roll coupling, especially prompted a renewed emphasis on simulating these dangerous conditions.[11] Thanks to the rise of electronic analog computing that followed World War II, and the creative minds at the nation's leading aviation research organization that knew how to apply this new capability, the era of precision in flight simulation had gained a foothold.

The simulation of high-speed aircraft flight reached a crescendo with the X-15. This NACA/NASA vehicle first flown in 1959 still holds the speed (4,519 miles per hour) and altitude (67 miles, beyond the Kármán line recognized as denoting the

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[9] Ibid, 9-10.

[10] Ibid, 173.

[11] Hansen, *First Man*, 148.

boundary between Earth's atmosphere and space) records for a piloted, powered airplane. Since the large aerospace company North American Aviation won the contract to manufacture the X-15, North American built a simulator of the aircraft linked to six analog computers. Though their flights only lasted about ten minutes, X-15 pilots spent fifteen to twenty hours preparing for each one. Historians have noted the shortcomings of the X-15 simulator in mimicking flights, such as the lack of motion and rudimentary displays out the window.[12] Yet in historical context, this machine is one of the most critical building blocks for spaceflight simulation. Waltman explained why when he remembered, "The X-15 simulator was the first complete ground-based simulation built by the FSL (Flight Systems Laboratory) for pilot training, mission planning, and research purposes."[13]

The method by which pilots prepared for X-15 flights especially bore a resemblance to astronaut training. The pilots first performed several missions on the simulator that progressed as intended, with no hardware failures. They had a chance to offer feedback at this point if they had any suggestions. But during subsequent simulations, the pilots had to respond to a "malfunction generator" capable of simulating the failure of 23 aircraft systems. If an engine failed, for instance, they had to quickly ascertain what emergency landing site they could reach. "To date, this type of training program has been of great value to the X-15 program," declared NASA's Dick Day in

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[12] Mindell, 53.

[13] Waltman, 9.

1961.[14] Generations of astronauts would build on the legacy of the X-15 simulator when they undertook a training program characterized first by successful simulations, then by troubled simulations that tested their problem solving skills. Astronauts would also have to prepare to follow detailed checklists while traveling at several times the speed of sound and while steeply descending from a space environment to air environment, building on the legacy of this simulator. Neil Armstrong, the youngest of NACA's X-15 pilots, summarized the device as "probably the best simulator that had ever been built up to that time, in terms of its accuracy and dependability."[15]

X-15 pilots also foreshadowed the training of future astronauts through their runs on the Navy's centrifuge in Johnsville, Pennsylvania. Researchers had long understood that the era of hypersonic flight would require preparation in not only the piloting aspect, but also the medical aspect. Would flight at several thousand miles per hour produce a force of gravity so strong that pilots would be unable to function? With the goal of answering this question, Navy officials spent over $2 million on a centrifuge arm that spun pilots located in a small gondola attached to it, so as to expose them to high G forces. This aspect of the X-15 pilots' training combined the elements of the two essential building blocks for spaceflight simulation, in that the gondola featured a replica X-15 cockpit and made use of analog computers so that the gondola could precisely mimic X-15 flight motions. Once again, the centrifuge runs began with the intention of

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[14] Dennis R. Jenkins, *X-15: Extending the Frontiers of Flight* (Washington, D.C.: NASA SP-2007, 2007), 281-282 and Armed Forces-National Research Council Committee on Bioastronautics, *The Training of Astronauts: Report of a Working Group Conference* (Washington, D.C.: National Research Council Pub. 873, 1961), 5-14.

[15] Hansen, *First Man*, 150.

simulating a nominal X-15 flight. But the next step in the training program was to simulate emergency conditions, which could expose pilots to an accelerations as great as 8 Gs. These runs provided a crucial learning experience for the *Mercury* astronauts, because pilots showed they could monitor instruments without blacking out even at accelerations this high, so long as the vehicle he was riding in contained restraints.[16] Armstrong even handled 15 Gs and remained conscious despite the massive loss of blood from his head. He then coauthored a report on the results which declared that high forces of gravity would not be a showstopper for pilots.[17]

As the X-15 pilots underwent their training, aviation medical specialists were already looking ahead to the selection and training of pilots who would make the first flights into orbit. In February 1957, two doctors at the School of Aviation Medicine in Texas wrote a report on the subject. The problems they foresaw with spaceflight ranged from the physical (acceleration forces of up to 9 Gs, according to then current research) to the psychological (the separation of pilots from Earth aboard a tightly confined spacecraft). Based on these issues, the doctors concluded that the first astronauts should come from the ranks of experienced pilots of high-performance aircraft. They recommended that the astronauts should also exhibit strong motivation, a strong ability to cooperate with associates, positive interpersonal attitudes, and emotional stability. They also predicted the most useful forms of astronaut training: academic instruction

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[16] Jenkins, 287-294.

[17] Hansen, *First Man*, 149-150.

and experience in simulators and near-space conditions.[18]

The two doctors were prescient in their analysis, except for one point: they foresaw the first astronauts reaching orbit aboard a winged vehicle like the X-15. The future of American spaceflight beyond the fringes of Earth's atmosphere lay not with vehicles like the X-15, but with small capsules launched atop rockets. This was the "quick and dirty" approach to sending the first Americans into space, ideally ahead of the competing Soviet program. A flurry of events in 1958 quickly established this as a national priority: the birth of NASA in October, the formation of NASA's Space Task Group of engineers who gathered at the Langley Research Center to ascertain the details of the first piloted spacecraft beginning in November, and the announcement of Project *Mercury* in December. The STG quickly established the guidelines of *Mercury* flights: the *Redstone* and *Atlas* boosters, both originally designed for military use, would be adapted to launch an astronaut into space aboard a bell-shaped capsule. On initial flights, the *Redstone* would send the vehicle to a suborbital altitude of just over 100 miles and a speed of just over 5,000 miles per hour. On later flights, the *Atlas* would send the vehicle into orbit, where it would fly around the Earth once every ninety minutes at a speed of 17,500 miles per hour. The vehicle would then fire retrorockets to decelerate, rotate so that the heat shield faced forward, and plunge through Earth's atmosphere to a splashdown.[19]

But what would an astronaut have to do during this time? The romantic era of

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[18] Henry C. Dethloff, *Suddenly, Tomorrow Came…A History of the Johnson Space Center* (Washington, D.C.: NASA SP-4307, 1993), 118.

[19] Hansen, *Spaceflight Revolution*, 38.

pilots exerting complete control over their vehicles had passed, replaced by automation. One of the *Mercury* spacecraft contractors at the McDonnell Aircraft Corporation stated in a 1959 presentation, "If everything goes well and if the operator desires, the mission may proceed through launch, boost, orbit, reentry, and rescue without the astronaut turning a hand, since the automatic systems and the ground environment can control the vehicle." But he said in the same presentation, "The presence of a trained operator is very important for the success of the mission through the secondary control that he exercises."[20] NASA officials working on the *Mercury* program felt the same way, and this organizational determination would guide astronaut training through the Space Shuttle era. The space agency could have treated the person aboard the vehicle as strictly a passenger at the mercy of automated maneuvers, and therefore placed the need to train that person on the backburner. Yet the STG members and the contractors at McDonnell made the wise decision that astronauts could contribute vitally to *Mercury* missions. This meant that astronauts would need training in the operation of the spacecraft.

Why was this a wise decision? Consider the failure rates of missions during the first years of the Space Age, beginning with the Soviet launch of *Sputnik* in 1957. The Soviets successfully launched the first two Earth orbiting satellites that year, but in the U.S. the *Vanguard* attempt to orbit a satellite ended in catastrophe. In 1958, the Soviets had one success against four failures. The U.S. had seven successes against ten failures. In 1959, the Soviets had three successes against one failure. The U.S. had eleven

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[20] Armed Forces-National Research Council Committee on Bioastronautics, 15.

successes against eight failures.[21] The high failure rate confirmed that the reliability of automated space technology needed improvement. Test pilots had experience in evaluating unreliable technology and making recommendations on how to improve it. These pilots possessed human brains, easily more powerful than any computer, which could experience firsthand the operation of the vehicle and therefore provide feedback that telemetry data on a screen could not provide. The feedback could improve the safety of the spacecraft for future missions. If an automated system malfunctioned, which was not a rare event as the statistics indicated, pilots could also manually guide the vehicle to safety. Finally, sending humans into space aboard a *Mercury* spacecraft marked the first step in a sequence that resulted in the *Apollo* Moon missions. The mental and physical flexibility of humans in exploring another celestial body would provide a key advantage for human spaceflight.

A variety of people deserve credit for making this organizational determination, both at NASA and McDonnell. Electronics specialists felt the most strongly biased in favor of automation and against manual control in the *Mercury* spacecraft. Even some of the most influential figures at the STG, such as Chris Kraft and spacecraft designer Max Faget, favored automation. Faget recalled, “The thing would work without them, no doubt about it, and I to this day said that’s (automation) the way to do it, of course, because we didn’t know what they’d do when they got up there, how they’d react and all

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[21] James Schefter, *The Race: The Uncensored Story of How America Beat Russia to the Moon* (New York: Doubleday, 1999), 98-99.

that."[22] Yet two groups of people argued in favor of giving astronauts critical tasks aboard the spacecraft. Not surprisingly, the test pilot community comprised the first group. Human factors engineers comprised the second group. These engineers specialized in the interaction between machines and the people intended to use them, and based on this expertise argued that the option of human intervention would make *Mercury* operations more robust.[23] Since the *Mercury* astronauts had not yet been selected when this argument began, and therefore did not yet have a chance to voice their own opinions, they owed these people a debt of gratitude for advocating on their behalf.

Some of this advocacy took place at McDonnell. John Yardley, the chief spacecraft designer at McDonnell, favored the idea of a human role aboard the spacecraft. In February 1959, the contractor hired a "human engineering expert" named Edward R. Jones. Jones performed a statistical computation of the implications of failures in the automated systems aboard the *Mercury* spacecraft, and concluded that the astronauts served a vital function through their flexibility in responding to failures of these systems. He wrote in a memo to Yardley, "A vast number of potentially different potential malfunctions may occur in the capsule's systems, and the isolation of these malfunctions can be extremely difficult. Mission reliability determinations assume the astronaut can detect and operate these systems without error." By the end of 1959, he

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[22] Alexander, Grimwood, and Swenson, 177 and Maxime A. Faget, Interviewed by Jim Slade, June 18 and 19, 1997, Houston, Texas, http:// http://www.jsc.nasa.gov/history/oral_histories/FagetMA/FagetMA_6-18-97.htm (accessed February 22, 2016).

[23] Alexander, Grimwood, and Swenson, 193-195.

made a more strident statement in a presentation for the American Rocket Society: "Serious discussions have advocated that man should be anesthetized or tranquilized or rendered passive in some other manner in order that he would not interfere with the operation of the vehicle…As equipment becomes available, a more realistic approach evolves. It is now apparent with the *Mercury* capsule that man, beyond his scientific role, is an essential component who can add considerably to systems effectiveness when he is given adequate instruments, controls, and is trained." Jones therefore recommended training the astronauts in procedures simulators. By the end of 1959, Yardley and Jones had convinced the bulk of engineers at the contractor that they should treat astronauts as a vital component of the spacecraft.[24]

The advocate of the human role who would become most essential to astronaut training, however, was NASA's Robert Voas. Voas had been educated as a psychologist, before working for the Navy on human factors aspects of naval aviation such as pilot selection, training, and operations. The Navy then assigned him to the STG, where he was instrumental in devising a criteria for the selection of the first astronaut group and then administering their training program.[25] Voas gave his most detailed public explanation of the human role aboard *Mercury* in a presentation at Boston's Human Factors Society on September 14, 1960. He argued, "Because of the limitations in the present state-of-the-art of engineering, ensuring…reliability is difficult, perhaps impossible, without man. The astronaut can make his greatest contribution by

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[24] Alexander, Grimwood, and Swenson, 193-195.

[25] Mindell, 76.

detecting malfunctions and taking corrective actions to overcome them."[26] Astronauts were necessary, then, to serve as "systems managers" in case of such malfunctions. He also listed the other basic astronaut functions during a flight: monitor the critical sequences of a flight, navigate and maneuver the vehicle, communicate with the ground, make research observations, and participate in launch and recovery operations.[27]

Besides making statements that favored a strong human role aboard the *Mercury* spacecraft, Voas made clear that astronauts would be anything but idle between flights. He planned for the astronauts to contribute to spacecraft design at the McDonnell plant in St. Louis, Missouri, participate in the development of procedures and equipment, and disseminate information to the public.[28] Voas had thus made an organizational determination that astronauts should be much more than passengers aboard a *Mercury* spacecraft, or "spam in a can" as some of their test pilot brethren called them. The astronauts therefore can serve as one case study in what scholars Nelly Oudshoorn and Trevor Pinch call "the co-construction of users and technology." These scholars expanded upon the theory of social construction of technology to make an argument about the importance of users in consuming, modifying, domesticating, designing, reconfiguring, and resisting technological development.[29] Those at NASA and McDonnell who worked on the *Mercury* spacecraft valued the contributions of the

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[26] Robert B. Voas, "A Description of the Astronaut's Task in Project *Mercury*" (Presentation, Fourth Annual Meeting of the Human Factors Society, September 14, 1960), 20.

[27] Ibid, 4.

[28] Ibid, 18-19.

[29] Nelly Oudshoorn and Trevor Pinch, eds., *How Users Matter: The Co-Construction of Users and Technologies* (Cambridge, MA: MIT Press, 2003).

"users" who would ride and operate it. Voas mentioned in his 1960 presentation that, "Shortly after the astronauts reported to Project *Mercury*, they were given an opportunity to go to McDonnell, view the capsule mockup and make suggestions for the crew-space layout, instrumentation, and manual-control system. These early contributions resulted in a number of significant improvements in these areas…The astronauts also aid in the *Mercury* program by contributing to the development of operational procedures for the vehicle, the launching site, and the range."[30]

While these critical organizational decisions were being made, the space agency went through with the selection of the *Mercury* astronauts. Despite initial consideration of divers, balloonists, submariners, and mountain climbers, the STG members made the decision to choose military test pilots in December 1958. Given the experience that military test pilots had with operating complex machinery and the risks that came with it, accumulating technical knowledge, and accepting discipline, the engineers at Langley considered them the best choices and President Dwight Eisenhower agreed.[31] Voas remembered that the additional criteria for selection reflected his wish for an astronaut group that would require as little training as possible. All applicants needed to be less than 40 years old, less than five feet eleven inches, in excellent physical condition, have a bachelor's degree, be a graduate of test pilot school, and be a qualified jet pilot with at least 1,500 hours of flight time. Voas and two colleagues screened the records of 508 pilots and found 110 who met the criteria. A selection committee consisting of

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[30] Voas, "A Description of the Astronaut's Task in Project *Mercury*," 18-19.

[31] Matthew H. Hersch, *Inventing the American Astronaut* (New York: Palgrave Macmillan, 2012), 14-26.

engineers and medical specialists then winnowed the 110 down to seven by April 1959. Scott Carpenter, Gordon Cooper, John Glenn, Gus Grissom, Wally Schirra, Alan Shepard, and Deke Slayton were, in Voas's opinion, so healthy, highly motivated, and experienced that they made it "possible to utilize self-instruction to a great extent and thus to minimize the amount of formal group training required."[32] But the STG members were determined to prepare the seven to react to any conceivable emergency aboard a vehicle no pilot had ever flown before, and this meant a group including Voas, Joseph Loftus, and Raymond Zedekar needed to devise a training program. By the time the seven first reported for work at Langley on April 27, Voas had completed the first outline.[33]

His training program reflected the unique circumstances surrounding *Mercury*. When the seven took the stage at Washington D.C.'s Dolley Madison House for their first press conference on April 9, the national media lauded them to such a degree that the famous *New York Times* columnist James Reston wrote, "Those gloomy students of the American character who think we've lost the hop on our fastball should have been around here this week when seven young American men dropped into Washington on their way to outer space."[34] In the Cold War environment of 1959, when the Soviets had already embarrassed the U.S. by launching the first satellite into orbit and wished to launch the first person there as well, the men needed to do nothing more than show up at

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[32] Robert B. Voas, "Project *Mercury* Astronaut Training Program" (Presentation, Symposium on Psychophysiological Aspects of Spaceflight, May 26-27, 1960), 23-24.

[33] Dethloff, 125.

[34] James Reston, "The Sky's No Longer the Limit," *New York Times*, April 12, 1959.

a press conference to capture the American imagination. The *Mercury* program also cost over $200 million of taxpayer money. Given these factors, catastrophic pilot error during a *Mercury* flight would devastate the American public and NASA. Voas thus wanted a level of reliability in the astronauts' performance that he described as "unusual" in his summary of *Mercury* training. He also pointed out that unlike new aircraft pilots, the seven could not train while in flight.[35] On their very first flights, the spacecraft could endanger their lives if any critical system malfunctioned. This placed a premium on ground-based training and suggested that when in doubt, Voas and his colleagues should over train the astronauts.

Mercury training certainly reflected this, as Deke Slayton wrote in a 1961 essay called "Pilot Training and Preflight Preparation." He recalled, "Since no ground rules existed for the training of astronauts at the inception of the program, three basic philosophies were adopted: utilize any training device or method which has even remote possibilities of being of value; make the training as difficult as possible with these devices even though analytical studies indicate the task is relatively easy; and conduct the training on an informal basis except in the interests of intelligent scheduling of trainer and trainer time since we were all assumed to be well motivated mature individuals."[36] Over the last two years, Slayton had crisscrossed the country training on devices designed to simulate conditions that in some cases were very unlikely to take

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[35] Voas, "Astronaut Training," 172.

[36] Donald K. "Deke" Slayton, "Pilot Training and Preflight Preparation," in *Results of the First U.S. Manned Suborbital Spaceflight*, June 6, 1961, Box 60, Folder 20, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

place on a *Mercury* mission. But Robert Voas and his colleagues did not have a textbook on astronaut training and could not guarantee the first space missions would go according to plan. This meant testing a variety of training devices to ensure the astronauts were at the peak of their ability should a malfunction endanger the mission or their lives. Slayton reflected, "As expected, some facets of the training program proved to be of relatively little value and will probably be eliminated from future training. On the other hand, some items proved to be of very great value, and we will probably place much greater emphasis on these facets in future training."[37]

The administration of the program took shape soon after the seven reported to Langley. Robert Voas headed a training committee that included Bill Douglas, George Guthrie, and Raymond Zedekar. Every Friday morning, these men would meet to review the astronauts' training schedule for the upcoming week, approve it, and report it to Chuck Mathews, the Chief of the Operations Division at Langley. In the afternoon, they would discuss the agenda with the astronauts.[38] The instructors understood that the training devices and manuals still needed to be built, so they immersed the seven in classroom studies instead during their initial months on the job. They also decreed that each astronaut should exercise at least four hours and fly aircraft at least three hours per week.[39] "The physical activity was important not only in ensuring a high level of fitness at the time of launch but it also served the purpose of giving the pilot an opportunity to relax from the pressing technical problems which occupied the majority of his day,"

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[37] Ibid.

[38] Dethloff, 126.

[39] Alexander, Grimwood, and Swenson, 235.

Voas explained, although the requirement to exercise a certain number of hours per week was eventually removed.[40] The flight requirement reflected his argument, with the strong encouragement of the astronauts themselves, that the seven should keep up their piloting proficiency. Voas and the astronauts reasoned that piloting was an essential part of the astronauts' professional identities and that the seven should maintain their proficiency in making decisions that carried life or death consequences. Training aboard a simulator did not carry these consequences, but actual flight did. The Air Force consequently loaned them F-102 and F-106 aircraft and began a tradition in the astronaut corps that continues to this day with T-38s.[41]

The classroom training for new recruits also set a precedent that continues into the 21st century. Langley engineers and scientists gave the astronauts 42 hours of lectures in 1959, divided between elementary mechanics and aerodynamics (10 hours), space physics (12 hours), principles of guidance and control (4 hours), space navigation (6 hours), communication (2 hours), and basic physiology (8 hours).[42] Deke Slayton expressed his opinion that "all of us needed to brush up on basic mechanics and aerodynamics. In addition, prior to this training we had been only briefly exposed to many fields of science." Along with his classroom instruction at Langley, he especially remembered the group's astronomy lessons in North Carolina. "Because one half of our orbital flight path will be on the dark side of the Earth, and because some people feel that stars can be seen even on the bright side, it was felt that some training in astronomy

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[40] Voas, "Astronaut Training," 196.

[41] Tom Wolfe, *The Right Stuff* (New York: Farrar, Straus & Giroux, 1979), 189-190.

[42] Alexander, Grimwood, and Swenson, 241.

was highly desirable," Slayton reflected. "Therefore, we went to the Morehead Planetarium at the University of North Carolina and were given basic instructions in the location of the various constellations and stars." The group then practiced navigating by the stars through a window like the one they would have in orbit, which "provided very valuable experience."[43] The idea of making astronauts well rounded at the outset of their careers through classroom instruction became a constant in the decades to come.

The astronauts also spent hundreds of hours crisscrossing the country so they could attend briefings at various *Mercury* production facilities. Their travels took them to NASA facilities at Cape Canaveral, Florida and Huntsville, Alabama, as well as contractor factories at McDonnell in St. Louis and Convair in San Diego, California, where contractors worked on the *Atlas* rocket. The astronauts quickly found that as the public faces of the *Mercury* program, their visits held inspirational value. Craftsmen at all levels now felt a personal connection to do their best in turning the numerous failures of the early years of the space age into successes, epitomized by Grissom's famous "three word speech" in San Diego: "Do good work!"[44] From July to December 1959, the seven traveled nearly one out of every three days. They spent half of this time on individual trips related to their specialty areas of focus, but Robert Voas decided that they should spend the other half together. He considered group training desirable because it easily facilitated the scheduling of activities with other organizations, and made for the most efficient use of astronaut and instructor time. The emphasis on group

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[43] Slayton, "Pilot Training and Preflight Preparation."

[44] Alexander, Grimwood, and Swenson, 241.

training extended through the Space Shuttle era.[45]

The seven also received areas of specialty on which to focus during their training. Scott Carpenter focused on communication and navigation, Gordon Cooper on development of the *Redstone* booster, John Glenn on cockpit layout, Gus Grissom on the manual and automatic attitude control systems, Wally Schirra on life support systems and pressure suits, Alan Shepard on tracking and recovery operations, and Deke Slayton on development of the *Atlas* booster. The assignments meant that the seven had a chance to provide their input from a pilot's viewpoint to engineers from Virginia to California. Their input did consequently affect the design of the *Mercury* suit, cockpit layout, spacecraft hatch, and spacecraft window.[46] The astronauts' first year on the job thus provided further evidence of the kind of people NASA wanted. The space agency did not want people who simply rode rockets like circus performers had once been shot out of cannons. As NASA officials worked on the unproven *Mercury* spacecraft in 1959, they instead wanted input from people experienced in the testing of unproven flight machinery. They also expected valuable feedback from the astronauts after their flights took place. But to prove the value of human spaceflight once the flights took place, they would need to train the seven in the operation of the vehicle. What was the best way to do this?

The answer to this question was not preordained. The Langley personnel had to make choices based on potential value, potential hazards, and cost. They considered

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[45] Voas, "Project *Mercury* Astronaut Training Program," 24-25.

[46] Alexander, Grimwood, and Swenson, 236-237.

carrying the actual spacecraft to altitudes of up to 100,000 feet on balloon flights, placing it on a training device that simulated tumbling during the reentry sequence, and placing an actual spacecraft atop a launch vehicle during a static firing so an astronaut could climb aboard and experience the noise and vibration of a simulated launch. But after several months of study, the instructors shelved all of these ideas as carrying too little value to justify the risk and cost. When the instructors could use simulators to stand in for actual flight equipment, they generally did so to cut down on cost.[47] By making a choice of simulators over actual vehicles, *Mercury* instructors had socially constructed the technologies of astronaut training. As *Mercury* gave way to *Gemini* and *Apollo*, the choice of simulators would gather momentum (to use a phrase from Hughes's concept of a technological system) and become the most vital form of astronaut training.

The *Mercury* astronauts trained on several such devices that built on the legacy of the computer age of flight simulation, still less than a decade old. In the summer of 1959, the McDonnell contractors supplied a hand controller for the astronauts to manipulate while looking at a *Mercury* attitude display simulated by an analog computer. This device built the astronauts' confidence in manually controlling the spacecraft should it become necessary during a flight.[48] But the astronauts needed a replica of their entire spacecraft to feel prepared. Thus the simulation engineers cannibalized a computer from an F-100 simulator to control a Closed Loop Analog

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[47] Voas, "Astronaut Training," 189.

[48] Voas, "Project *Mercury* Astronaut Training Program," 28.

Static Simulator. In this device, the men could sit in their custom-fitted couches, wear their pressure suits, see all the instruments in front of them that they would see during their flights, and turn the hand controller to pitch, roll, and yaw the spacecraft. Potentiometers sensed the movements of the controller and fed them into the computer, which in turn sent readings to the instrument panel in front of the astronaut. The instructors then examined strip chart data from the astronauts' manipulation of the controller to evaluate their performance.[49]

Additional devices broke new ground by preparing the astronauts for the physical and visual sensations of their flights. No such device was more painful than the Navy's centrifuge in Johnsville. The X-15 pilots had already survived runs producing accelerations of several times the force of gravity, but *Mercury* instructors wished to expose the astronauts to the specific conditions of a *Mercury* flight. Thus the seven spent two weeks in August 1959 in Johnsville being whipped around a gondola at the end of the fifty-foot arm.[50] The following April, the astronauts returned and this time climbed into a gondola modified to replicate all of the controls and displays of the *Mercury* cabin. They wore their silver pressure suits and breathed pure oxygen, just as they would during a flight. The instructors then played a recording of a rocket firing over the astronauts' headsets, to expose them to the sound of liftoff (expected to be 90 to 110 decibels), and programmed the computer to spin the centrifuge so as to simulate an entire flight from launch to reentry. This meant that the arm spun fast enough to subject

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[49] Martin Caidin, *Man Into Space* (New York: Pyramid Books, 1961), 149-150.

[50] Alexander, Grimwood, and Swenson, 235-245.

the men to six Gs during a simulated *Redstone* liftoff and between eight and nine Gs during a simulated *Atlas* liftoff, because engineers had calculated the force these events would produce. The astronauts still had to speak into their microphones despite the intense pressure, just as in an actual flight. The pressure then abruptly dropped, simulating the cutoff of the booster engine and the transition to zero gravity, before building up again to simulate reentry. Engineers felt much less confident in projecting the force of reentry, so the astronauts underwent runs of up to 16 Gs.[51]

But since preparation for spaceflight revolved around the "what if" questions, especially before any person had yet flown there, the centrifuge also simulated scenarios that were even more painful for the astronauts. If the spacecraft had to make an emergency return prior to reaching orbit, the reentry angle would be much steeper than in a nominal mission. This meant the astronauts would have to brace themselves for a force of gravity that would build up to 18 Gs in just 15 seconds, then decay in another 15 seconds. What if the escape tower had to whisk the spacecraft away from an exploding *Redstone* or *Atlas* and carry it to an emergency reentry and splashdown? The firing of the escape rocket would make the astronauts feel a sudden burst of acceleration pressing them into their couches, but then the rocket would stop firing and aerodynamic braking would abruptly slow the spacecraft. This would make them feel an abrupt onset of negative Gs that would throw them against their shoulder straps. The instructors thus simulated this effect, called the "Eyeballs In, Eyeballs Out" test, by rotating the gondola 180 degrees. This subjected the riders to G reversals of as large as +9 G to -9 G, in just a

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[51] Wolfe, 182-183.

few seconds.[52] "When we first talked about doing this, I didn't think it would be possible," Glenn wrote in a letter to a friend near the end of 1959. "But in doing careful buildup we happily discovered that this was not so horrible. At plus 9 G to minus 9 G we were bouncing around quite a bit but it was tolerable."[53]

The astronauts explored ways to counteract the pain of repeated runs on the centrifuge. The seven each had two factors working in their favor: they sat lying on their backs and on seats that were custom fitted for them. Even so, they could barely lift their arms to flip switches during the launch sequences and during reentry sequences, could not lift their arms at all. The force of gravity whipped back the skin on their faces and even broke blood vessels on their backs. They found that the best antidote was to tense their muscles in a strenuous effort to keep the blood from draining from their head and causing blackout.[54] Glenn captured the ordeal best in his letter: "With the angles we were using, we found that even lying down at 16 Gs it took just about every bit of strength and technique you could muster to regain consciousness. I found there was quite a bit more technique involved in taking this kind of G than we had thought. Our tolerances from beginning to end of runs during the period we worked up there went up considerably as we each developed our own technique for taking this high G. A few runs a day like that can really get to you."[55] He recalled in his memoir, "It's something I never want to do again."[56]

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[52] Caidin, 148-149.

[53] Alexander, Grimwood, and Swenson, 239.

[54] Thompson, 188-189.

[55] Alexander, Grimwood, and Swenson, 239.

[56] John Glenn and Nick Taylor, *John Glenn: A Memoir* (New York: Bantam Books, 1999), 177.

The entire NASA team reaped several benefits from the astronauts' several trips to Johnsville, as one document from 1960 attests. Medical specialists evaluated the effectiveness of the biomedical sensors strapped to each astronaut's body and gathered physiological data, which they could use as baseline information for interpreting inflight and postflight data concerning each astronaut's well-being. A 16 mm camera inside the gondola even provided them with video of the astronauts under high acceleration. Engineers evaluated the astronauts' personal equipment during this period of stress, such as the harness, couch, pressure suit, urine bag, and communication system. The personnel who manned the console stations at Johnsville also gained experience in monitoring data during centrifuge runs, in preparation for their trips to worldwide tracking stations during *Mercury* missions. The centrifuge training thus emphasized the notion of a *Mercury* team striving toward the goal of safe and successful spaceflight.[57]

Robert Voas and the astronauts each agreed in the wake of *Mercury's* success that the centrifuge was one of the crucial elements in preparing for flights, even if the runs were more stressful than actual missions. During World War II, some American fighter pilots had found that high g-forces incurred in dives and turns had caused them to blackout, or left them unable to lift their arms.[58] But after each of the seven had spent an average of 45 hours riding a centrifuge, Voas found that the astronauts could maintain consciousness and read instruments even under heavy accelerations. The medical

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[57] "Centrifuge Refresher Course," 1960, Box 64, Folder 28, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[58] Wolfe, 182.

specialists monitoring the biosensors strapped to each man's body also found no showstoppers to a successful *Mercury* flight (the only bad news on the medical front was Slayton's heart arrhythmia, which eventually resulted in his being grounded from spaceflight).[59] The subjects of the runs were quick to point out during their postflight debriefings that the centrifuge was not the highest fidelity simulation machine. "There is no correlation between any of the noise and vibrations on the centrifuge and that experienced in the flight case," Shepard remembered. The computer controlled noises and vibrations "were rather jerky" on the centrifuge and more violent and abrupt than the experience of riding a *Mercury* spacecraft to and from space, he believed. Yet Shepard still picked the centrifuge as one of his top three training devices and stated, "I do feel that the centrifuge is valuable as a training aid during periods of launch and reentry…I think we'll find it valuable for future training programs on this basis."[60] Grissom and Glenn also commented on the greater intensity of the centrifuge compared to actual flight, yet still picked it as one of their top three training devices.[61]

The simulation of physical sensations took on a radically new form with arguably the most unique *Mercury* training device: the Multiple Axis Space Test Inertia Facility (MASTIF) at the Lewis Research Center in Cleveland, Ohio. This device featured a large set of three concentric cages that rotated independently from each other, all with an

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[59] Voas, "Astronaut Training," 186 and Donald K. "Deke" Slayton with Mike Cassutt, *Deke!*: U.S. Manned Space From *Mercury* to the Shuttle (New York: Forge, 1994), 85.

[60] [*Mercury-Redstone 3* Technical Crew Debriefing., Box GH-133, *Mercury* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, D3-4, D7-9, and D28-33.

[61] [*Mercury-Redstone 4* Technical Crew Debriefing, Box GH-133, *Mercury* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, C78-81 and [*Mercury-Atlas* 6 Technical Crew Debriefing, Box GH-133, *Mercury* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 7-6.

astronaut strapped inside one of the cages so he could be whipped around as if he was aboard a tumbling spacecraft. Instructors could program the machine to either rotate one, two, or all three cages, and watch as the astronaut tried to use a hand controller to release spurts of gas that halted the rotation of the cages and stopped the tumbling. After a mechanical engineer at Lewis conceived this machine in 1959, one of his colleagues and a test pilot at Lewis saw its potential as an aid to astronaut training and began an extensive test program designed to determine how much motion a human could withstand. The two of them set a limit of 30 revolutions per minute for the machine, because any higher speed would risk sickness incapacitating the astronauts.[62]

The *Mercury* astronauts quickly learned that the MASTIF stretched their capabilities as no other training device did, except for the centrifuge. When Shepard went to Cleveland for his first run in February 1960, he had to press the red "chicken switch" that signaled instructors to stop the machine early. But by March, all seven had learned to stop their rotation before sickness incapacitated them.[63] Jerrie Cobb, one of the thirteen women pilots who underwent runs on some of the same training devices as the astronauts, also made a trip to Cleveland that year and impressed the instructors through her quick reactions in a 45-minute ride.[64]

The astronauts agreed in retrospect that riding the MASTIF was a painful experience and definitely not their most important tool with which to prepare for their

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[62] Alexander, Grimwood, and Swenson, 244-245.

[63] Ibid.

[64] David Shayler and Ian A. Moule, *Women in Space: Following Valentina* (Chichester, U.K.: Springer-Praxis, 2005), 81.

missions. Although all seven were seasoned test pilots who had flown tumbling aircraft, training aboard the MASTIF was unlike any experience they'd had and highlighted the separation between training for flight within the atmosphere and training for flight outside it. Schirra called the machine "a bulldog tearing away at you."[65] In terms of the value of the machine, Shepard said during a debriefing, "Some of the disorientation devices that we used may be eliminated in future training programs as they are primarily a confidence-building device…it (the MASTIF) is certainly not an important training aid."[66] Glenn said during his debriefing, "The MASTIF and weightlessness, even though they were short, let you know that you could be in this kind of a crazy environment and do what you were supposed to do. So they all fit into a background of confidence building. But I would not say that our zero g training prior to flight was of real great importance nor would I say that the MASTIF was."[67] The *Mercury* astronauts were the last to use the MASTIF as a training device, though generations of children have ridden a version of the machine at Space Camp.

The *Mercury* flights would produce one other physical sensation that required training: weightlessness. World War II had stimulated the thinking of scientists on this issue, just as it had on large G forces. When Allied fighter and bomber planes flew over Germany, German fighter pilots developed a new type of pass on the enemy. The Germans dove their planes from high altitudes, made their pass at the Allied bombers from below after a violent pull up, then evaded the enemy's firepower through another

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[65] Thompson, 187-188.

[66] *Mercury-Redstone 3* Technical Crew Debriefing, D4-6 and D22-27.

[67] *Mercury-Atlas 6* Technical Crew Debriefing, 11-5.

dive. During this maneuver, German pilots experienced weightlessness during the pushover into the second dive. The pilots reported disturbances of vision and frequent misses with their gunnery during this period. With this knowledge in hand, several American pilots flew parabolic trajectories that produced brief periods of weightlessness during the 1950s. Acclaimed aviators such as Chuck Yeager, Bill Bridgeman, and Scott Crossfield reported on the disorientation they felt. But by the time the *Mercury* astronauts were selected, the USAF School of Aviation Medicine had made experiments on the effects of this condition and found that it was safe to conduct further research.[68]

Training for weightlessness in the *Mercury* era was not nearly as important as in later programs, because in flight the astronauts would not be able to move from their seats. Yet NASA medical specialists wanted data on the astronauts' reactions to weightlessness and the instructors accommodated them by taking the astronauts aboard aircraft that flew a parabolic trajectory capable of inducing weightlessness. The seven attained their first experience with this not aboard the KC-135 that eventually earned the affectionate nickname "Vomit Comet," but aboard an aircraft with a very cramped cabin: the F-100. The astronauts traveled to the School of Aviation Medicine in San Antonio, and for sixty seconds at a time performed psychomotor tasks aboard the F-100. Eating, drinking, and speaking into a voice recorder did not present any serious problems, nor did the heart, respiratory rate and depth, or blood pressure data that medical specialists

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[68] Siegfried J. Gerathewohl, "Weightlessness: The Problem and the Air Force Research Program," in *Reports on Space Medicine*, 1958, Box 69, Folder 46, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

received via telemetry. But to practice maneuvering their bodies in weightlessness, the astronauts needed a large cargo aircraft. The instructors thus arranged for runs aboard the C-131 at the Wright-Patterson Air Force Base in Ohio. The seven donned crash helmets and experienced fifteen seconds of weightlessness in a padded cargo bay before the plane's steep descent began and slammed them onto the floor and walls.[69] By the time *Mercury* ended, each of them had trained in weightlessness for an average of 40 minutes.[70]

In their postflight debriefing sessions, Shepard, Grissom, and Glenn considered this training a useful tool to build confidence but not one of their most important assets. "I don't think that we have to fly it to the extent that we did," Shepard recalled. "I think that maybe one or two flights in the back seat of an F-100 and one or two flights in a KC-135 and a Convair are certainly plenty. Weightlessness, as exhibited on a Redstone profile, provides no problem at all." Grissom and Glenn both remarked that the experience was not of great importance, with Glenn adding, "On the airplane flight, you don't have the lengths of time to really settle down and really start working."[71] What appears clear in retrospect is that Robert Voas and his colleagues at Langley viewed the weightlessness training as a means to desensitize the astronauts to this novel feeling they would experience on their groundbreaking missions, as Voas alluded to in his summary of *Mercury* training when the program ended. In completing their checklists, making

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[69] Caidin, 151 and Thompson, 189.

[70] Voas, "Astronaut Training," 188.

[71] *Mercury-Redstone 3* Technical Crew Debriefing, D22-27, *Mercury-Redstone 4* Technical Crew Debriefing, C74-75 and *Mercury-Atlas 6* Technical Crew Debriefing, 11-4.

scientific observations, and especially in reacting to a potential emergency, the astronauts would have to set aside their reactions to the sensation and think rapidly and precisely.[72] The weightlessness training was also a precursor of the future, when astronauts would need to learn to maneuver their bodies in a much more expansive environment than *Mercury*. If Shepard, Grissom, and Glenn could have looked into the future and seen the progressively larger spacecraft that astronauts would fly, from *Gemini* to *Apollo* to a *Skylab* space station measuring 82 by 55 feet, they probably would have had a different assessment of weightlessness training.

From today's perspective, it is surprising to note that *Mercury* instructors did not place a great emphasis on sending astronauts underwater to simulate weightlessness. The instructors did understand the principle of neutral buoyancy, meaning the condition in which a physical body's density is equal to the density of the fluid in which it is immersed. This condition offsets the force of gravity and causes the physical body to neither sink nor rise. The "Original Seven" astronauts did test this principle in a tank at Langley.[73] But as historian Michael Neufeld and NASA scientist John Charles recounted in a 2015 article, *Mercury* instructors did not take a great interest in this training method.[74] The Astronaut Debriefing Forms for Alan Shepard, Gus Grissom, and John Glenn did contain the question, "Do you feel there is any future for submersion simulations for weightlessness training," which suggests that Voas and his colleagues

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[72] Voas, "Astronaut Training," 189.

[73] Alexander, Grimwood, and Swenson, 243.

[74] Michael J. Neufeld and John B. Charles, "Practicing for Space Underwater: Inventing Neutral Buoyancy Training, 1963-1968," *Endeavour* Vol. 39, Issues 3-4 (September-December 2015): 147-159.

were at least weighing the possibility. But Shepard and Grissom each said no, while Glenn said he could not comment. Comments such as Shepard's "Weightlessness is not a real problem," or Voas's "The effects of weightless on performance appear to be minor and transitory," illustrated the naiveté of astronauts and their instructors at a time before any astronaut had stepped outside a spacecraft to perform complex tasks. Voas argued in a 1963 presentation, "Ground simulation methods using water seem to be too cumbersome and unrealistic to be fully acceptable substitutes," and this attitude prevailed until the *Gemini* program.[75]

The astronauts also prepared for the environmental conditions they would experience on their flights. Engineers constructed an Environmental Simulator at the Navy Aircrew Equipment Laboratory in Philadelphia. This simulator featured a spacecraft replica, pressurized to 5 psi as the real vehicles would be during flight, which was housed in a decompression chamber to simulate spaceflight. The astronauts each took turns sitting inside and making the proper response to simulated emergencies, such as closing the faceplate on their pressure suits or dumping cabin pressure. The astronauts also felt the heat and humidity they would feel during reentry.[76] "We dressed in ventilated pressure suits and climbed into a steel box," Deke Slayton remembered. "The interior of the box was heated up to approximately 250 degrees Fahrenheit by radiating heat from quartz lamps through the walls. We found that these temperatures were no great problem at all, and since the time this program was run, we

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[75] *Mercury-Redstone 3* Technical Crew Debriefing, D33-37, *Mercury-Redstone 4* Technical Crew Debriefing, C100-106, *Mercury-Atlas 6* Technical Crew Debriefing, 12-3, and Voas, "Project *Mercury* Astronaut Training Program, 40.

[76] Caidin, 150-151 and Voas, "Astronaut Training," 188.

have discovered that our interior cabin heat load during an actual *Mercury* reentry is considerably lower."[77]

Robert Voas's training program sent the seven across the country to experience still more environmental conditions. In these earliest days when no person had yet flown in space, medical specialists feared the worst about how the human body would react. The seven therefore traveled to the Pensacola Naval Air Station and entered a "slowly revolving room" designed to simulate disorientation. "This room rotates at approximately 10 r.p.m. in an attempt to simulate proposals for rotating a small spaceship to induce a small G-field artificially, with the assumption that weightlessness becomes a major problem," Deke Slayton explained.[78] Voas marked the "slowly revolving room" as being of "questionable value" in his summary of *Mercury* training, and indeed this type of disorientation training was discontinued after *Mercury*.[79] The seven also traveled to Bethesda, Maryland and entered a carbon dioxide chamber. "We climbed into the chamber; it was sealed; and the carbon dioxide content was gradually increased from a normal 0.05 percent to approximately 4 percent over a period of 3 hours," Slayton remembered. "We were able to note the physiological effects such as increased breathing, pulse rate, flushing, and in some cases, a slight headache. We feel that this carbon dioxide chamber was a valuable part of our training, since no one has been able to devise a completely satisfactory partial-pressure measuring device, at least

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[77] Slayton, "Pilot Training and Preflight Preparation."

[78] Ibid.

[79] Voas, "Astronaut Training," 174-175.

for measuring small partial pressures."[80]

The astronauts found training involving their actual spacecraft especially helpful in preparing for the environmental conditions of their flight. When the men traveled to Cape Canaveral, they could sit inside their actual spacecraft as it sat inside a decompression chamber. "This is one of the most valuable tests we do at the hangar," recalled Gus Grissom. "You get into the capsule and pump the chamber up to 200,000 feet and see that everything works and works as it should. This is another real confidence builder...So, on launch day, I had no feeling of sitting on top of a booster ready for launch. I felt just like I felt at the hangar or anyplace else. Here is home. Here are surroundings that are familiar to me."[81] Grissom's comments support a point made by Tom Wolfe in his classic study of the *Mercury* astronauts, *The Right Stuff*. Wolfe argued that the point of the training exercises was largely to "desensitize" the astronauts to the heat, noises, and motions of the unprecedented act of sending a human into space.[82] Grissom and his colleagues believed sitting aboard the actual vehicle was one of the most effective means of doing this.

One of the most crucial environments the astronauts would encounter during their flights was the ocean, because the mission profile called for a splashdown. This meant the seven required training in exiting their spacecraft under normal and emergency conditions. If all went according to plan, the vehicle would splash down only a few miles away from a recovery ship. A helicopter would then fly from the ship

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[80] Slayton, "Pilot Training and Preflight Preparation."

[81] *Mercury-Redstone 4* Technical Crew Debriefing, C74-75 and C76-78.

[82] Wolfe, 185.

to the spacecraft, lower a hook onto it, and lift it partially out of the water so that the lower frame of the door was above the water line. The astronaut would then climb out onto a raft, climb into a "horse collar" lowered to him, and ride it into the helicopter.[83] But as usual, the instructors had a list of "what if" questions that needed answering. What if the spacecraft splashed down off target and out of the range of recovery forces? What if the vehicle became submerged beneath the ocean and the astronaut needed to make a quick escape? What if the side hatch malfunctioned, and the astronaut had no choice but to exit through the top hatch?

Robert Voas placed a high emphasis on the astronauts' proficiency in water in light of these possibilities. In May 1959, only one month after they first reported for work, he sent the men to a Naval Amphibious Base near Norfolk, Virginia and had them scuba dive with Underwater Demolition Unit Two. The astronauts varied widely in underwater ability, from Scott Carpenter (a Navy man who would develop a distinguished record in undersea research) to Deke Slayton (an Air Force man who did not even know how to swim).[84] The different backgrounds of the seven made this initial training necessary. With all of them having this experience under their belts, they donned their pressure suits, went to a pool at Langley and made their first spacecraft egresses in February 1960. The astronauts found they could exit the spacecraft in ten seconds even while the vehicle was submerged and the pool generated waves of up to two feet. They also successfully practiced exiting from the top hatch. The following

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[83] Slayton, "Pilot Training and Preflight Preparation."

[84] Slayton with Cassutt, 78.

month, the seven went to the Pensacola Naval Air Station and spent a day training in the Gulf of Mexico. This allowed them to train for the possibility of being temporarily stranded from recovery forces and drawing on survival equipment such as shark repellant packages and dye markers. "We spent approximately one-half day in one-man rafts learning how to distill water, protect ourselves from the Sun, and signal the rescue forces," Slayton recalled. "This exercise convinced us that we could survive for a number of days if forced to reenter in an unspecified recovery area."[85]

The seven had to contend with one more "what if" question surrounding their return to Earth that required training. What if a spacecraft landed so far off target that it missed the ocean altogether? Engineers knew in 1960 that the orbital path of the vehicles would take them over the Atlantic Ocean, Africa, the Indian Ocean, Australia, the Pacific Ocean, and the continental United States. If the spacecraft needed to make an emergency landing in a remote desert, particularly in Africa or Australia, the astronauts would need to know how to survive until recovery forces could locate them. As usual in the *Mercury* training program, the armed forces could provide assistance in preparing the astronauts. Air Force officials had selected Stead Air Force Base in Reno, Nevada as an ideal location for pilot survival training. Pilots traveled there to take a three week class in Evasion, Resistance, and Escape. Because of the success of this class, Robert Voas and his fellow instructors decided to send the astronauts to Stead for desert survival training in July 1960.[86] "The field training area was characterized by scarcity of

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[85] Voas, "Astronaut Training," 190 and Slayton, "Pilot Training and Preflight Preparation."

[86] John Evanoff, "Helicopters, Astronauts, and Other Birds," March 2007, *Visit Reno,* http://www.go-reno.com/evanoff/mar-07.php (accessed March 13, 2016).

vegetation, evidence of a limited amount of animal life, high daytime air and surface temperatures, and relatively cool nights, and was, therefore, considered to be representative of either the North African or Australian desert regions," explained instructor Keith Lindell.[87]

The program lasted five and a half days and progressed from observation to hands-on activities. For one and a half days, the astronauts received classroom instruction at the USAF Survival School. The next day, each of them ventured into the desert and placed themselves alongside their own spacecraft mockup. Each mockup contained a *Mercury* survival kit, which included first aid supplies, distress signals, a signal mirror, a radio, matches, a whistle, 10 feet of nylon cord, a knife, a flashlight, and six pints of drinking water. The astronauts also had access to a sixty-three foot parachute used during the spacecraft's descent. The instructors told them to live on their own for the next three days, with only these items to assist them. Amid daytime temperatures that hovered around 105 degrees, the seven cut up their parachutes to construct clothing and tents that shielded them from the Sun, and practiced signaling their location through mirrors and fires.[88] But the length of time they could survive depended almost entirely on the amount of drinking water available, as Lindell explained in his memo on the session. "The six pints of drinking water which is now provided in the *Mercury* capsule would be sufficient to maintain an astronaut in good physical

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[87] Keith Lindell to Charles Donlan, October 7, 1960, Box 69, Folder 35, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[88] Desert Survival Training Course Syllabus, July 1960, Box 69, Folder 35, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

condition for approximately twenty-four hours, provided he were in good physical condition after impact, he remained out of the direct rays of the Sun except to perform an urgent task, and he remained sheltered and almost totally inactive once the urgent tasks had been accomplished," he wrote. After that, an astronaut would face "near-total incapacitation, both physical and mental." But since the instructors replenished each astronaut's water supply, the seven survived for three days in Nevada.[89]

In 1960, the training program entered a new era as the two simulators that the seven agreed were their most valuable training aids became operational. Contractors at the Link Trainer Company in Binghamton, New York, under the direction of the McDonnell contractors, manufactured both of them. The first was a motion-base simulator that gave them the physical and visual sensations of a flight, all wrapped in one machine. The Air Lubricated Free Attitude (ALFA) trainer consisted of a replica spacecraft that moved via air jets in response to the hand controller. The ALFA was thus a precursor of the motion-base training that Space Shuttle astronauts would experience into the 21st century. It also contained an optical viewing system so when the astronauts looked through their periscope, they would see a simulated view of the Earth. They could then practice orienting the spacecraft based on that view, in case a malfunction of their instruments would ever require them to do so.[90] "The maximum effectiveness of the control jets I think is best practiced on the ALFA Trainer," remembered Shepard in a debriefing session after he made his *Freedom 7* flight. "There is, of course, some

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[89] Lindell.

[90] Caidin, 150-151.

correlation between maximum effectiveness of control on the Procedures Trainer in the actual flight case, but I think the ALFA Trainer here is more valuable because you are able to observe movement in the horizon as well as movement on the instruments." He then picked the ALFA as one of the top three devices he would pick to feel adequately trained for a *Mercury* flight. Grissom did the same after his *Liberty Bell 7* flight, stating, "I think it's a very valuable trainer for this program or for any program which is coming along." Glenn also picked the ALFA as one of his top three training devices. While acknowledging that the machine needed representations of stars and cloud cover over Earth to become as high fidelity as possible, he agreed that ALFA sessions were some of the most essential at the dawn of human spaceflight.[91]

The other simulator was a fixed-base machine that also served as a precursor of astronaut training through the Space Shuttle era: the *Mercury* Procedures Trainer (MPT). Mike Collins remembered of his experience in the *Gemini* and *Apollo* simulators, "This was the very heart and soul of the NASA system; this was where we spent our time above all other choices…one is not to fly until the simulator has told him he is ready."[92] The logic behind Collins's statement was the complexity of the early spacecraft. Though much less complex than *Gemini* and *Apollo*, *Mercury* vehicles featured over 120 controls inside the phone booth sized cockpit in which the astronaut would sit. If an automated system failed, he would need to know the proper response from this set of controls. The McDonnell contractors thus wrote an "Astronauts' Handbook" that

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[91] *Mercury-Redstone 3* Technical Crew Debriefing, D3-4 and D28-33, *Mercury-Redstone 4* Technical Crew Debriefing, C69-72 and *Mercury-Atlas 6* Technical Crew Debriefing, 11-3, 12-4 and 12-5.

[92] Michael Collins, *Carrying the Fire: An Astronaut's Journey* (New York: Farrar, Straus and Giroux, 1974), 191.

described operating procedures under normal and emergency conditions. In a normal orbital mission, the handbook called for the astronaut to complete a 130-item checklist. If an emergency took place during either launch, orbit, reentry, descent, or landing, the handbook listed 156 possible actions the astronaut could take to save the mission.[93] The MPT replicated all the controls so that astronauts could practice all these actions in a risk-free environment.

A task group at Langley made a critical decision: that astronauts should train in the MPT along with the flight controllers and those at tracking sites around the world who would support the missions. This group formed in September 1959 under the leadership of Jack Cohen. Although Cohen left the group after about a year, he contributed the idea of linking the MPT into the Mission Control Center. This way, astronauts would train by operating controls in the simulator while flight controllers would train by following telemetry signals from the simulator in the control center. This idea of an integrated simulation involving all people responsible for mission success endured through the Space Shuttle era. The original members assigned to work with Cohen were Arthur Hand, Glynn Lunney, and Harold Miller. Dick Hoover, Stanley Faber, Dick Koos, and William Sullivan had joined the group by 1960.[94]

Some of these people had backgrounds as NACA engineers, while Koos joined the group on the basis of his experience in computers while working in the military. "I was in the Army at Fort Bliss," he explains. "I had a bachelor's degree in math and

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[93] Alexander, Grimwood, and Swenson, 240-246.

[94] Harold G. Miller, "The Early Days of Simulation and Operations," June 30, 2013, http://www.jsc.nasa.gov/history/history/oral_histories/MillerHG/MillerHG_paper.pdf (accessed February 26, 2016), 1-15.

economics, having double majored. I really wasn't sure about what I wanted to do or where I wanted to go. But I ended up at Fort Bliss, working on antiaircraft programs. It ended up being a perfect fit for what I did at NASA. During the last part of my service down there, I was part of a group that was doing prototypical work with software programming. It was for war games on air defense systems. It was an IBM 650 vacuum tube computer with big drum memory. I learned a little bit about machine language when I was there. Whatever it was I put on my resume and sent it around, it caught someone's attention at NASA."[95]

Koos also remembers the vagueness of his job description when he left Iowa for Virginia in September 1960. "When I was driving to Virginia, I had just gotten the offer in the mail and with it came this nice, slick brochure from the Langley Research Center," he says. "I was told, 'We have some telemetry that will be between the *Mercury* Procedures Trainer and the control center. Your job is to man a console during simulations and figure out what this is all about and what to do.' We started from scratch. There was no training for us." By the time he arrived, NASA had already been launching satellites into orbit for the past two years. But he quickly learned that unmanned spaceflight had only limited applicability in his new job of simulating piloted *Mercury* flights, because "there wasn't much monitoring of internal systems of satellites at that time. Maybe the military had done something with the *Discoverer* program, but mainly it was just tracking to see where they could be. There wasn't any downlink of

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[95] Dick Koos, Interview by Author, Davenport, Iowa, July 11, 2016.

internal systems until *Mercury* when they had a crewman onboard. It was all brand new."[96]

What especially drove Koos and his colleagues was the knowledge that although engineers had provided computer driven simulations of aircraft flights over the past decade, simulations of spaceflights called for a new degree of urgency. Even the X-15 aircraft had a long series of flights that only gradually increased in speed and altitude. But the very first time an astronaut climbed inside a *Mercury* spacecraft, he would be propelled over 100 miles high and the spacecraft pushed to its limits of stress and endurance. This meant that emergencies could threaten the astronauts' lives, in which case they would need to understand the proper course of action. The flight controllers would also receive data during such an emergency, and would also need to understand what to do. If a controller received a particular signal, should he call for a mission abort or not?[97] Koos and his colleagues decided that simulations should test the understanding of both astronauts and controllers. Under their plan, Simulation Supervisors (SimSups) would institute malfunctions into the MPT, to which astronauts and controllers would have to respond.

Koos remembers the criteria by which he and the other early SimSups decided to institute malfunctions. "When we started, and this was new also, they had developed flight rules," Koos explains. "The rules stated that you should take this action if this sort of thing happens. We picked at those mission rules and system limits and tried to

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[96] Ibid.

[97] James E. Tomayko, *Computers in Spaceflight: The NASA Experience* (Washington, D.C.: NASA Scientific and Technical Information Division, 1987), 271.

simulate something that could happen, so flight controllers could recognize it. For example, if the cabin pressure valve didn't seat itself at 5 psi during a *Mercury* launch, you had to do an abort. The flight controller saw that, and he would have to take action and call to the flight director for an abort. The crew had the same indicators onboard, but there were many indicators only available on the ground. We also pulled communications lines to the control center at the Cape, so it would be down and then the backup control center would have to take over. We also had remote sites across the world with somebody at the site to talk directly with the astronauts and also to monitor the data as they went over. All communicated back to the control center by teletype, so we interfered with teletype communications. That wasn't really out of the ordinary, because in Australia those sites were out in the outback. Some of that data went over the top of a wire fence, if you can believe that. So it wasn't out of the question to simulate that type of thing at all. The other thing we did was to put failures in the instrumentation system (so that a controller would have to decide whether an indication on his console was real or just a glitch)."[98]

Thus began a tradition that continues to this day: the contest between SimSups who devised emergency scenarios and the astronauts and flight controllers who tried to solve them. When asked if the groups developed a competitive mentality with one another, Koos says yes. "We were the guys with the black hats," he explains. "In my later years, I was on the other side. I wasn't in simulation. When you're sitting there knowing that something is going to happen, and God only knows what they're going to

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[98] Author Interview with Koos.

do, I understand you're under a fair amount of pressure. And we're the guys doing it. We developed that kind of (competitive) relationship. It was like memories on a football team. They get after each other."[99]

The SimSups believed that Jack Cohen's idea of integrated simulations proved beneficial for the entire *Mercury* team. Harold Miller remembered that the sessions successfully exercised procedures, interfaces, and mission rules, screened flight controllers and weeded out those who were not skilled at real time operation, and helped the astronauts and flight controllers meld as a team.[100] His colleague Dick Koos shares these opinions today. "I think Kraft and those guys would say that it allowed them to build the team," he reflects. "Wherever we ran a simulation, there was always a debriefing at the end. Kraft started all that. It was like a confessional. Everybody went around the room. We would have our say about what we tried to do."[101] Those debriefings gave flight controllers a sense of trepidation because they knew they would have to hear about their mistakes, but the controllers understood their value. Glynn Lunney provided an apt description of simulations and debriefings from a flight controller's point of view: "These sims were a baptism by fire. The palms always got sweaty; any decision had to be justified, and one's honor was at stake, naked in front of his peers and the boss. And, most all of us spent some time in that naked position. But, it did raise one's determination to avoid screwing up."[102]

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[99] Ibid.

[100] Miller, 13-17.

[101] Author Interview with Koos.

[102] Glynn Lunney, *Highways Into Space: A First-Hand Account of the Beginnings of the Human Space Program* (Self-published book, 2014), 53.

The SimSups had at their consoles a list of cards containing possible malfunctions of spacecraft systems. They would then flip a switch to institute a failure into a system and observe the action the astronaut took to correct the malfunction.[103] The SimSups would also fill out an Exercise Record Form for each run. "It is not intended that the Exercise Record Forms be used as a 'performance record,' nor is there any intention to set up any kind of formal performance evaluation scheme or grading system," simulation engineer Bruce Aikenhead explained in a memo. "Rather, it is agreed that there seems to be too many intangibles for any simple system to be meaningful." He felt the forms would instead be useful for three purposes. First, they would help to determine whether a particular astronaut was having trouble with systems management, indicating the need for more practice. Second, they would help to determine whether all astronauts were experiencing difficulty of a sort which might be avoided by a change in a system or procedure. Third, they would help in evaluating the training program when information from actual spaceflights became available.[104] The form listed the name of the exercise, the trainee, the instructor, the date and time, whether pressure suits, restraint harnesses, helmets, gloves, and capsule lighting were used, the imposed malfunctions on each mission phase, and the corrective actions taken by astronauts. One surviving form lists a three-orbit simulation that John Glenn made on August 15, 1960 and includes the following remarks: "Flight controllers need more practice…Can't detect smell of smoke when pressure suit is in operation. Check with

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[103] Voas, "Project *Mercury* Astronaut Training Program," 30-31.

[104] Bruce A. Aikenhead to Chuck W. Mathews, June 3, 1960, Box 63, Folder 39, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

systems. Modify trainer if necessary."[105]

When the astronauts climbed into the MPT, they understood just how much the experience of a *Mercury* flight would differ from the aircraft they had flown. Here, the pilot could not leave the ground through his own actions. The "Astronauts' Handbook" instead called for them to monitor the lights on the instrument panel in front of them during a completely automated rocket launch. When the MPT reached simulated orbit, the vehicle could only have its path changed through attitude adjustments. Even this was usually under the control of the Automatic Stabilization and Control System (ASCS), though the astronauts did have the option of taking control via the fly-by-wire and manual modes. Simulator runs thus highlighted the impulse toward automation, but also that *Mercury* flights would seriously test the astronauts' skills should emergencies intervene. The seven might have to notice an engine failure, pass the information onto flight controllers, and then receive an order from the Capsule Communicator (CapCom) to fire the escape rocket that would be attached to the spacecraft in an actual mission. They might also have to determine the source of fire or fumes. Or, in a preview of what would actually happen during the *Mercury* program, they might have to undertake the lifesaving maneuver of manually controlling the spacecraft attitude for reentry.[106] The SimSups considered failures at each point of a mission fair game, but not catastrophic failures, because the point of the simulations was to determine if astronauts and flight

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[105] "Exercise Record Form," August 15, 1960, Box 63, Folder 39, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[106] "Astronauts' Handbook," December 4, 1959, Box 58, Folder 2, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

controllers could find a way out of emergencies.

The method of crew escape deserves special consideration, given the high number of launch failures in NASA's first years. Engineers decided that the most effective means of crew escape would be a tower containing a solid rocket motor, attached to the spacecraft, which would whisk the vehicle away from a rocket breaking apart on the pad or during the first 2 minutes and 23 seconds of ascent. Though the vehicle would then expose the astronaut to exceptionally high G forces, in theory it would make a safe splashdown. The engineers did develop an Abort Sensing and Implementation System (ASIS) that would electronically sense the impending failure of the *Redstone* or *Atlas* booster and activate the tower in time to save a spacecraft and astronaut. But the astronaut also had access to a "chicken switch" in front of his left arm rest, which could initiate the abort sequence as well.[107] Thus from the earliest era of spaceflight training, astronauts had to prepare to make a decision that could save their lives and drastically affect the national effort to achieve supremacy in space. This underscored the necessity of a training program that could build their confidence, to use the phrase that *Mercury* astronauts emphasized in their debriefings. In later programs, this escape system would be abandoned in favor of systems less likely to save crews. But most engineers would agree that during *Mercury*, astronauts had access to the best escape system attainable at the time.

Robert Voas and his fellow instructors had to learn as they went along, and thus

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[107] David Shayler, *Space Rescue: Ensuring the Safety of Manned Spaceflight* (Chichester, U.K.: Springer-Praxis, 2009), 108-114.

invited feedback from astronauts on how they could improve procedures training. The instructors faced the dilemma of whether to spend extra money improving the fidelity of the MPT, or trusting that the device did not need to simulate every aspect of a spaceflight. One issue concerned whether to mount the MPT on a centrifuge, which would have cost $10 million. Shepard, Grissom, and Glenn all answered no, with Glenn explaining, "I think the problems that we would have now in mounting the procedures instructor on the centrifuge would preclude any day-in, day-out procedures trainer operation." The first three astronauts to fly also generally recommended that the instructors did not need to go to great effort to simulate the sounds of a spaceflight, or the star field outside the vehicle, for the MPT.[108] The men agreed that the SimSups had provided a proper balance between normal and emergency runs on the MPT. Shepard supported the heavy emphasis on simulated failures, stating, "I think that in the training program one should specifically over-train. By that I mean create more failures than could possibly occur in an actual flight." Glenn shared this sentiment, but remarked that SimSups should mix up normal and emergency runs without warning. "If you know for sure during a simulation that they don't plan to give you any emergencies, no matter how hard you fight it, there is a tendency to relax," he argued. "Maybe a third of the training runs should be normal runs, but without the trainee knowing when he is going to get a normal run."[109]

But when asked to evaluate the MPT in general, the astronauts universally

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[108] *Mercury-Redstone 3* Technical Crew Debriefing, D10-15 and D28-33, *Mercury-Redstone 4* Technical Crew Debriefing, C100-106 and *Mercury-Atlas 6* Technical Crew Debriefing, 12-2.

[109] Ibid.

praised the device in their debriefings. Especially given that President John F. Kennedy had challenged the nation to send men to the Moon, instructors wanted an assessment for the benefit of the *Gemini* and *Apollo* programs that would follow *Mercury*. Shepard provided his assessment by declaring, "I feel that the procedures developed in meeting emergencies, in using manual override, and general observation are indeed valuable, and I think that for later capsules, we will find that the Procedures Trainer is one of our most valuable aids in preflight training programs." Though he believed in the need for a motion base simulator like ALFA, he praised the fixed base MPT as the most essential training asset.[110] Grissom and Glenn also placed the MPT at the top of their lists, with Glenn explaining his choice by saying that this machine gave the best presentation of *Mercury* instruments and provided the best place to practice systems monitoring, failure analysis, and task loading.[111]

Long after the *Mercury* program ended, scholarly literature on training supported the astronauts' contention that they stood to benefit from this kind of training. In the 21st century, U.S. organizations alone spend more than $100 billion per year on employee training. Researchers have performed experiments on the value of this, including for those in technical fields such as astronauts. The researchers have measured trainees to find that mentally rehearsing tasks allows them to increase declarative knowledge (facts) and procedural knowledge (how to perform skilled tasks) for up to 10 days later. Researchers have also focused specifically on aviation, because human error has

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[110] *Mercury-Redstone 3* Technical Crew Debriefing, D3-4 and D28-33.

[111] *Mercury-Redstone 4* Technical Crew Debriefing, C100-106 and *Mercury-Atlas 6* Technical Crew Debriefing, 12-4 and 12-5.

consistently been one of the major causes of air crashes since the late 1970s. Their studies have shown that errors in this field are often the result of inadequate team coordination, and thus pilots should focus on team-based training. “This type of training is usually conducted using sophisticated flight simulators, and it addresses communication, teamwork, decision making, and awareness with respect to accidents and incidents and the role played by human error,” write two authors in a 2009 literature review on training.[112] By including astronauts and flight controllers in integrated simulations, *Mercury* instructors emphasized teamwork. Close cooperation with flight controllers remains an essential part of an astronaut’s identity, and sessions on the procedures trainer helped instill this into the original astronauts’ thinking while also helping them to mentally rehearse their tasks. But would the seven ever get their chance to place all of this training to the test?

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[112] Herman Aguinis and Kurt Kraiger, “Benefits of Training and Development for Individuals and Teams, Organizations, and Society,” *Annual Review of Psychology* (2009): 454-456.

CHAPTER III

MERCURY: "THE MOST EXTRAORDINARY COMPUTER OF ALL"

The future of America's fledgling space effort remained in doubt. As 1960 progressed, the astronauts demonstrated that their capabilities would not be the weak link in the *Mercury* program but realized that their hardware remained suspect. The first attempted launch of the *Mercury-Atlas* combination failed miserably on July 29. The first attempted launch of the *Mercury-Redstone* combination on November 21 was an even more embarrassing failure, as the rocket rose just four inches off the ground and settled back onto the launch pad. Only the escape tower launched.[1] Meanwhile, concern about the progress and the value of Project *Mercury* grew in Washington, D.C. President Dwight Eisenhower spent his last year in office less than enthusiastic about *Mercury* or human spaceflight in general, and the election of John F. Kennedy in November did not necessarily spell greater support for the program. The *Mercury* team knew that Kennedy's science adviser Jerome Wiesner was a fierce critic of human spaceflight. Kennedy and Wiesner delegated a committee to write a report on *Mercury*, due in April 1961. After visiting Langley, Cape Canaveral, and the McDonnell factory, the committee judged astronaut training to be in the highest reliability class of the program: 95 to 100 percent. Thus the weak link of the program was not the people preparing to fly into space, but the boosters intended to take them there, judged to be in

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[1] Alexander, Grimwood, and Swenson, 272-295.

the 70 to 85 percent class.[2]

Despite the booster mishaps, the *Mercury* team by 1960 did have a mission in mind for the first launch of an American astronaut: *Mercury-Redstone 3*. This would be a 15-minute suborbital flight. During the fall, the astronauts began to move away from general training and toward preparation for this mission at the Johnsville centrifuge and in the MPT.[3] "The malfunctions which can be simulated on the Procedures Trainer and which are relevant to the *MR-3* mission have been reviewed and 50 failures selected which appear to cover all the major capsule systems," Robert Voas wrote in a memo to the seven that November. "These 50 failures have been distributed through 12 standard *Redstone* missions…It is hoped that the anticipated success of every man handling these malfunctions will demonstrate the readiness status of the astronauts for the *MR-3* mission…In order to determine the effects of the increased load due to these malfunctions on each astronaut's ability to carry out the normal *MR-3* mission, error scores for the retrofire period will be recorded as will the accuracy with which the pitch, yaw, and roll attitude maneuvers during the early part of the *Redstone* flight are performed. After each mission, a debriefing will be held in which the astronaut should report the emergencies he recognized and any problems he had in handling them, together with his estimate of how well he performed the normal flight activities."[4] Voas thus signaled that astronaut training had entered a new phase, oriented toward a brief hop

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[2] Ibid, 304 and 331.

[3] Ibid, 288.

[4] Robert Voas to *Mercury* astronauts, November 28, 1960, Box 63, Folder 39, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

that the *Mercury* team still hoped would be the first venture of a human being beyond planet Earth.

The STG members at Langley took the training program into consideration when choosing the astronaut for that first mission. On January 19, 1961, the seven stayed late in their office at the instruction of STG head Bob Gilruth. Gilruth then walked into the room and dropped a bombshell on the astronauts: "Alan Shepard will make the first suborbital flight." He added that Gus Grissom would make the second flight and John Glenn would backup both Shepard and Grissom. Over nearly two years, Shepard had impressed the STG members with his attention to detail in mastering the training devices, studying the spacecraft, and studying flight plans. "We wanted to put our best foot forward," wrote Walt Williams, and his colleagues agreed with him that Shepard should lead America into space based on technical ability.[5] The other astronauts would participate in the mission, however, whether by backing him up (John Glenn), traveling to the pad for prelaunch preparations (Glenn and Gus Grissom), serving as Capsule Communicator (Gordon Cooper in the blockhouse prior to the launch and Deke Slayton in the *Mercury* Control Center during the mission), or flying F-106 chase planes at the launch site (Scott Carpenter and Wally Schirra).[6]

As the mission drew nearer, Shepard spent more of his time at Cape Canaveral. The STG members and the astronauts themselves agreed that the crewmember for each *Mercury* mission should observe preflight tests of the spacecraft at the pad. Thus he

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[5] Thompson, 228-232.

[6] Ibid, 240-248.

spent 18 days in February at the Cape, watching as engineers tested the systems of the ship he had named *Freedom 7,* and climbing inside as the vehicle was placed in a decompression chamber.[7] "Even though all the spacecraft are built to a specific set of drawings and specifications, each is an individual and has peculiarities which are not the same in the others," explained Slayton. "In order for the astronaut to become intimately familiar with his particular spacecraft, he participated in all the hangar checkouts on it. He participates in reaction control system checks where he can develop a good feel for his particular control system. This participation is also where we get our primary environmental control system training. The astronaut rides in the spacecraft when it is put in the pressure chamber for pressure checks, and he operates the environmental control system in conjunction with this checkout. He also attends all meetings concerned with the checkout and modification of the spacecraft, so he is probably the one person most familiar with all details of the spacecraft."[8]

Besides these interactions with the real vehicle, Robert Voas and his colleagues made sure Shepard stayed sharp in his knowledge of *Mercury* spacecraft operation while at Cape Canaveral. He participated in 120 simulations of his mission inside the MPT at Langley and the Cape.[9] The logic of housing the device at the latter location was to ensure that the training regimen remained as intense as ever during the last months of the process, when the astronauts spent most of their time at the Cape. The instructors did not want an astronaut so bogged down in other activities that his skills were rusty when

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[7] Alexander, Grimwood, and Swenson, 344.

[8] Slayton, "Pilot Training and Preflight Preparation."

[9] Alexander, Grimwood, and Swenson, 344.

launch day arrived. When asked about this during his debriefing, Shepard praised the intensity of training at this late stage.[10]

On the morning of April 12, Shepard received a call in his Cape hotel room and heard the news he had dreaded: the Soviet Union had sent a cosmonaut into space in advance of his own launch. Shepard knew that he could have been first. He had felt ready to launch after the chimpanzee Ham had made a suborbital flight like his own in January. Despite Ham's safe return, Marshall Spaceflight Center Director Wernher von Braun and the STG members agreed to perform one more unmanned test of the *Redstone* after a faulty valve had resulted in an over acceleration of Ham's *Redstone*. That additional test had succeeded in March, but now came the news that Yuri Gagarin had not only become the first person to reach space, but had completed a one orbit mission of much greater speed, altitude, and duration than Shepard's. The feisty astronaut slammed his hand on a table in his hotel room.[11]

Gagarin had undertaken a training program to fly aboard the *Vostok* spacecraft that was similar in many respects but less varied than the *Mercury* program. Only thirteen months earlier, in March 1960, he had reported for work in Star City, Russia. Over the ensuing year, he went through centrifuge runs that reached accelerations up to 12 Gs. He spent hours in a spacecraft mockup, manipulating controls until he could reach them while blindfolded. He maintained his piloting skills by regularly flying aircraft, underwent survival training for an off-target landing, and underwent hours in an

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[10] *Mercury-Redstone 3* Technical Crew Debriefing, D4-6.

[11] Thompson, 235-238.

isolation chamber designed to acclimatize him to sensory deprivation (as the *Mercury* astronauts had done during the selection process in 1959). For two weeks prior to the April 12 flight, he and three other cosmonauts had studied the *Vostok* cabin at the Baikonur Cosmodrome just as Shepard had spent an increasing amount of time with *Freedom 7* at the Cape. The *Mercury* astronauts learned these details via an American analysis of about 200 reports and articles published in Soviet open literature.[12] Still, Gagarin did not have the diversity of training devices that Shepard had available to him, from the MASTIF, to the revolving room, to the environmental simulator, to the ALFA. Part of the reason he required less training aboard a device like the ALFA was that the *Vostok* mission profile did not require him to manually control the spacecraft, as Shepard would during his *Mercury* mission. As Soviet space historian Asif Siddiqi wrote, "Because of physicians' concerns about the adverse effects of weightlessness on the psychology of the cosmonauts, precautions were taken to ensure that the cosmonaut could not control the spacecraft and endanger his life."[13]

Despite his frustration, Shepard had less than one month remaining before his launch. This meant it was time for the final element of the *Mercury* training regimen: multiple full rehearsals of launch day procedures. On April 18, a transfer van sent Shepard from his living quarters in Hangar S to Launch Pad 5, where he rode the elevator to the top of the gantry that connected to the 83-foot *Redstone* rocket. From

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[12] "Soviet Manned Spaceflight: The Soviet Cosmonaut Training System," February 1962, Box 69, Folder 17, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[13] Asif Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945-1974* (Washington, D.C.: NASA SP-4408, 2000), 278.

there, he walked across the crew access arm to the White Room, the small facility enclosing *Freedom 7*, and climbed inside the 100 cubic foot vehicle. With the launch control team following along in the blockhouse, he went through a simulated countdown and flight. He went through the process again the next day, and again on April 20 with the hatch closed and the gantry pulled away. Medical specialists collected physiological data on him during these simulations, so as to gain assurance that he was healthy enough for his groundbreaking feat. At the end of the simulations, he practiced an emergency evacuation that required him to leave the launch pad and board an armored vehicle that could quickly whisk him away from the *Redstone*.[14] Shepard thus began the tradition of high fidelity launch simulations that Space Shuttle astronauts would undergo in their Terminal Countdown Demonstration Tests. These rehearsals benefited Shepard by giving him familiarity with the people in the blockhouse and with *Freedom 7's* hardware. He also began an astronaut tradition by attending technical briefings on the launch preparations.[15] Through all of this time, he focused on preventing any illnesses from hampering his performance. "Medical personnel are continuously monitoring his health and ensuring he stays healthy during this period," Slayton explained. "Part of the program involves placing the astronaut on a special low-residue diet and collecting specimens for comparison with postflight specimens."[16]

The preparation finally reached a conclusion in May, two years after Alan

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[14] George Leopold, *Calculated Risk: The Supersonic Life and Times of Gus Grissom* (West Lafayette: Purdue University Press, 2016), 120.

[15] Alexander, Grimwood, and Swenson, 345.

[16] Slayton, "Pilot Training and Preflight Preparation."

Shepard had given up his career as a Navy test pilot to join a risky and fledgling space effort. After a final briefing with Voas on his flight tasks the night before, he awoke on May 2 and donned his pressure suit only to find out that the heavy Florida rain had forced a launch cancellation. Over the next two days, he released his tension by taking a long jog on the beach with John Glenn and even found the time to log a few more sessions in the MPT. When he awoke at 1:10 a.m. on May 5, his preparation had reached an unprecedented level.[17] He had spent two years preparing his mind and body not only for every voice communication and movement he would make while in his spacecraft, but for some of the most unlikely contingencies that his instructors could imagine. He had gone through the same simulated 15 minute sequence more than a hundred times. He had taken the ride to his actual spacecraft multiple times. As if that had not been enough, he had even awoken on May 2 thinking this was his day to fly. The amount of money and time devoted to familiarizing him to his actions and surroundings easily surpassed that of Shepard's aviation hero, Charles Lindbergh, and other explorers of the land, sea, or air. None of those previous explorers had journeyed beyond their planet of origin, to an environment that contained no oxygen and which would expose a traveler to a constant state of free fall. Most of these explorers also did not have national prestige riding on their efforts to the extent that Shepard did.

The paradox was that even the repetition of procedures could not eliminate the anxiety of May 5. In response to a debriefing question, Shepard said he was most anxious when the White Room personnel closed *Freedom 7's* hatch around him. "I

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[17] Alexander, Grimwood, and Swenson, 345-351 and Thompson, 240-241.

don't know how you overcome this," he reflected. "This is an individual problem, I think, and not a function of the training phase."[18] When the countdown reached T-2 minutes and he heard each flight controller report a Go for launch, he reported that he felt so eager to lift off that the process seemed slow to him. He did not hear much of the rest of the countdown due to his anxiety, during which time his heart rate rose from 80 to 126.[19] The training process thus did not eliminate Shepard's emotions, but the objective of Voas's training regimen was only to ensure that astronauts performed their tasks properly. Shepard's performance over the 15 minutes after the *Redstone* vaulted from the pad suggested that his training was sufficient for this new frontier.

The flight plan ensured that Shepard had the chance to make this point. As the *Redstone* propelled him 116 miles high, he made 78 communications and monitored 27 spacecraft events. Especially during the five minutes that he was weightless, the flight plan kept him busy by requiring him to control the vehicle in pitch, roll, and yaw, and observe the Earth below him. The flight thus kept him busier than a typical aircraft test flight of the kind Shepard had made during the 1950s. When Robert Voas and three other instructors evaluated his performance, they found that "The pilot met all requirements of the mission, that he monitored and reported accurately the critical events of the flight, that he controlled the attitude of the spacecraft within normal limits, that he was alert at all times to novel or unprogrammed events, and that he showed no tendency to become fixated on irrelevant instrumentation or activities." The authors went even

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[18] *Mercury-Redstone 3* Technical Crew Debriefing, D7-9.

[19] Alexander, Grimwood, and Swenson, 351.

further by declaring, "The close correspondence between attitude maneuvers or manual control in the simulator and those in flight indicate that the trainers used in the *Mercury* program were relatively successful in reproducing the vehicle characteristics in flight."[20] Deke Slayton, the CapCom for the mission, concurred by stating, "The success of any training program can only be evaluated when compared with an actual flight. It appears that our training was entirely adequate for the flight and that nothing was missed."[21] *Freedom 7* splashed down in the Atlantic Ocean after a voyage that engineers called "an unqualified success" and a waiting helicopter took Shepard to the *USS Lake Champlain*.

From there, he undertook an extensive debriefing of his training regimen both at Grand Bahama Island and back at Langley.[22] This meant that Shepard, a student for two years, transitioned into an instructor by explaining his spaceflight experience for his instructors. The debriefings were thus a prime example of the co-construction of users and technology. The instructors did not treat Shepard as a mere passenger; they wanted to hear the knowledge Shepard had obtained as a user of the *Mercury* spacecraft, which could influence training technology. With this in mind, the instructors asked him questions such as which training device he found most useful and what device he could have done without. He also reported confidently, "I was sufficiently trained for the mission…I think we were over-trained rather than under-trained…I found that at no time during the flight did I run into anything unexpected as a result of having prepared for it

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[20] Robert Voas, John Von Bockel, Raymond Zedekar, and Paul Backer, "Results of In-Flight Pilot Performance," June 6, 1961, Box 60, Folder 20, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[21] Slayton, "Pilot Training and Preflight Preparation."

[22] Alexander, Grimwood, and Swenson, 356-358.

using our training program."[23] Shepard was hardly alone in his assessment, as everyone from his fellow astronauts, to Voas, to Chris Kraft's flight control team, to the people around the world who followed the mission marveled at the ease with which Shepard operated in an environment only one other person had ever trespassed. The familiarity that the training regimen had provided enabled author Martin Caidin to write, "The performance of Alan Shepard was absolutely astounding in its crispness and matter-of-fact control of everything that was happening…Shepard's performance can be described only as flawless, or as close to perfection as one could ever possibly expect…We heard the voice of a test pilot, in absolute command of himself and his situation, confident, believing in his equipment and his team. It was the most incredible performance I have ever had the privilege to hear."[24]

But the most important person of all monitoring his performance was President Kennedy. If Shepard had not succeeded in his mission, one can never know whether the President would have had the confidence in NASA to press for a long-term commitment in human spaceflight. But a failure on the very first attempt to send an American to space would have certainly undermined the confidence of the President, members of Congress, and their constituents. Kennedy instead went before Congress on May 25 and declared, despite knowing that his country had a scant 15 minutes of piloted spaceflight experience, "I believe this nation should commit itself, to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth.[25] If

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[23] *Mercury-Redstone 3* Technical Crew Debriefing, D1-3.

[24] Caidin, 8-9.

[25] Alexander, Grimwood, and Swenson, 362.

the astronauts and their instructors had felt that spaceflight was only a brief detour in their careers, here was the moment that captured more dramatically than any other that their profession would remain intact for the long haul. Here was the moment that made clear the need for more astronauts beyond the "Original Seven," that these astronauts would attempt ever more complex tasks that required more complex training, and that the personnel devoted to training would dramatically expand. The expansion of spaceflight beyond *Mercury* would also require these personnel to move out of Virginia, to a new facility that could house a larger workforce and more equipment than Langley.[26] The support of the federal government enunciated in 1961 paved the way toward the human spaceflight infrastructure to which 21st century Americans have become accustomed.

But for the time being, the *Mercury* team had to prepare for a second mission on July 21. Although Gus Grissom's mission was a repeat of Shepard's 15 minute suborbital voyage, the Mitchell, Indiana native proved the differences between himself and Shepard through his flight and subsequent opinions on his training experience. Despite over a hundred sessions on the procedures trainer, extensive centrifuge training, and his experience flying combat missions in the Korean War, his heart rate soared even higher than Shepard's. Whereas Shepard had stayed below 140 during his entire flight, Grissom surpassed 150 during the five minutes he was weightless and 171 when *Liberty Bell 7's* retrorockets fired to return him to Earth. Thus he came close to the 180 level

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[26] Ibid, 364.

that medical specialists considered reason to abort a mission.[27] Grissom also reported feeling most anxious at a different point than Shepard. "I think the time that I was the most anxious was during the early period of launch, the first 40 to 60 seconds when an abort might have occurred and the tower wouldn't have jettisoned," he recalled. "I wasn't really convinced that I could get everything unhooked, get the parachute out and get out the hatch in time." Though he did not feel that training could necessarily help him with this feeling, he said, "I felt that this was one of my weaker areas."[28] When he reached space, he reported one more feeling that separated him from Shepard: his urge to look out his window (because Grissom's was the first spacecraft to be equipped with a window). Since his procedures trainer runs did not simulate the view of Earth out the window, he felt distracted by the sight and fell behind on his checklist. Fortunately, Grissom did match Shepard by completing all his significant assigned tasks successfully, including manual control of his spacecraft.[29]

Grissom felt the training process could have better prepared him for the infamous mishap that came next: the sinking of *Liberty Bell 7*. This was the first serious emergency that an astronaut ever faced during a mission. Fortunately, this emergency matched one the instructors had anticipated in their "what if" exercises, because they had sent the astronauts to practice emergency egresses in a Langley pool and in the Gulf of Mexico one year earlier. Grissom heard a thud, saw the hatch cover blow away from him and salt water enter the vehicle, and knew his ship was rapidly sinking. His life

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[27] Wolfe, 280.

[28] *Mercury-Atlas 6* Technical Crew Debriefing, C76-78 and C78-81.

[29] Alexander, Grimwood, and Swenson, 371.

depended on his reaction, and he vindicated the training process by correctly removing his helmet, grabbing the instrument panel with his right hand as he climbed out of the ship, and keeping himself afloat for four minutes in the Atlantic Ocean. He remained in the water for this long because helicopter pilots Jim Lewis and John Reinhard initially focused on recovering *Liberty Bell 7* rather than Grissom. The pilots had judged that the astronauts enjoyed being in the water while in training, and thus the sight of Grissom outside the vehicle did not immediately alarm them. George Cox, a pilot aboard a second helicopter, finally tossed a “horse collar” to Grissom that the astronaut used to lift himself to safety.[30] “Extra training might have helped on the rapid egress, although it would be difficult to simulate,” Grissom reflected. “You must have a suit on for this training, and when you’ve got to get out in a hurry you’re not going to be worried about ripping the suit…It probably ought to be done so we have a procedure firm and tight. This was an area where I felt I was weak.”[31]

The knowledge accumulated by Shepard and Grissom helped to guide Voas as he decided on how astronauts should best prepare for the next step in the conquest of space: orbital flight. Though the STG members had originally planned to launch all seven astronauts on suborbital flights, the success of the Shepard and Grissom suborbital voyages convinced them that this phase of *Mercury* had succeeded. Instead of training each astronaut on 15 minute hops, it was time to match Gagarin.[32] On the next piloted mission, John Glenn would ride an *Atlas* booster to an orbital velocity of 17,500 miles

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[30] Ibid, 373-375.

[31] *Mercury-Redstone 4* Technical Crew Debriefing, C78-81.

[32] Alexander, Grimwood, and Swenson, 364-365.

per hour, and circle Earth three times over five hours. This flight thus marked the chance for Voas to decide which tasks astronauts should perform during a long-term stay in microgravity, and have them train accordingly. He placed great credence in what his students believed had worked best in the past. That meant he favored the MPT as the most effective training device. It meant he favored the idea of sending astronauts to observe their real spacecraft in preflight checkouts and, while in Cape Canaveral, attend engineers' meetings concerning the spacecraft and mission. It meant he favored the idea of egress training close to flight, granting Grissom's request.[33]

Yet orbital flights of several hours would also give the astronauts a chance to forge a new identity. Since 1959, Voas had instituted a training program that had fostered their identities as troubleshooters of malfunctioning equipment; their runs in the ALFA and MPT simulators had served this purpose. But his training program for the orbital phase of *Mercury* fostered their identities as scientific observers as well. In September 1961, Voas wrote a memo to the astronauts concerning their duties in orbit. He determined they should train to recognize landmarks outside the spacecraft window, report on phenomena such as cloud cover and lightning as seen from the day and night sides of Earth, and scan star fields. They would also have to take photos using handheld cameras. Some of these observation duties could save an astronaut's life in case of emergency; if the automatic attitude control system failed, Earth's horizon or stars could provide reference points so the astronaut could orient his vehicle correctly for reentry. But the assigned duties would also prove an astronaut's ability to bring the human

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[33] Ibid, 413-419.

element into space science, a task which continues to this day in the ISS era. The scientific identity Voas laid out for the *Mercury* seven required them to study star patterns in the Morehead Planetarium, study maps, and receive briefings from the U.S. Weather Bureau shortly before flight.[34]

Voas did not believe that this emphasis should preclude the kind of procedures training that might save the astronauts' lives, as he made clear in a memo to them in March 1961. "The *Mercury* trainers have hardly been experiencing a stampede during the last three months," he complained. "It is interesting to note that only two out of seven of you have put in enough time on the trainers to qualify for flight pay during this period. While I am sure no one can say exactly how many hours on the trainers it takes to make an astronaut, it seems probable that it is not as near to zero as these figures indicate. It is likely that most of you have spent several times this much time briefing the press and radio…The *Mercury* training facilities represent an investment of several million dollars and are occupying the efforts of a sizable staff. We have just reviewed the costs of the training program to date and they run something on the order of three-quarters of a million dollars per man. I don't believe that the present use of these facilities justifies this type of expenditure. Far more important than this, however, is the fact that the time presently being devoted to the trainers is not consistent with you being adequately prepared for a *Mercury* flight."[35] Voas authored a report in September laying out the training procedures he expected astronauts to follow for the rest of the program,

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[34] Ibid.

[35] Robert Voas to *Mercury* astronauts, March 27, 1961, Box 69, Folder 43, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

which the STG members approved. He called for at least three hours per week in the MPT, making clear the astronauts had reached a more intense phase of *Mercury* training.[36]

John Glenn underwent MPT training in three phases. First, he sat inside wearing casual clothes in runs lasting ninety minutes. He then donned his pressure suit in runs lasting five hours, matching his expected flight time. But the final phase provided the greatest test of his skills, as the SimSups instituted emergencies in 30 minute sessions. Glenn saved several evaluation forms from the runs he made in preparation for his *Friendship 7* flight. During one session, the spacecraft experienced a direct current power failure at one minute after launch. At 3 minutes and 50 seconds, a double direct current failure prompted the CapCom to call for an abort. Yet Glenn did not abort and did not agree that the failure called for an abort. “This is to be checked into,” the instructor remarked on the form.[37] One of the other emergencies the SimSups instituted during this period, though with a different astronaut in the MPT, would prove prescient. An indication that the heat shield was loose appeared on the instrument panel, raising the possibility that the shield would become detached from the vehicle and expose the astronaut to incinerating heat. Since the retrorocket package was located right underneath the heat shield, the controllers concluded that leaving the package in place through reentry (rather than jettisoning it, as planned) might help hold the shield in

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[36] Alexander, Grimwood, and Swenson, 413-419.

[37] “Insertion Aborts,” January 1962, Box 64, Folder 22, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

place.[38]

Integrated simulations took on a new level of importance during the preparation for Glenn's flight, because *Friendship 7* would orbit the Earth and therefore the teams at tracking stations around the globe would each have to communicate with Glenn. Though Chris Kraft's flight control team at Cape Canaveral would have the ultimate authority for the mission, they would only be in direct contact with the astronaut when the spacecraft passed within range of the control center. At all other times, they would depend on remote site teams in the continental United States, Mexico, the Grand Canary Island, Africa, the Indian Ocean, Australia, the Pacific Ocean, and Hawaii to stay in contact and assist in solving a life threatening problem. The teams consisted of astronauts and NASA civil servants who were mostly recent college graduates and members of the electronics company Philco.[39] Harold Miller recalled that the simulations included these far-flung personnel to develop teamwork in advance of a flight. He remembered, "Altogether they were rather awkward, but most of the controllers endured well and seemed to get some benefit from seeing closed-loop data before they had to actually deploy."[40]

The state of preparation for a *Mercury* flight reached a new peak with Glenn's experience, in part because his launch was delayed from December 1961 to the following February. The time he spent on the procedures trainer preparing for *Mercury-Atlas 6* doubled the amount of time Voas had called for in his memo the previous

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[38] Miller, 14-15.

[39] Kranz, 59-60.

[40] Miller, 18.

September: about 60 hours, during which time he reacted to 189 simulated systems failures. He also spent 25 hours and 25 minutes inside *Friendship 7* itself. He adhered to the philosophy that an astronaut should stay as sharp as possible by training until the last possible moment before a groundbreaking flight, and indeed he spent the evening of February 19 by reading a section in the flight controller's handbook on the ASCS.[41] The advocates of an active human role aboard a spacecraft understood that when he climbed inside *Friendship 7* the next morning, he had the first chance to prove a highly trained astronaut could be an integral component in orbit amid all of the technology surrounding him.

All evidence from February 20, 1962 indicates Glenn and the controllers devoted to his mission took a major step toward proving this point. The scientists who had speculated that weightlessness would mentally and physically impair an astronaut listened as Glenn reported on how pleasant he felt in orbit. One of his first tasks, at Voas's suggestion, was to look out the window and estimate the distance between his spacecraft and the spent *Atlas* booster tumbling away from it. His estimate matched the telemetry data very well, indicating an astronaut's vision could be an asset. He successfully took photos of landmarks on Earth below him and constellations above him. Even more importantly, he controlled the vehicle's attitude in fly-by-wire mode when the ASCS caused the vehicle to drift about one and a half degrees per second to the right. The extensive time Glenn had spent building confidence on the ALFA and MPT simulators benefited him as he switched control modes and correctly oriented the vehicle

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[41] Alexander, Grimwood, and Swenson, 419-422.

using the least amount of fuel.[42]

The people supporting him back on Earth also benefited from the training process during the five hours that Glenn was in orbit. When a flight controller at the Telemetry console saw the same loose heat shield indication that had appeared in training, spacecraft designer Max Faget suggested to Chris Kraft that Glenn leave his retrorocket package in place. Though engineers later found the indication was false, the decision making at the Cape demonstrated the value of integrated simulations. The performance of the remote site teams also demonstrated this, as CapComs around the world reacted to the loose heat shield alarm and communicated with Glenn under time pressure. From California, Wally Schirra gave him the surprising news that he should leave the retrorocket package in place even after the retrorockets fired. Alan Shepard then had a few minutes to explain to him why the flight controllers wanted him to do this. When Glenn made it to the recovery ship *Noa*, Kraft lit a cigar in honor of the well-honed teamwork that had brought *Friendship 7* home safely.[43]

What difference did it make to have a trained astronaut on an orbital *Mercury* flight? The two previous flights without astronauts can help to answer this question. On *Mercury-Atlas 4* the previous September, the spacecraft had made one orbit and splashed down safely but had been plagued by control system malfunctions. If an astronaut had been aboard, he could have taken over manual control and flown three orbits within attitude and fuel usage constraints. On *Mercury-Atlas 5* in November, yet another

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[42] Ibid, 425-429.

[43] Chris Kraft, *Flight: My Life in Mission Control* (New York: Dutton, 2001), 159-160.

control system malfunction cut the chimpanzee Enos's flight to two orbits rather than three. Again, an astronaut utilizing manual control could have completed the entire mission. If Glenn had not been aboard *Mercury-Atlas 6*, Kraft would have had to end another mission early because not enough fuel would have been available in automatic mode for a three orbit flight. If the heat shield signal had been correct, and Glenn had not overridden the automatic jettison of the retrorocket package, the vehicle would have been destroyed during reentry.[44] Glenn had therefore helped to illustrate that the purpose of sending a human into space was not to simply make a hero who the world could celebrate with a ticker tape parade. As long as they were trained adequately, astronauts had the gift of flexibility in overcoming malfunctions.

Glenn deserves the final word on the significance of his own voyage. "The biggest single thing we've found most important is a general statement that a pilot can operate in this environment satisfactorily," he argued during his debriefing. "I think we can even judge from just this one flight that we probably know enough to say that in future designs we can rely on the pilot to be an operable part of the system, at least for missions of this length. We don't need quite so many automatic systems. We don't need systems designed so that we can completely perform the mission whether the man is or is not aboard."[45] When the "Original Seven" had made their trips across the country to training devices, they did not know if the longstanding concerns of scientists about their ability to function in space would prove true or not. But Glenn had given the

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[44] John H. Boynton, "The Pilot's Role During *Mercury* System Failures" (Presentation, First Annual Meeting of the American Institute of Aeronautics and Astronautics, June 29-July 2, 1964), 3-4.

[45] *Mercury-Atlas 6* Technical Crew Debriefing, 12-5.

space agency and the country an answer: so long as an astronaut had received extensive training, he could be a strong link in the operation of a mission. This suggested NASA should continue to pour resources into training people to meet Kennedy's challenge rather than the more difficult task of completely automating spacecraft. By contrast, the Soviets would focus on designing and constructing heavily automated vehicles in their effort to send cosmonauts to the Moon. Cosmonaut instructor Nikolai Kamanin felt this delayed the development of the *Soyuz* spacecraft to the point that the Soviets fell behind the U.S.[46]

The flight that followed Glenn's featured an unprecedented situation: the replacement of a crewmember. Deke Slayton had been training to make the second orbital mission since November 1961, but shortly after the new year began, NASA Administrator Jim Webb reevaluated his health in light of his heart arrhythmia that a centrifuge run had revealed. Despite a lack of conclusive evidence that this condition would jeopardize him, Jim Webb and the STG members decided in March to replace Slayton with Scott Carpenter.[47] This raised the question of whether Carpenter could train to make a flight on such short notice. He had already logged 79 hours training inside *Friendship 7* as Glenn's backup, but this next mission featured new yaw and roll maneuvers and a series of new science experiments ranging from observation of a colored balloon, to observation of a weightless liquid inside a bottle, to observation of the Earth. "He had been thrust into the complex MA-7 mission at short notice, when so

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[46] Gerovitch, 98.

[47] Alexander, Grimwood, and Swenson, 440-442.

many unknowns still existed, and the overcrowded flight program was already proving burdensome and cause for some concern," wrote Colin Burgess in his recent book on the mission. "While he knew in his test pilot's heart he was quite capable of carrying out a successful mission, he simply felt he was not fully prepared for the April launch date, and time was rapidly slipping away with the world's eyes squarely on him." But after the mission slipped to May, Carpenter "built up confidence and began thinking again the way I'd been thinking for three years."[48]

Carpenter's performance on May 24 is easily the most controversial of any *Mercury* astronaut's, even though he performed his assigned experiments and returned safely after three orbits. This is primarily because of Chris Kraft. "The *Mercury* capsule worked, but the astronaut didn't," the flight director wrote in his memoir about the *Aurora 7* flight. He explained that Carpenter felt too fascinated with his view and too dismissive of his own safety. The astronaut consumed fuel at a dangerous rate and failed to report one critical problem with which the flight controllers could have helped him: the spacecraft instruments did not match the position of the horizon he could see out his window. Instead, he left the control team and waiting world in deep suspense as he manually aligned his spacecraft for reentry and fired his retrorockets. Yet he fired the retrorockets late and did not have the vehicle in the proper yaw attitude, meaning he splashed down 250 miles off target. Kraft's animosity caused him to swear "an oath that Scott Carpenter would never again fly in space. He didn't."[49] Carpenter stubbornly

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[48] Colin Burgess, *Aurora 7: The Mercury Flight of M. Scott Carpenter* (Chichester, UK: Springer-Praxis, 2015), 79.
[49] Kraft, 162-170.

denied Kraft's view until his death in 2013, even claiming that the hard feelings toward him stemmed from his replacing Slayton on the mission. "He and I have been on opposite sides of the appraisal of my flight," he said. "He thinks it involves the failure of the man, and I think it involves the failure of the machine. And I think that there's no meeting between the two of us."[50]

In considering this dispute, a few points work in Carpenter's favor. The horizon scanner malfunction that hampered *Aurora 7* could not be simulated on the MPT. Kraft is correct that Carpenter could have responded more promptly to the horizon scanner flaw by promptly communicating the problem during his first orbit. But in his defense, Carpenter had no training experience with the situation he encountered. As far as the maneuvers that he did practice on the simulator were concerned, John Boynton of Langley's *Mercury* Project Office gave Carpenter high marks in his report on the mission: "On the *Mercury* procedures trainers, the pilot achieved a high level of skill in performing maneuvers such as the turnaround, retrofire, and reentry rate damping. The pilot reported that during the flight these particular maneuvers seemed familiar."[51] Kraft claims that "Carpenter had been Glenn's backup and, in training sessions, wasn't half as good at handling problems or emergencies," but this opinion is uncorroborated.[52] Carpenter did well enough in his training runs that Bob Gilruth cleared him for the mission.

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[50] Burgess, 175-176.

[51] John H. Boynton, ed., *Second United States Manned Three-Pass Orbital Mission (Mercury-Atlas 7, Spacecraft 18) Description and Performance Analysis* (Washington, D.C.: NASA TN D-3814, 1967), 14.

[52] Kraft, 164.

Above all else, the *Aurora 7* flight indicated once again the value of having highly trained astronauts aboard spacecraft because Carpenter made a manual reentry. As with John Glenn's flight, one must imagine what would have happened if an astronaut had not been aboard. The spacecraft attitude might have permanently remained outside an acceptable orientation for reentry. But Carpenter overcame the horizon scanner error by looking out his window and aligning his spacecraft in pitch, even if he was off on the more difficult task of yaw alignment and returned off target. The flight controllers could not have done this for an unmanned vehicle.[53] In short, there was a valid reason why the astronauts had undertaken a thorough training regimen. The *Mercury* program was continuing to prove that a prepared space traveler had the flexibility to overcome failures in automatic systems.

But to continue that effort, the astronauts had to bid Virginia farewell and move to a new training site capable of housing an expanded human spaceflight workforce. After a site selection team surveyed twenty cities in Louisiana, Texas, Florida, Massachusetts, Ohio, Missouri, and California, NASA Administrator Jim Webb had announced Houston as the site of the Manned Spacecraft Center on September 19, 1961. The decision to place a thousand acre facility several miles south of downtown, bordering Clear Lake, owed to influence from Texas politicians, but also to a skilled workforce, a large industrial complex, nearby colleges and universities, port facilities, and a warm climate. The STG members who had handled human spaceflight operations from Virginia formed the nucleus of the MSC staff. NASA even offered employees and

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[53] Boynton, "The Pilot's Role During *Mercury* System Failures," 4-5.

their families a tour of the Houston area so they would feel comfortable with the move, and by the summer of 1962 over 700 had made the move. On July 4, the seven astronauts received their official welcome in a Houston parade. Their introductions, complete with cowboy hats and barbecue, began a new era in astronaut training as federal dollars afforded Houston thousands of skilled personnel, and state of the art facilities from aircraft, to simulators, to neutral buoyancy pools.[54]

When the astronauts moved to Houston, only two *Mercury* missions remained. After the overly dramatic Scott Carpenter flight, the task of restoring precision fell to a worthy candidate: Wally Schirra. He had one new device to help him with this: the yaw recognition trainer. Given that Carpenter had been off 24 degrees in his attempt to manually align his vehicle in yaw, the question remained whether any astronaut could pull off the feat by looking out the window of his spacecraft and using Earth as a reference. This held implications not only for future reentries, but also for the rendezvous of two ships in orbit that would be needed to reach the Moon. Thus the instructors built a 33-foot diameter screen that displayed a moving image of simulated clouds produced by a film strip moving through a slide projector. Schirra placed a box over his head, which contained an opening the size and shape of the *Mercury* window, and gained a sense of the motion cues he would experience. In judging *Mercury* training as a whole, Robert Voas deemed this device "essential."[55] By the time October rolled around, Schirra had undertaken the most efficient training program yet. Boynton praised

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[54] Kevin M. Brady, "NASA Launches Houston into Orbit: The Political, Economic, and Social Impact of the Space Agency on Southeast Texas, 1961-1961" (Ph.D. diss., Texas Christian University, 2009), 35-82.

[55] Voas, "Astronaut Training," 174-185.

Schirra's willingness to make simulator runs only after he knew each system in depth, which permitted him to make rapid progress.[56] Schirra also benefited from the experience of previous *Mercury* missions, which highlighted the importance of each flight as a stepping stone toward more precise training, more precise flying, and eventually the grandest goal in the history of exploration: the Moon. On October 3, he went on to fly the most trouble-free *Mercury* mission of all: six orbits over nine hours, with no failures seriously threatening the mission. His experience on the new trainer helped him align the vehicle in yaw with an error of only four degrees, even while using the nighttime Earth as a reference.[57]

Schirra paved the way toward the finale that the STG members had dreamed about since conceiving *Mercury*: a daylong mission. As Gordon Cooper prepared for and flew his mission aboard *Faith 7*, he expressed his admiration at the speed of this first effort to send Americans into space. Only four years and one month after sitting on that stage at the Dolley Madison House, hailed as a hero without even knowing just what the job of astronaut would entail, Cooper found himself sitting atop an *Atlas* rocket on May 15, 1963. "I consider it remarkable that Project *Mercury* ran so close to its originally planned time schedule," he reflected. "Few programs in the history of airplane development ever ran as close, and no airplane program ever had so many unknowns staring the test operations team in the face."[58] This was the reality in a Cold War

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[56] John H. Boynton, ed., *First U.S. Manned Six-Pass Orbital Mission (Mercury-Atlas 8, Spacecraft 16) Description and Performance Analysis* (Washington, D.C.: NASA TN D-4807, 1968), 23.

[57] Boynton, "The Pilot's Role During *Mercury* System Failures," 5, and Alexander, Grimwood, and Swenson, 472-486.

[58] L. Gordon Cooper, Jr., "Astronaut's Summary Flight Report," in *Mercury Project Summary* (Washington, D.C.: NASA SP-45, 1963), 349.

environment when NASA already consumed more than 2 percent of the federal budget (compared with about 0.5 percent today). From past experience, Robert Voas and the training committee called for Cooper to undertake training in 10 to 12 hour days, at least six days a week from January through May. His pattern of flights from Texas, to North Carolina, and to Florida continued to establish the life of an astronaut as a grueling profession detached from family.[59] But they also built his confidence to the point that he remembered, "I had thought that I would become a bit more tense as the count neared minus 1 or 2 minutes, but found that I have been more tense for kickoff when playing football than I was for the launch of May 15."[60]

None of the *Mercury* astronauts proved better than Cooper the value of sending a highly trained aviator into space. The last person ever launched alone flew eighteen sublime orbits before encountering a flaw that could have been the work of a SimSup determined to test his mettle. Only here his life was at stake. The first sign of trouble came when he noticed the 0.05 G light had illuminated, inexplicably indicating that reentry had begun. By the 21st orbit, a short circuit had struck the main inverter and left Cooper's ASCS without power. Once again, an unmanned mission would have failed to reenter in the proper attitude.[61] Only an astronaut, drawing on his experience as a test pilot, sessions on the MPT and ALFA, and reports from colleagues who had already flown, could have achieved what Cooper pulled off next. He took over manual control, aligned *Faith 7* in pitch, roll, and yaw using stars and clouds as references, and

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[59] Voas, "Astronaut Training," 192.

[60] Cooper, 351.

[61] Boynton, "The Pilot's Role During *Mercury* System Failures," 5.

controlled the ship's oscillations as he descended through the blast furnace of reentry. Scott Carpenter's experience had shown how difficult it was to align the vehicle in yaw. But Cooper bettered Carpenter in all respects by using less fuel, completing all tasks on time, and staying so close to the pitch and yaw targets that the vehicle splashed down only four miles away from the recovery ship.[62] When a smiling Cooper left *Faith 7* and walked across the deck of the *USS Kearsarge*, he knew he had carried out a finale worthy of the 10 to 12 hour days of preparation. Although Alan Shepard had expressed interest in a three-day mission, Administrator Jim Webb announced in June that the *Mercury* program was over.[63]

The *Mercury* training experience contained several lessons applicable to future spaceflight. *Mercury* established the idea that procedures simulators were the one most effective tool in preparing astronauts to fly successful missions. The most effective MPT sessions of all involved astronauts and flight controllers, because these could refine mission rules and communication procedures. The MPT was not perfect, as it lacked a simulation of the view out the window that could have especially helped Gus Grissom and Scott Carpenter. The instructors would need to rectify this flaw for *Gemini* and *Apollo* simulators, because astronauts would need a simulated view in preparing for rendezvous and docking with another vehicle. But in general, the training devices effectively built the astronauts' confidence and helped them transition from the job of jet pilot to astronaut as effectively as possible given the state of computer technology. The

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[62] Warren J. North, Helmut A. Kuehnel, John J. Van Bockel, and Jeremy B. Jones, "Astronaut Performance," in *Mercury Project Summary* (Washington, D.C.: NASA SP-45, 1963), 287-289.

[63] Alexander, Grimwood, and Swenson, 503.

instructors' guesses concerning what devices astronauts would need to prepare were also generally accurate. Only a few disorientation devices did not make it into future programs.[64]

But the most important legacy of the *Mercury* program concerned the ability of astronauts to contribute useful tasks. The six piloted flights vindicated the original beliefs of Edward Jones, John Yardley, and Robert Voas, because of all of them only Schirra's spacecraft would have completed the intended mission without an astronaut aboard. The roughly $5 million spent on training devices was a plenty justifiable cost given that the entire program cost slightly more than $400 million and the training aided the astronauts in saving multiple missions.[65] Future astronauts planned to draw upon this legacy of success in controlling the *Mercury* spacecraft until they found themselves standing on the surface of the Moon, in fulfillment of Kennedy's challenge. The President accurately summarized the legacy of *Mercury* while presenting Gordon Cooper with his Distinguished Service Medal: "I think one of the things which warmed us the most during this flight was the realization that however extraordinary computers may be that we are still ahead of them and that man is still the most extraordinary computer of all. His judgment, his nerve, and the lessons he can learn from experience still make him unique and, therefore, make manned flight necessary and not merely that of satellites…I think before the end of the sixties we will send a man to the Moon, an American, and I think in doing so it is not merely that we are interested in making this

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[64] Ibid.

[65] Voas, "Astronaut Training," 174-175 and Alexander, Grimwood, and Swenson, 508.

particular journey but we are interested in demonstrating a dominance of this new sea, and making sure that in this new, great, adventurous period the Americans are playing their great role, as they have in the past."[66]

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[66] John F. Kennedy, "Remarks Upon Presenting the NASA Distinguished Service Medal to Astronaut L. Gordon Cooper," May 21, 1963, *The American Presidency Project*, http://www.presidency.ucsb.edu (accessed April 5, 2016).

CHAPTER IV

GEMINI: “IN OUR BUSINESS THAT’S JUST TOUGH”

As the early 1960s progressed, a group of families populated the small communities to the southeast of Houston, from El Lago, to Seabrook, to Nassau Bay. The men at the head of these families were experienced jet pilots who looked to follow the successes of the “Original Seven” astronauts and fulfill the lunar challenge. But the most powerful astronaut resided in Friendswood, to the west of the space center. Ironically, he was also the only one of the seven who had not flown during *Mercury*. When NASA needed a manager to coordinate all astronaut activities in 1962, MSC Director Bob Gilruth and Associate Director Walt Williams decided on Deke Slayton. “They had been looking at a couple of military guys when Al Shepard, in particular, decided, hell, if we’re going to have a boss, why bring somebody in from the outside and superimpose him on us?” Slayton remembered of the reasoning.[1] Beginning in September, the grounded astronaut became vital for his responsibility in selecting future crews, giving the crews training assignments, and advising Gilruth and Williams on their progress.[2]

Slayton presided over a corps that expanded from seven to thirty by 1963. Since the *Gemini* spacecraft would carry crews of two each on ten missions, the “Original Seven” would have to share the astronaut title. Slayton, Shepard, and Warren North

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[1] Slayton with Cassutt, 116.

[2] “Trainees Comment on ‘Why?’” September 19, 1962, *Space News Roundup*, http://www.jsc.nasa.gov/history/roundups/1962.htm (accessed April 6, 2016).

formed the selection board for the second group, which featured slightly less stringent requirements than the original group. The board considered candidates with scientific as well as engineering degrees and civilian as well as military test pilot experience.[3] After a grueling physical exam at Brooks Air Force Base in San Antonio and interviews with the board, the "Next Nine" joined the "Original Seven" in September 1962. In hindsight, Slayton argued that the second group of astronauts "is probably the best all-around group ever put together."[4] Two of them, Elliot See and Ed White, would be lost in tragic accidents over the next five years. But the other seven—Neil Armstrong, Frank Borman, Pete Conrad, Jim Lovell, Jim McDivitt, Tom Stafford, and John Young—would all command *Gemini* missions and go on to receive the most prestigious position of all: Commander of an *Apollo* mission. The expansion of the astronaut office continued with a third group of fourteen, selected in 1963. This group featured five more men who would fly on *Gemini* (Buzz Aldrin, Gene Cernan, Mike Collins, Dick Gordon, and David Scott) and several *Apollo* moon voyagers.[5]

Integrating the novices into the fold mainly followed the pattern established by the "Original Seven." The "Next Nine" received their introduction to spaceflight by traveling to Cape Canaveral, watching Wally Schirra's launch, and meeting the flight controllers who worked the mission there. Also at the Cape, the nine climbed aboard the *Mercury* simulator and learned to control a spacecraft in pitch, roll, and yaw. All of the nine and fourteen received classroom instruction from some of the most qualified

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[3] Dethloff, 127.

[4] Slayton with Cassutt, 119.

[5] Dethloff, 127-128.

scientific minds in the country, made centrifuge runs at Johnsville, made parabolic flights aboard the KC-135, and made water survival outings at Galveston Bay. One difference was that these later astronauts made jungle survival outings in addition to desert survival. John Young recalled, "Training for jungle survival took us to Panama, again divided into teams of two…From my surveying work in the Florida swamps, I knew you could do well in the jungle if you boiled the water, cut out hearts of palm with your machete, and caught fish using worms and safety-pin hooks. So Gus and I got along well."[6]

As with the seven *Mercury* astronauts, the instructors counted on these new additions to assist them in the development of *Gemini* training. When Deke Slayton gave the "Next Nine" their technical assignments, he assigned training and simulators to Armstrong. This choice made sense, because Armstrong arrived at the astronaut corps after spending seven years in high speed flight research at the NACA/NASA. Whereas most of the astronauts had flown for the military prior to joining, and had little experience with flight simulation, Armstrong found himself in an organization that pioneered the use of analog computers to simulate flight. "No astronaut played a more vital role in the development of flight simulators for *Gemini* and *Apollo* than did Armstrong," asserted Armstrong's biographer James R. Hansen. Armstrong did this by operating simulators not only for training purposes, but also to understand if the designers had mechanized the equations of motion properly. He then offered feedback

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[6] John W. Young with James R. Hansen, *Forever Young: A Life of Adventure in Air and Space* (Gainesville: University Press of Florida, 2012), 61-62.

for the designers to improve the machine and shared memos about his experiences with his fellow astronauts. “The guys who were mechanizing the equations—sometimes contractors, sometimes NASA employees—oftentimes did not have the perspective of a pilot,” he recalled. “They would just do the arithmetic without regard to the sense of being proper.”[7] Charlie Bassett also assisted the instructors, as he received the same assignment on behalf of the third astronaut class.[8] As with their *Mercury* predecessors, Armstrong’s and Bassett’s contributions illustrate the significance of the user in the development of spaceflight operations.

Below the astronauts on the new space center’s administrative structure was the MSC branch most focused on training: the Flight Crew Support Division (FCSD). Warren North, a World War II pilot who had joined NACA and then assisted Robert Voas in the selection and training of the *Mercury* astronauts, headed the division. FCSD contained about 300 people divided into those who focused on the simulation of spaceflights, those who focused on the integration of crews with flight hardware, and those who focused on flight planning.[9] The need for such a large workforce meant that participation in astronaut training had now become a career path for qualified college graduates. As chief, North could report on their behalf through the chain of command that extended upward to Chief Astronaut Deke Slayton, to *Gemini* Project Office Manager James Chamberlin, and finally to Bob Gilruth and Walt Williams in the Office

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[7] Hansen, *First Man*, 224-226.

[8] Collins, 103-104.

[9] Warren J. North, Interviewed by Summer Chick Bergen, September 30, 1998, Houston, Texas, http:/www.jsc.nasa.gov/history/oral_histories/NorthWJ/NorthWJ_9-30-98.htm (accessed April 6, 2016).

of the Director.[10] Meanwhile, the Flight Operations Division under the command of Chris Kraft contributed to training as well. Mel Brooks oversaw flight controller training from this division, while the SimSups designed simulations from this division.[11] The transition from *Mercury* to *Gemini* thus included the formation of a large administration that would guide astronaut training through the 21st century.

Riley McCafferty, a simulator engineer and later the chief of the FCSD, explained the kind of people he sought to facilitate training in this branch and how he organized them. "I went out and got good, qualified engineers who had aerospace, aeronautical, physics, and electrical engineering degrees," he recalled. "If you get a man with any one of these four, he's been exposed to the world." He then used what he called a "military approach" to organize his personnel: "I believe that there's a boss and a sub-boss, and there's a general and a colonel and a captain and a major. Because I feel like, in our program, where everything is so subject to change and everything is so subject to flexibility—that's a big word, in this case—that if you aren't regimented and the guy isn't willing to do immediately what you want without a bunch of second-guessing to you, you'll never get the job done…I feel like you have to have a situation where you tell a guy, 'I want you in here at five o'clock in the morning,' and that guy's going to be there at five o'clock in the morning. You get a sort of pantywaist that says, well, I don't like to work nights or I don't like to work certain shifts. In our business

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[10] Dethloff, 66-67.

[11] Miller, 23.

that's just tough. We explain that to the guy before he comes on board."[12] Such were the sacrifices required of the personnel who toiled to meet President John F. Kennedy's lunar commitment.

Why did the training profession dramatically expand as *Mercury* wound down and gave way to *Gemini*? *Gemini* far surpassed *Mercury* in complexity of astronaut tasks, mainly due to two factors: rendezvous and EVA. *Mercury* astronauts could only manipulate their spacecraft's attitude. *Gemini* astronauts were expected to change their spacecraft's orbit so as to rendezvous and dock with an *Agena* Target Vehicle, which would require piloting tactics in accord with the laws of orbital mechanics and counterintuitive to a pilot on Earth. By 1962, NASA had selected an *Apollo* mission configuration that called for two astronauts to take a small landing vehicle to the lunar surface, then lift off, rendezvous, and dock with the mothership in lunar orbit. *Gemini* would be the crucial proving ground for this concept. One of the two crewmembers on a *Gemini* mission was also expected to leave the spacecraft and maneuver in the vacuum, as opposed to the *Mercury* astronauts who remained strapped in their seats throughout their missions. Again, this would be the proving ground for the feat of walking on the Moon in *Apollo*. This raised the question of how to best prepare astronauts for the kind of weightlessness maneuvering that *Mercury* astronauts had not attempted.[13]

Just a few months after *Gemini* received approval from NASA Headquarters, and right after John Glenn became the first American to orbit, Harold Johnson of the FCOD

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[12] [Interview with Riley D. McCafferty, Cocoa, Florida, November 15, 1969, Box APO-074-46, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 11.

[13] Hansen, *First Man*, 225.

was already thinking about how to simulate these next generation missions. He circulated a March 1962 memo that called for the contractors at the Link Trainer Company to assemble, as they had for *Mercury*, a mission simulator that could give astronauts, flight controllers, and remote site teams practice in normal and emergency conditions. But just as the real *Gemini* spacecraft would be upgraded from *Mercury*, so would the simulator designed to mimic it, as Johnson expected the machine to provide the advanced visual display out the windows that *Mercury* astronauts had lacked. He also called for a docking trainer, which would mimic all the displays a crew would have before them and simulate a view of the *Agena* moving in on them for a docking. Johnson also called for training in the landing sequence. Since *Gemini* engineers envisioned the vehicle descending onto land under a paraglider, he believed crews would need experience with this via a boilerplate spacecraft.[14] NASA made Johnson's wish list official in 1963 by awarding contracts for the simulators he mentioned, with one addition. Link manufactured a *Gemini* Mission Simulator and a Translation and Docking Simulator. Dallas contractor Ling-Temco-Vought, Inc., provided the addition: a Dynamic Crew Procedures Simulator (DCPS).[15]

The DCPS became the latest device reflecting the idea that a trained astronaut could be one of the strongest assets during the most dangerous phases of spaceflight. The instructors knew that during a launch, the Commander sitting in the left-hand seat

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[14] James M. Grimwood, Barton C. Hacker, and Peter J. Vorzimmer, *Project Gemini Technology and Operations: A Chronology* (Washington, D.C.: NASA SP-4002, 1968), 27-28.

[15] Donald K. Slayton, Warren J. North, and C.H. Woodling, "Flight Crew Procedures and Training," in *Gemini* Midprogram Conference (Washington, D.C.: NASA SP-121, 1966), 201-211.

could observe propellant tank pressures, engine status lights, and the rates and attitudes of the *Titan* booster carrying him to space. But the Commander could do more than monitor; he could also actuate a switch that would direct the spacecraft guidance system to guide the *Titan* booster, in case the *Titan*'s own system caused the booster to drift off course. He could also initiate an abort if necessary and activate a set of ejection seats that would fling him and his crewmate away from the *Titan*. The Commander of each mission would need to know where to focus his attention during this fast-paced, high pressure phase and the criteria for actuating a guidance switch or aborting an ascent. The DCPS familiarized the astronauts with this, beginning in June 1964. Since the device was connected to a computer complex, instructors could set the computers to simulate one of 80 possible launch sequences and the computers would alter the cockpit displays seen by the crew accordingly. "Our rules on abort are two cues—if you get a light that says abort, you don't do anything until you get some other cue," recalled Stanley Faber, head of the Simulation Branch of the FCSD, of the decision making incumbent on the astronauts. "Vibration is found to be a real good one, they can tell if they've lost an engine from the vibration profile that they're feeling."[16] To mimic the environment the crews would be operating in, the computers controlled the sound inside the cabin in accordance with the acoustic histories observed during past launches and controlled the motion by pitching, yawing, and rolling the cabin.[17]

One problem that the astronauts and their instructors needed to grapple with

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[16] [Interview with Stanley Faber, Houston, Texas, April 22, 1970, Box APO-074-43, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas.

[17] Ibid, 201.

concerned the pogo effect that crews would experience during liftoff. Like the *Redstone* and *Atlas*, the *Titan* booster was originally designed to carry intercontinental ballistic missiles as a payload. The booster produced a pogo of 5.5 Gs, which would not be a problem for an Intercontinental Ballistic Missile (ICBM) in the nose cone but would pose a problem for astronauts who needed to read their instrument panel and activate ejection seats if necessary. Astronauts thus underwent runs on the DCPS and in a centrifuge to determine the limits of the pogo effect they could experience and still accomplish these tasks, and found the answer was about 1.5 Gs. The results of these runs prompted the *Titan* contractors at the Martin Company in Baltimore to install a pogo suppressor in the booster.[18] Gus Grissom explained the success of this effort in the debriefing following his *Gemini III* mission (NASA used roman numerals to denote missions in this program): "The booster ride is a lot smoother and a lot easier than the simulations…This booster is very smooth all the way. We never felt it steer. It's like riding a Corvette."[19] Most *Gemini* astronauts made similar comments, the one exception being the pogo that plagued the *Gemini V* launch, and even in that case the effect lasted only a few seconds.[20] The work of the FCSD had informed the engineering of hardware, and contributed to smooth liftoffs.

Astronauts were unanimous in their agreement that training for emergencies aboard the DCPS was one of their most useful tools. None of these men knew if they

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[18] Young with Hansen, 62.

[19] [*Gemini III* Technical Crew Debriefing Box GH-133, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 3-15.

[20] Virgil I. Grissom, James A. McDivitt, L. Gordon Cooper, Jr., Walter M. Schirra, Jr., and Frank Borman, "Astronauts' Reactions to Flight," in *Gemini* Midprogram Conference (Washington, D.C.: NASA SP-121, 1966), 272.

would need to activate ejection seats with seconds to spare, in the tradition of aircraft pilots over the past several decades, but all felt this simulator gave them confidence in making that decision if necessary. *Gemini IV* Commander Jim McDivitt attested during his debriefing, "We were able to do a great number of runs in a very short period of time, and we got all our abort procedures down pat in just a very short period of time. I think that I can't say enough for this." The instructors continued to value astronaut comments such as these, as indicated in the timing of the DCPS runs. *Gemini VIII* astronauts Armstrong and Scott recommended finishing this training three weeks prior to launch, so as to ensure it was fresh on astronauts' minds, and this became the standard for *Gemini* crews.[21]

But if a catastrophic failure caused an astronaut to pull a D-ring and eject from a *Gemini* spacecraft, he would also need experience in what would come next. Pyrotechnic charges would whisk the two crewmembers away in their ejection seats and a parachute would then send them to a touchdown, either at land or sea. "The ejection seat concept was selected for the *Gemini* spacecraft after careful consideration of weights, launch vehicle performance reliability, and total system integration required to provide escape over the complete flight region…This system has been tested for the worst conditions in altitude and dynamic pressure using anthropomorphic dummies and, in certain areas, men," explained two MSC engineers in a technical report.[22] Some of the *Gemini* astronauts eventually testified that the ejection seat was less safe than the escape tower

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[21] [*Gemini IV* Technical Crew Debriefing, Box GH-134, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas and Thomas P. Stafford and Charles Conrad, Jr., "Astronaut Flight and Simulation Experiences," in *Gemini* Summary Conference (Washington, D.C.: NASA SP-138, 1967), 321.

[22] Hilary A. Ray, Jr. and Frederick T. Burns, *Development and Qualification of the Gemini Escape System* (Washington, D.C.: NASA TN D-4031, 1967), 1 and 25.

method used during *Mercury* before it and *Apollo* after it.[23] Yet each of these men had experience with ejection seats from their careers as aircraft pilots and felt well prepared to operate a *Gemini* ejection seat after training in its operation. The men also undertook parachute training in 1963 and 1964. "Ground School at Ellington Air Force Base would tow you up into the air to about three hundred feet and cut you loose and then you maneuvered down to a landing," Armstrong remembered. "We did that over land as well as over water, the latter near Galveston Island off the coast of Texas, in the Gulf of Mexico. That training went for quite a substantial period of time on an intermittent basis."[24]

But the most important task of the *Gemini* program concerned the rendezvous of spacecraft once in orbit. The training for and execution of this new maneuver again reflected the idea of astronauts as being able to perform useful tasks in space, a legacy of *Mercury*. Gus Grissom, the astronaut so closely involved with the development of the *Gemini* spacecraft at the McDonnell plant that the vehicle became known as the "Gusmobile," called this ship "the first true pilot's spacecraft." This especially applied to rendezvous, because the astronaut in the left-hand seat (the Commander) would have to make the final approach to the *Agena*.[25] The instrument panel would provide him with details he would need to know to do this, such as the "8-ball" indicator for attitude reference and readouts of the range and range rate with respect to the *Agena*. But the Commander himself would provide the trained mind interpreting the information the

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[23] Young with Hansen, 72-73 and Thomas P. Stafford, Interviewed by William Vantine, October 15, 1997, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/StaffordTP/StaffordTP_10-15-97.htm (accessed May 1, 2016).

[24] Hansen, *First Man*, 222.

[25] Mindell, 83-84.

computer provided. The task of then manipulating the hand controller to fire *Gemini's* sixteen thrusters would fall to him. The thrusters would enable the spacecraft to catch up to the *Agena*, intercept it, and then slow the relative motion between the *Gemini* and the *Agena* so as to make a safe rendezvous.[26] How could instructors ensure that the astronauts had the skill to meet with (and on later missions, dock with) another spacecraft?

The astronauts honed their skills first with classroom instruction, then with hands-on simulations. The instruction in orbital mechanics taught them that to catch up with a target, they would need to travel in a lower and therefore faster orbit, then travel to a higher orbit at just the right time to intercept the *Agena*. Since this lesson was counterintuitive for pilots accustomed to flying aircraft on Earth, the classroom work introduced them to the demands of space maneuvering. The hands-on work then took the astronauts to a simulator at the McDonnell plant to test rendezvous procedures. These runs not only gave the astronauts confidence in maneuvering the *Gemini* toward the *Agena*, but also gave instructors the chance to stand alongside the simulator and decide what procedures worked best. The amount of fuel astronauts used guided instructors in their projections of how much fuel crews would need on real missions. The instructors found that the astronauts should ideally catch up with the *Agena* by traveling in an orbit 15 miles beneath it, before rising to a higher orbit with a transfer angle of 130 degrees. For an ideal lighting situation, the Sun should be behind the *Gemini* as it slowed to a rendezvous with the *Agena*. These conclusions point to an important side benefit of astronaut training: the value of simulators

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[26] Slayton, North, and Woodling, 201 and Edgar C. Lineberry, "*Gemini VI-A* Rendezvous Mission Planning," in *Gemini* Midprogram Conference (Washington, D.C.: NASA SP-121, 1966), 277-281.

in aiding mission planners. But this earliest simulator contained only the displays of the *Gemini* Guidance and Control System and Propulsion System. The astronauts needed a machine that mimicked the entire spacecraft and compellingly mimicked the visual sensation of a rendezvous.[27]

The Translation and Docking Simulator (TDS), located in a 100 by 60 by 40 foot building at MSC, provided them with the level of sophistication they needed. This device featured a rail assembly on which a simulated *Gemini* slid laterally toward a docking with a simulated *Agena*. A simulator instructor could insert failures into the systems of both spacecraft. Even in a normal rendezvous, the astronauts would have their hands full monitoring the instrument panel, watching the scene out the window, and maneuvering the vehicle in four degrees of freedom while the *Agena* moved in two degrees of freedom. Simulating failures tested their ability to improvise solutions as quickly as possible and informed mission planners as to the proper solutions. For instance, simulating a thruster that would not turn on instructed the entire team in the unusual handling characteristics of a partially disabled *Gemini*. Simulating a docking aid light that would not turn on instructed the team in the visibility needed for a rendezvous.[28] After Wally Schirra became the first *Gemini* Commander to make a rendezvous in space, he called the device "probably one of the best dynamic devices we will ever find for this type of mission planning and training."[29]

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[27] Stafford and Conrad, 323-325 and Hansen, *First Man*, 249-250.

[28] Wayne K. Williams, "The Translation and Docking Simulator," *Simulator* Vol. 15, No. 1 (July 1970): 19-21 and Slayton, North, and Woodling, 205.

[29] [*Gemini VI* Technical Crew Debriefing, Box GH-134, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 244.

Once again, training for rendezvous also allowed instructors to ask a pair of "what if" questions concerning human spaceflight. What if the *Gemini* inadvertently moved out of plane with respect to the *Agena*, so that it approached its target while off to the side? The astronauts trained for this possibility aboard the TDS by making a helix-shaped approach to the target, known as a whifferdill in the tradition of pilots at air shows, to correct the error that had placed it off to the *Agena's* side.[30] What if the *Gemini's* radar, computer, or inertial platform failed as the spacecraft approached the *Agena*? The teams at MSC and McDonnell worked together to develop a chart displaying the data a crew would need to make a manual rendezvous. An astronaut could use a sextant to measure the angle between the *Gemini* and the *Agena* he could see out his window, and plot this number on a chart to determine the time of ignition and velocity required for an upcoming engine burn to take them to the *Agena*.[31] Before *Gemini* had ended, one crew would feel especially thankful for the training in whifferdills (*Gemini X*) and another for the backup rendezvous procedure (*Gemini XII*).

But the *Gemini* Mission Simulator (GMS), located both in Houston and the Cape beginning in 1964, provided the centerpiece of flight simulation. After undergoing runs in the DCPS and TDS, both part-task trainers, the astronauts moved to this device to simulate all phases of a flight from launch through splashdown in sessions of up to four hours. These simulations added a degree of realism over those in the part-task trainers because the astronauts could wear pressure suits and communicate with flight controllers

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[30] Collins, 188.

[31] Slayton, North, and Woodling, 202.

in case of a malfunction, continuing the legacy of integrated simulations that had proven effective during *Mercury*. In integrated simulations, the flight controllers and tracking network personnel even received about 300 telemetry signals from the simulator in which to guide their decision making. The simulator also replicated the exact cockpit stowage configuration so that crewmembers could learn how to operate with equipment, experiments, camera, and food strewn around them.[32]

One look inside the simulator underscored that these astronauts needed more proficiency than their *Mercury* predecessors. The *Gemini* instrument panel dwarfed the *Mercury* instrument panel. Especially in case of an emergency, astronauts would need to quickly know the location of the panels for the flight parameters, the environmental control system, the fuel cells, the propulsion system, the communications system, the inertial platform, and water management. They increased their proficiency in systems management in stages: first by listening to briefings on each *Gemini* system, then by using six breadboard-type trainers that replicated the control displays of the spacecraft, and finally by sitting aboard the GMS with the eyes and ears of SimSups and flight controllers on them.[33] Each of the men who climbed inside the simulator had flight experience ranging from 3,000 to 5,000 hours, and this was the reason they were chosen as astronauts: their ability to manage systems at high speeds when their life depended on their quick reactions.

Training aboard the GMS included preparation not only for the task of piloting,

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[32] Slayton, North, and Woodling, 204-205.

[33] Ibid, 206.

but also a task that preoccupies astronauts through the 21st century: carrying out experiments in the unique microgravity environment. Knowing the success of the *Mercury* program in proving the potential of humans as assets in this environment, NASA accepted *Gemini* experiment proposals from universities, laboratories, hospitals, industry, and government agencies. The selected proposals mainly fell into three categories: study of the Earth and the space around it, technology demonstrations, and studies of the effects of weightlessness on astronauts' bones, muscles, and bodily fluids. The Principal Investigators (PIs) fortunate enough to have their proposals selected then gave a briefing to the crew for which their experiment was assigned, which included their estimate on the training the crew would have to perform.[34]

For instance, Paul Lowman gave at least one two to three hour briefing as the PI for the Synoptic Terrain Photography Experiment. He brought orbital photos from previous missions, geologic maps of the areas the next *Gemini* crew would fly over, and the flight path maps so he could discuss which areas he wanted the crew to photograph. The photos previous crews had taken served as a guide of what to do and what not to do. Eventually the crews had access to a notebook at the Cape Kennedy crew quarters containing the best and worst photos from the *Mercury* and *Gemini* programs. Lowman also gave astronauts the scientific rationale for each photo he wanted them to take during the briefings, with the hope that this background detail would develop their interest in the

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[34] Norman G. Foster and Olav Smistad, "*Gemini* Experiments Program Summary," in *Gemini Summary Conference* (Washington, D.C.: NASA SP-138, 1967), 221-227

subject and possibly lead them to observe targets that he had not discussed.[35] Training for these experiments established an important precedent: astronauts needed to begin their mission understanding not only the operation of each experiment, but also the principles underlying them. Training personnel would expect astronauts through the ISS era to be not merely mechanics, but knowledgeable experimenters.

The last task astronauts needed to perform aboard the GMS concerned the reentry through Earth's atmosphere. Not only could a *Gemini* astronaut choose to eject during launch, change the spacecraft's orbit, pilot the spacecraft to a rendezvous and docking, and perform experiments, he could also exercise control during reentry. By placing his hand on the control stick and consulting the "8-ball" attitude indicator, he could damp oscillations in pitch and yaw while rolling the vehicle to affect its lift. These maneuvers could control the splashdown point by up to 300 miles down range and more than 25 miles side to side. Once through the atmosphere, the astronauts could consult the altimeter readout and light indications to deploy the drogue and then main parachute in advance of splashdown (NASA Associate Administrator George Mueller announced in 1964 that the idea of a paraglider guiding the spacecraft to a land touchdown had been shelved, meaning all flights would end in splashdowns).[36] The determination to give astronauts useful tasks once again guided the space agency in allocating time, money, and personnel to the training process.

The procedures for integrated simulations, involving not only astronauts but also

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[35] William C. Phinney, *Science Training History of the Apollo Astronauts* (Washington, D.C.: NASA-2015-626, 2015), 19-20.

[36] Stafford and Conrad, 321-328 and Mindell, 85.

flight controllers and the SimSups who gave them problems to solve, evolved during the *Gemini* era. Carl Shelley remembered the preparation that went into the job of being a SimSup. While the flight controllers SimSups were trying to train received classroom instruction in spacecraft systems, "we went to all the same courses…The training people were basically just like controllers who had the job of training the other guys associated with them."[37] Meanwhile, Shelley's colleague Harold Miller made the decisions on how SimSups would go about their work. He decided to install a simulation control room at MSC, separated only by a viewing window from the Mission Operations Control Room (MOCR). This allowed a SimSup to sit at his computer console injecting failures into the spacecraft, see all the controllers and displays the flight controllers saw, and then stay in close contact with the controllers for debriefing sessions. Miller also established the job of "sim coordinator." During the training for each mission, the sim coordinator worked with the SimSup to generate and document all the specific cases intended to test the crew and controllers. "Without these guys we would never have been able to run the number and quality of sims we did for each mission," Miller explained.[38]

Both Miller and Shelley believed the entire human spaceflight operation owed a debt of gratitude to the SimSups. Astronauts and flight controllers alike might have griped that the problems the SimSups injected into simulations were unrealistic, but Miller argued that actual events proved their complaints wrong in many cases. "(Flight Director) Cliff Charlesworth would, after several simulations, tell me that was the most unrealistic

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[37] Carl B. Shelley, Interviewed by Carol Butler, April 17, 2001, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/ShelleyCB/ShelleyCB_4-17-01.htm (accessed May 23, 2016).

[38] Miller, 27-29.

simulation he had ever seen," he recalled. "Invariably that specific problem would occur in the mission and he would have to eat crow." The design of simulations by people such as Miller and Shelley thus foresaw the problems that flight controllers would have to grapple with while astronauts' lives were on the line. Miller also felt the competition between SimSups and the flight controllers who tried to solve the problems they implemented was healthy, because this toughened the controllers prior to a real mission. "Controllers would say that simulations were more stressful than the real missions, which of course was our objective," he explained.[39] Shelley agreed with these thoughts, while also noting that the training procedures established during these early years persisted into the 21st century. "Fundamentally, the same types of activity go on," he explained. "Training teams spend a lot of time…really understanding what are you trying to do and what can go wrong in this situation, or how does the flight control team plus its infrastructure really gear itself up to support this activity, and where are the weaknesses in the overall plan."[40] The fact that the concept of integrated simulations survived through multiple generations indicated the value of the work these 1960s pioneers did.

The astronauts offered their own praise of GMS runs. When asked to evaluate the machine, they followed their *Mercury* predecessors by consistently saying that a simulator replicating their vehicle was the most useful way to build their confidence in advance of a groundbreaking flight. As Commander of the first piloted mission, Gus Grissom set the tone by saying, "The mission simulator is the best trainer we have. It looks exactly like a

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[39] Ibid, 36-40.

[40] Shelley.

spacecraft, and when we got inside that spacecraft on launch day, for all you could tell, you were just sitting right in the trainer."[41] Twenty months later, Jim Lovell echoed this thought as Commander of the last mission: "There is no doubt in my mind that the *Gemini* Mission Simulator is the best single device in preparing for a *Gemini* mission."[42] When asked to assess the device in a conference at the end of the program, Tom Stafford and Pete Conrad pointed out that simulator data closely matched flight data and concluded, "The success with which the flight crews accomplished each *Gemini* mission was a direct result of high-fidelity simulation training."[43] But these glowing comments should not disguise the progress over the course of *Gemini* that eliminated two shortcomings in simulation.

The first was a problem inherent in a fast-paced program designed to meet Kennedy's end-of-the-decade lunar commitment: making sure the *Gemini* Mission Simulator kept up with the updates in the actual spacecraft and could turn around quickly to support the training of new crews. The program featured ten piloted flights in only twenty months, meaning the simulator needed to undergo updates and train new crews at a quick pace. "They could make changes in the spacecraft faster than we could make them to the simulator," explained Stan Faber. "The reason for that is that they would develop their hardware and make sure it worked and then they'd say, let's stick it in the spacecraft. Well, that's when we would start developing it for the simulator and the lead time could

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[41] *Gemini III* Technical Crew Debriefing, 8-7.

[42] [*Gemini XII* Technical Crew Debriefing, Box GH-134, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston Texas, 438.

[43] Stafford and Conrad, 327.

be expensive."[44] Astronauts made comments such as Ed White's "I think, also, they're caught as second-rate citizens as far as keeping their simulators up to date and getting the latest spacecraft changes in them." His *Gemini IV* crewmate Jim McDivitt also voiced the complaint, "I think the big problem with it is that it takes too long to turn it around. I think that we're fooling around with it too much, committing it to supporting other functions besides flight crew training."[45]

These complaints contrasted with the positive debriefing comments of the *Gemini IX-A* crew, about one year later. Tom Stafford commented, "The crew station was upgraded to our configuration and, in fact, we had the control system change into the crew station at approximately the same time that the spacecraft had a control system change into it. All in one day, which I thought was very good…The *Gemini* Mission Simulator has finally matured into a very worthwhile apparatus and it's available for training a large percent of the time. Also, the crew can work in it two shifts a day, plus occasionally a night shift. The modifications and maintenance and repair to the simulator was done from midnight to six or seven in the morning and this worked out very good."[46] Stafford's comments underscored the time that hundreds of FCOD personnel spent away from families in an era when human spaceflight progressed more rapidly than in the post-*Apollo* era. One lunar scientist offered one of the best summations of this era, while looking back thirty years after *Apollo 11*: "Space advocates often lament the lack of direction of today's

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[44] Interview with Stanley Faber, April 22, 1970.

[45] *Gemini IV* Technical Crew Debriefing, 255-257.

[46] [*Gemini IX-A* Technical Crew Debriefing, Box GH-134, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 301-303.

space program…They look back wistfully on the glory days of *Apollo*, when *espirit de corps* was high, the work days were long and hard, and sleeves were rolled up and teeth were set in determination. It was like a war then. It was. And we won it."[47] Those who worked night shifts on the simulator, making sure the device was up to date and ready to support crews, were as much a part of that war as those who cut the metal on the rockets and spacecraft.

The other major shortcoming was the one that Robert Voas had considered one of the major weaknesses of *Mercury* training: simulating a realistic view out an astronaut's window. This remained a weakness through the first three *Gemini* flights. Gus Grissom noted during his debriefing after commanding the first flight: "An out-the-window display would certainly be of value. It would give you confidence that you can align the spacecraft in yaw…If we had a good out-of-the-window display, I think it would add a lot to our confidence that we can do it."[48] Fulfilling Grissom's request required a new innovation in the world of astronaut training: the digital computer. Whereas analog computers measure changes in physical quantities to make calculations, digital computers process discrete quantities numerically (as 0s and 1s). Digital computers were more versatile and accurate than their predecessors, meaning they were much better candidates to simulate the motion, instrument panel displays, or out-the-window views of a spaceflight. One of the people who understood this was Harold Miller, the simulation designer. "We were scheduled to fly *Gemini* missions on a two-month schedule and to keep a hardware/analog

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[47] Paul D. Spudis, "Apollo: An American Victory in the Cold War," July 1999, *Spudis Lunar Resources*, http://www.spudislunarresources.com/Opinion_Editorial/Apollo_30_op-ed.htm (accessed May 15, 2016).

[48] *Gemini III* Technical Crew Debriefing, 4-38.

simulator up to date would have been an impossible task and possibly improperly train the flight controllers and crew," he recalled. "The battle over how to simulate the *Agena* was a rather bitterly fought battle between Mel Brooks and me…The argument finally came to a head in John Hodge's office where IBM (the company awarded the contract for computers) presented the arguments for a digital simulation. Mel argued for the analog version. In what I considered, for the time, a real leap forward, Hodge agreed to let IBM simulate the *Agena*'s trajectory and systems."[49]

On the basis of this logic, the GMS also featured three digital computers that controlled cockpit displays for the crew and signals to control the scene generators the crew would see outside their windows.[50] The Farrand Optical Company of the Bronx, New York won the contract to create the scene generators, as they later would for the *Apollo* Command and Lunar Module simulators. The contractors for that company created scenes via an infinity optics display system. This refers to a system of projection whereby the distance from an eyepiece to an objective is set to infinity. A tube lens is then placed within the body tube between the eyepiece and objective to produce an intermediate image. Although this system did not become commonplace until the 1980s, a German microscope manufacturer had begun experimenting with it in the 1930s.[51] The Farrand contractors utilized this principle to project an *Agena* Target Vehicle, a star field, and the Earth for viewing outside the GMS window by astronauts. Beginning

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[49] Miller, 26-27.

[50] Tomayko, 272-273.

[51] "Infinity Corrected Optics," *Microscope World*, http://www.microscopeworld.com/infinity_corrected_optics.aspx (accessed August 19, 2016).

when Wally Schirra and Tom Stafford trained to make the first space rendezvous on *Gemini VI-A*, crews saw this scene move outside their window to approximate flying in space. Thanks to the infinity optics system, all of the elements in the scene appeared to move correctly even as the astronauts moved their heads. The astronauts reported that the visual simulations could have used more accuracy in mimicking the magnitude of the lights on the *Agena*, but that otherwise they benefited from being able to visualize scenes outside their windows.[52]

Stan Faber remembered the significance of this technological leap forward. He said of the *Gemini* Mission Simulator, "Our big jump there was in the visual area." He explained the jump by pointing to the desire of NASA instructors like himself to build off the capabilities of aircraft simulation: "Traditionally, in airplane simulations and training of pilots, they trained them to land on the runway with a camera-model type system. I can remember the first one I ever saw, happened to have been at the FAA's headquarters in Oklahoma, and it was the worst television picture I ever saw." NASA instructors thus funded the development of superior digitally generated images while collaborating with aircraft instructors at the Air Force on how best to go about this. "In fact, I, for a time was on the American Institute of Aeronautics and Astronautics committee on simulation, and that was just so I could go visit these other people and see what they were doing and how they were handling things," Faber remembered.[53] Through the invention of one of the defining technologies of the twentieth centuries (the

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[52] Stafford and Conrad, 324.

[53] Stanley Faber, Interviewed by Kevin M. Rusnak, May 8, 2002, Houston, Texas, http://www.jsc.nasa.gov/history/ /oral_histories/FaberS/FaberS_5-8-02.htm (accessed April 11, 2016).

digital computer), and through a team effort to apply this technology, the instructors solved what Thomas Hughes would call one of the reverse salients in the technological system of astronaut training. *Gemini* astronauts could train for the sensation of looking out a window while a target vehicle approached at 17,500 miles per hour. Nobody could know at this point that the astronauts on the last *Gemini* mission would need to do this to make a manual rendezvous when the automatic system failed. It was only one of the many glitches that crewmembers on ten *Gemini* missions encountered, each of which deserve consideration from a training standpoint.

CHAPTER V

GEMINI: "I HAD MY BUTT WORKING FOR ME"

The vehicle nicknamed the "Gusmobile" had a fitting first Commander. As the training progressed and engineers moved the spacecraft and *Titan* booster closer to flight readiness, Deke Slayton knew he would have to select crews for the ten piloted *Gemini* missions. He explained that he developed five guidelines in selecting crews: he considered everybody acceptable for any mission when selected by NASA; he considered some astronauts more qualified than others for specific missions, however; he tried to match people in a two-man crew based on talents and personal compatibility; he always kept future requirements and training in mind; and he assumed a ten percent attrition rate in the astronaut corps each year. He also favored assigning the job of Commander to those with spaceflight experience. Of the six *Mercury* veterans who had that experience, only four remained in consideration for *Gemini* missions (John Glenn departed to pursue a political career and Scott Carpenter, viewed as unacceptable to management because of his *Mercury* flight, would depart in 1967 without flying another mission). Slayton decided in 1963 that since Alan Shepard had served as backup on the last *Mercury* mission and was the most capable pilot in the corps, Shepard should command the first *Gemini* mission. He also observed the training of the "Next Nine" and recalled, "By this time I had a pretty good idea as to who was more equal in the new group." On this basis, he decided on Tom Stafford as Shepard's crewmate. But Shepard fell ill with an inner ear disorder called Ménière's disease, and when the diagnosis was confirmed in October 1963, he was disqualified from flying. Thus Slayton decided to make Gus Grissom the Commander of the first piloted *Gemini* mission and John Young his crewmate.[1]

Grissom and Young each brought reputations as talented pilots and astronauts who were unafraid to speak their minds if they saw a shortcoming. One NASA medical officer remembered, "It may be imagination, but he (Young) seems to walk like Gus, talk like Gus, and sometimes, he can be just as obstinate as Gus. I think they named this program right when they called it *Gemini* and selected these two for the first flight."[2] The two also had proven they could work together effectively during their jungle survival training in Panama. Deke Slayton therefore felt confident enough to forward his selection to Bob Gilruth, who made the assignment official on April 13, 1964. The *Gemini III* crew knew that an unmanned test of the spacecraft and booster remained a hurdle to be cleared, while their own vehicle needed to be tested and checked out. When Young asked Grissom when he thought they would launch, the Commander immediately responded with remarkable prescience, "March 1965." "We had an incredible amount to learn, and only eleven months to do it," Young recalled.[3]

The two of them demonstrated more convincingly than ever before that NASA and McDonnell personnel valued the contribution of users. Based on his experience during the *Mercury* program, Grissom believed he and Young should participate in the test and checkout of the ship he eventually named the *Molly Brown*. The McDonnell

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[1] Slayton with Cassutt, 136-140.

[2] Ray E. Boomhower, *Gus Grissom: The Lost Astronaut* (Indianapolis: Indiana Historical Society Press, 2004), 250.

[3] Young with Hansen, 64-65.

contractors accepted this request, so the *Gemini III* crew commuted to St. Louis about forty-five times during their training, mostly using the T-38 aircraft they flew to keep their piloting skills sharp. "The final report on *Gemini III* would indicate that Gus and I spent on the order of 40 hours in spacecraft tests for our flight, but if the truth be told, it was more like 300 or 400 hours," Young remembered. "There were plenty of times at McDonnell when we stayed in the spacecraft all day and all night. The way they checked out the first manned *Gemini* spacecraft, they'd put in a system, check it out, take it out again, put in another system, check it out, and take it out again…The attention to detail was truly extraordinary." The commitment to participate in every test allowed the two men to share their input with the contractors and to learn every idiosyncrasy of the vehicle, which they considered necessary in case the simulator did not capture every unique aspect of the *Molly Brown*.[4] As husbands and fathers, Grissom and Young also learned that their training routine left them with precious little time for their families. The two spent days sleeping at the Chase-Plaza Park Hotel in St. Louis and could only return to their homes in Houston at the end of each week.[5] When Grissom died, his wife remarked that she would "miss the phone calls," because this was her only hope of maintaining reliable contact with him."[6]

By the time March 1965 arrived, the statistics indicated the staggering amount of preparation Grissom and Young underwent for such a short mission (three orbits in

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[4] Ibid, 65-68.

[5] Boomhower, 247.

[6] Eugene A. Cernan with Donald A. Davis, *The Last Man on the Moon: Astronaut Eugene Cernan and America's Race in Space* (New York: St. Martin's Press, 1999), 176.

about five hours). The men first spent time in an early version of the *Gemini* Mission Simulator in St. Louis, to learn general operations. Link then constructed a simulator updated to exactly match the *Gemini III* spacecraft and shipped it to Cape Kennedy (President Lyndon Johnson had issued an executive order renaming Cape Canaveral in honor of his fallen predecessor in 1963. The Canaveral name was restored in 1973). Beginning in November 1964, Grissom spent over 77 hours and Young over 85 hours at the Cape in this simulator. Simulator time thus outpaced the time of the actual flight by about a 17:1 ratio. Though he would only launch once, Grissom made 20 normal and 46 aborted launches to give him the confidence he would need to handle any contingency as he soared to 17,500 miles per hour. He also made 107 retrofires and 64 reentries. He went through the entire flight plan nine times so that his tasks would feel as close to second nature as possible. By the time he stepped into the actual vehicle on launch day, he had responded to 211 systems malfunctions aboard the simulator. The simulator time combined with DCPS runs during the previous July and August, egresses from the spacecraft in October, centrifuge runs in November and December, 25 hours per month flying time, and the litany of tests aboard the actual spacecraft desensitized Grissom and Young to the experiences of piloting and spaceflight more than any astronauts before them.[7]

Gemini III succeeded as well as any engineer could have hoped. On March 23, Grissom and Young tested every system of the *Molly Brown*, became the first astronauts

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[7] Barton C. Hacker and James M. Grimwood, *On the Shoulders of Titans: A History of Project Gemini* (Washington, D.C.: NASA SP-4203, 1977), 221-224.

to alter a ship's orbit, and proved the ship worthy of the high expectations placed upon it. The brief flight also indicated the value of the training process. A few minutes into the first orbit, the two men saw an indication that their cabin pressure had fallen to zero. Young lowered his helmet visor, but scanned the instrument panel just as he had over those 85 hours of simulated flight and saw unusual readings on several other meters. He surmised that the problem was not a real loss of cabin pressure, but a loss of the electricity that powered the dials on the instrument panel. He switched to the secondary electrical converter and the dials returned to normal. In solving this problem in only 45 seconds, Young proved the value of mentally rehearsing tasks in a technically complex vehicle where a life-threatening problem could emerge in seconds.[8] The flight also proved the value of training during reentry, when the visual and auditory experience matched the simulations even to the plasma sheath that surrounded the vehicle.[9]

Grissom had the first chance to control the spacecraft during reentry. Some of the astronauts later compared the *Gemini* to a fighter plane, because the vehicle responded more crisply to the two hand controllers than *Mercury* before it or *Apollo* and the Space Shuttle after it.[10] Grissom drew upon his experience in fighter planes and the GMS to manipulate the translation and attitude controllers, succeeding in lifting the spacecraft about 130 miles. This was necessary because the retrofire burn set up the *Molly Brown* to splash down well short of its target. Although the ship's lift-to-drag

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[8] Young with Hansen, 79-80.

[9] Hacker and Grimwood, 236.

[10] D.C. Agle, "Flying the Gusmobile," September 1998, *Air & Space Magazine*, http://www.airspacemag.com/flight-today/flying-the-gusmobile-218187/ (accessed May 22, 2016).

ratio proved 31 percent lower than expected, Grissom proved a well-trained astronaut could eliminate such an error to as great an extent as the vehicle allowed.[11]

By this point, Jim McDivitt and Ed White were deep in training for a mission that would take a far greater leap forward than any in the past: *Gemini IV*. Medical specialists wondered whether astronauts would be able to function for four days in a weightless environment, and this crew would provide the answer. Engineers wondered whether astronauts would be able to rendezvous, and this crew would provide an initial answer by maneuvering toward the spent second stage of their *Titan* booster, then staying a short distance away from it in the same plane and at the same velocity. Engineers called this feat stationkeeping and considered it a precursor to a rendezvous and docking with another spacecraft. Both engineers and medical specialists also wondered if an astronaut would be able to maneuver outside a spacecraft, and White would provide an answer by becoming the first American to perform an EVA.[12] Of these three tasks, the last two were especially instructive in terms of lessons learned for training.

Bob Gilruth and fellow administrator George Low added the stationkeeping task late in the astronauts' training process after receiving a positive response from the *Gemini* Project Office. But the task contained two major problems. First, the rendezvous radar that future crews wished to use to close in on other spacecraft was not yet available. This meant McDivitt and White needed to track their booster stage by eye.

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[11] Young with Hansen, 80-82.

[12] Hacker and Grimwood, 239-245.

That requirement placed a premium on the astronauts' skill level. But the second problem was that the simulators at the Cape and Houston were not designed to train them for optical stationkeeping. The results when *Gemini IV* launched on June 3 failed to meet expectations. McDivitt thrusted toward the rocket stage from a few hundred feet away, but could not catch up with it. His eyes and brain told him to thrust toward the stage, but in doing so he increased his own ship's altitude, and placing the *Gemini* in a higher altitude meant it traveled slower than the stage. While over Hawaii, McDivitt understood that he had expended almost half of his ship's fuel and ended his futile effort.[13] Langley engineer Paul Purser summarized the experience by stating, "no one was 'adequately' trained in that the differences between motions on Earth and motions in orbit were not intuitively realized or 'second nature' to anyone."[14] But as counterintuitive a concept as orbital mechanics was for a pilot accustomed to flying on Earth, McDivitt would have benefited from thorough simulator training.

No task during the *Gemini* era proved more confounding, or more instructive to the training process, than EVA. As early as January 1964, engineers had considered making *Gemini IV* the first mission when an astronaut would leave his spacecraft. But management at Houston and NASA Headquarters remained skeptical of the idea until engineers could develop realistic training methods. MSC engineers tried to persuade management first by way of vacuum chamber simulations with Gus Grissom and John Young at the McDonnell plant in St. Louis. This required NASA and McDonnell to put

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[13] Ibid, 243-248 and Kraft, 220.

[14] Hacker and Grimwood, 254.

“guys in vacuums with nothing between them but that little old lady from Worcester, Massachusetts, and her glue pot and that suit,” as Young recalled in his wry way. But the vacuum chamber simulations, beginning in November 1964, gave the astronauts experience in depressurizing the *Gemini* spacecraft and opening and closing the hatch at a simulated altitude of 40,000 feet. When Soviet Alexei Leonov became the first human to make an EVA the following March, his feat stirred the *Gemini* team to make an American EVA in the next few months. By late April, the vacuum chamber at MSC was ready for full-scale simulations.[15] But even as the *Gemini IV* crew gained experience with a vacuum environment, how could White feel confident about his ability to maneuver in a weightless environment?

The answer would come as a surprise to almost every astronaut who has ever walked in space, if he or she is not aware of the history of the corps. White did not train to maneuver his body through the concept of neutral buoyancy. Instead, he traveled to Wright-Patterson Air Force Base and flew aboard a KC-135 aircraft that made parabolic flights to produce weightlessness. Inside the fuselage, he practiced climbing out of the hatch and maneuvering toward the adapter section of the *Gemini*. This method had one advantage over the neutral buoyancy method, in that he could maneuver without the drag that water created. But more importantly, KC-135 flights had a weakness: they could only produce 30 seconds of weightlessness at a time.[16] This meant they could not replicate the fatigue that an astronaut would encounter on a long EVA. This posed a

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[15] Ibid, 241-242.

[16] Slayton, North, and Woodling, 206-207.

problem for the future, but White only planned to spend about 20 minutes outside. Both he and McDivitt praised the KC-135 flights during their mission debriefing, with the Commander arguing, “Without this we wouldn’t have had the confidence in ourselves in getting in and out of the spacecraft and opening and closing the hatch that was required, so that we probably wouldn’t have even done it.”[17]

White did have one other helpful but flawed method with which to prepare: the MSC’s Air Bearing Facility. This room measured 21 by 24 feet and contained a smooth metal floor estimated to be flat within about 0.002 inches. Engineers placed a circular platform on it and lifted the platform a fraction of an inch off the floor via gas jets. The flat floor then allowed a suited astronaut mounted on the platform to maneuver his body with as little friction as possible. White carried a Hand Held Maneuvering Unit (HHMU) and when he pressed the unit’s trigger, compressed oxygen gas propelled him up to 6 feet per second. As he propelled himself, his body yawed to one side and he learned how to eliminate this motion and still arrive at his intended target. He could also experiment with pitch motion by lying on his side and roll motion by lying on his back. White spent 12 hours in the Air Bearing Facility, but like the KC-135 flights, this means of preparing him contained a critical weakness. He could only reproduce motion in one axis at a time, not the simultaneous pitch, roll, and yaw motions an astronaut might need to reach another spacecraft. He also could not fly up or down, only back and forth in two dimensions. This method did succeed in preparing White for a 20 minute EVA, but long-term success in the kind of work spacewalking astronauts eventually performed in

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[17] *Gemini IV* Technical Crew Debriefing, 278.

the Space Shuttle/International Space Station era called for improvement.[18]

As *Gemini IV* flew over the Indian Ocean on June 3, White became the first American to drift out of his spacecraft into the vacuum. His brief stay outside carried two major positives. First, he turned his body and stopped easily with short bursts of the HHMU trigger. Pulling the trigger felt natural to him thanks to his Air Bearing Facility experience. Second, he did not feel disoriented in what later spacewalkers would call a "three dimensional ice skating rink." When he ran out of maneuvering fuel, he felt in such good spirits that he made his famous statement, "It's the saddest moment of my life." He only encountered one major problem: closing the hatch after he returned to his seat. But White's EVA still carried signs of the trouble his successors would face. When he maneuvered himself, he felt the tendency to pitch, roll, and yaw simultaneously that the Air Bearing Facility could not reproduce. By the time he returned to the spacecraft, even this West Point graduate who had nearly qualified as a U.S. Olympic runner felt physically exhausted. Sweat fogged his faceplate. The Ventilation Control Module did not have the capacity to cool his body.[19] White's training could not produce this sensation either, and this was after a 20 minute EVA. Serious work in space would require several hours outside. Yet these signs did not alter the training process as they probably should have in retrospect. Only the more dramatic difficulties of the next three *Gemini* spacewalkers stirred the instructors to action.

McDivitt and White were most successful in proving the ability of astronauts as

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[18] Harold I. Johnson, William C. Huber, Edward H. White II, and Michael Collins, "Extravehicular Maneuvering About Space Vehicles," in *Gemini Summary Conference* (Washington, D.C.: NASA SP-138, 1967), 98-101.

[19] Hacker and Grimwood, 249-250 and Johnson, Huber, White, and Collins, 128-129.

experimenters. "Crew understanding is vital to achieve maximum benefit from man in space," two authors wrote for the *Gemini Summary Conference*.[20] Since *Gemini* instructors adhered to this philosophy, McDivitt and White went into space having stayed in close touch with the PIs throughout training and knowing they would be available on the ground if needed during the flight. The astronauts also possessed the understanding, honed through their briefings with the PIs, to make adjustments to experiments on their own. The results of the experiments provided yet another justification for sending trained crews into orbit, especially for those involving photography. As the PI for the Synoptic Terrain Photography experiment, Paul Lowman argued, "Despite the fact that many of the planned terrain target areas were not covered for various reasons, the gaps were more than compensated for by coverage of unplanned areas or features." For instance, McDivitt and White took photos of a circular structure in the African nation of Mauritania because although they were not briefed on this area, they still recognized it as an important feature to document. The first photos of this structure from space sparked an investigation that expanded scientific knowledge about the geology of Mauritania.[21] The Director of Manned Flight Experiments coauthored an article about the entire program stating, "Over half of the experiments were photographic in technique, indicating that the investigators wished to take advantage of the flight crew being available to guide and select the targets and to return the film for permanent

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[20] Norman G. Foster and Olav Smistad, "*Gemini* Experiments Program Summary," in *Gemini Summary Conference* (Washington, D.C.: NASA SP-138, 1967), 230.

[21] Phinney, 20.

record."[22]

Astronauts capitalized on their training and on this faith in their abilities to take photos that returned useful data to the scientific community, beginning with McDivitt and White. Their 100 photos of Earth terrain gave geologists a bird's eye view of surface features that helped them understand continental drift, the structure of Earth's mantle, and even draw a comparison between Earth terrain and the terrain of other planets or moons. For instance, geologists compared rift valleys in the Middle East and Africa to rilles on the Earth's Moon. The two men also took about 200 photos of meteorological phenomena. The Synoptic Terrain and Synoptic Weather Photography of *Gemini* crews established a precedent of utilizing the human mind's ability to identify the most useful times to take photos of Earth. This culminated in the Crew Earth Observations program that ISS astronauts carry out to this day.[23]

The physiological experiments fortunately revealed that extended stays in weightlessness would not prevent astronauts from carrying out such tasks. Medical Director Chuck Berry recalled hearing the same comment from several physiologists in advance of *Gemini IV*: "Don't you…know that these guys are going to…pass out and might, indeed, die from this flight?" One experiment did find significant losses in the bone mass of the two men compared to bed rested patients over four days. But McDivitt and White were well conditioned astronauts who exercised regularly before and during the flight with a pair of bungee cords. The two defied the critics by walking on the

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[22] Jocelyn R. Gill and Willis B. Foster, "Science Experiments Summary," in *Gemini Summary Conference* (Washington, D.C.: NASA SP-138, 1967), 292.

[23] Ibid, 292-297 and Hacker and Grimwood, Appendix D-1.

recovery carrier immediately after four days in weightlessness. One day later, White even took part in a tug-of-war on the carrier.[24]

Gordon Cooper and Pete Conrad pushed the envelope even further during the *Gemini V* mission in August: eight days. One of the challenges of *Gemini* was to launch missions just two months apart, for the astronauts and instructors as well as the engineers building the rockets and spacecraft. In the first half of 1965, 12 astronauts had to share the *Gemini* simulators. This caused a delay in the *Gemini V* launch, but Cooper and Conrad worked 16 hour days, including weekends, to make up lost time and the launch only slipped 10 days.[25] Chris Kraft remembered feeling during integrated simulations that the entire *Gemini* team reached a new level of professionalism at this point: "This was the longest spaceflight ever attempted by anyone, and the number of things that could go wrong grew incrementally with each day. We couldn't train for all of them. But my teams were so sharp and well-practiced at handling new situations that I developed a strong confidence in their ability to cope."[26]

Indeed, *Gemini V* continued the trend of solving problems unprecedented in any previous piloted flight. The pressure in a fuel cell, which had replaced batteries as the means of providing electricity to the spacecraft, inadvertently dropped. Cooper responded as he would in the simulator, carrying out an emergency power down of the ship's electrical systems while out of contact with Earth. The flight controllers then gave the crew instructions for a powering-up procedure, and the fuel cell pressure began

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[24] Hacker and Grimwood, 244-253.

[25] Ibid, 255.

[26] Kraft, 229.

to build again. Two of the ship's sixteen maneuvering thrusters failed, but Cooper compensated by placing the spacecraft into a drifting mode. An engineer had fed incorrect data into the computer, resulting in an off-target reentry at too steep an angle, but Cooper compensated by lifting the spacecraft to a more acceptable splashdown point despite 7.5 Gs pressing him down in his seat. The mark of a successful training program was that he, Conrad, and the flight controllers did not let the mechanical glitches in a new and complex vehicle prevent them from fulfilling their jobs. The crew carried out 16 of 17 planned experiments and performed a "phantom rendezvous" with a moving point in space, which proved the value of Cooper's flying skills and the *Gemini* maneuvering system by taking the ship to the exact point Chris Kraft wanted.[27]

But the most important objective of the program remained unfulfilled. Thus Wally Schirra and Tom Stafford spent several months training to make the first ever rendezvous with another spacecraft on *Gemini VI*. These men especially benefited from the contributions of MSC engineer Dean Grimm and Buzz Aldrin, the astronaut known as "Dr. Rendezvous" for his expertise in this subject dating back to his Ph.D. dissertation at the Massachusetts Institute of Technology (MIT). Grimm and Aldrin developed the crew procedures that would allow *Gemini VI* to catch up with an *Agena* by flying in a lower orbit and then intercepting the *Agena* at the right moment. Grimm remembered the sacrifices he made in doing so: "I'd work with the engineering people after the crews left at 6 p.m., and I'd be there until 4 a.m. Then I'd go home and sleep for four or five

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[27] Hacker and Grimwood, 256-263 and Colin Burgess and Francis French, *In the Shadow of the Moon: A Challenging Journey to Tranquility, 1965-1969* (Lincoln: University of Nebraska Press, 2007), 42-50.

hours and then be there about 8:00 to 8:30, and then they'd come in about 9:00. Then we'd start working with the procedures that I had developed overnight. That's the way we incrementally trained the crews."[28] Thanks to his persistence, Schirra and Stafford had a manual by their side which they consulted in making 50 rendezvous simulations. As they thrusted toward the *Agena* in the safety of a simulator, they could take notes and consult with Aldrin.[29]

Gemini VI training once again demonstrated that ubiquitous point that dated back to *Mercury*: the trust placed in astronauts as users of new technology. As an engineer who worked with Schirra, Stafford, and subsequent crews closely, Grimm recalled, "Of course the crews were always great, and they always had a lot of ideas. Although they didn't have a lot of time to spend on solutions, they could tell you what the problem was. Of course then it was our responsibility to figure out a solution to the problem and then we'd work it out and go fly the simulation ourselves to make sure it worked. Then we'd bring the crew in and they'd tweak it however they wanted some procedure or something or other. Then we'd put it in concrete and that would be it."[30] Grimm's words indicate that rather than treating astronauts as "spam in a can," engineers who developed procedures valued the input of astronauts. The presence of an astronaut who had written a Ph.D. dissertation on rendezvous, the first in what eventually became a long line of Ph.D. astronauts, further emphasized the trust placed in users to contribute to this most

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[28] Dean F. Grimm, Interviewed by Carol Butler, August 17, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/GrimmDF/GrimmDF_8-17-00.htm (accessed May 28, 2016).

[29] Hacker and Grimwood, 267.

[30] Grimm.

important task of the whole program. Astronauts were more than just “fighter jocks,” as Aldrin especially proved. Chris Kraft spoke effusively of his importance in rendezvous: “In the early stages of the development of the *Gemini* rendezvous mission plan, Major Aldrin almost singlehandedly conceived and pressed through certain basic concepts which were incorporated in this operation, without which the probability of mission success would have unquestionably been considerably reduced.”[31]

But before Schirra and Stafford could rendezvous, the more elementary task of launching into space bedeviled the *Gemini* team twice. The two traveled to the launch pad and climbed into their spacecraft on October 25, while an *Atlas* rocket stood poised on a nearby launch pad carrying the *Agena* Target Vehicle. But the *Agena* exploded into five pieces during the *Atlas's* ascent, leaving the crew without a mission. Walter Burke, a spacecraft manager at McDonnell, ingeniously suggested an alternative that kept the rendezvous objective alive: send Schirra and Stafford on a mission renamed *Gemini VI-A* to maneuver to the *Gemini VII* spacecraft, carrying Frank Borman and Jim Lovell.[32] *Gemini VII* did launch safely on December 4. But another miscue prevented Schirra and Stafford from lifting off on December 12, and this one dramatically proved a point about crew training. At 9:54 a.m., the *Titan* roared to life. But an electrical plug disconnected from the booster too soon and activated a clock in the spacecraft that was not supposed to start until the *Titan* left the pad. The Malfunction Detection System sensed this problem and stopped the engines 1.2 seconds into the flight. Schirra and Stafford

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[31] Buzz Aldrin with Malcolm McConnell, *Men From Earth* (New York: Bantam Books, 1989), 70-72.

[32] Hacker and Grimwood, 270-275.

managed to climb out of the spacecraft and go back to their crew quarters at the Cape that day, and one could rightly argue that this was a tribute to the detection system.[33]

But this was also a tribute to Schirra, who proved the potential of highly trained humans in a crisis situation. If Schirra had followed the mission rule established for him, he would have activated the ejection seats for him and his crewmate. Ejection seat specialist Kenneth Hecht expected this, as did a nervous Flight Director Kraft watching on television. But Schirra had flown in jets since shortly after World War II, he had launched atop a rocket once before, and he had taken part in hours of launch simulations aboard the DCPS. He also paid close attention as the countdown reached zero and his trained mind told him that the vehicle had not left the pad. If he was wrong, 150 tons of propellant would have come crashing back to the ground in a fireball and the whole world would have seen two astronauts killed on live television. Yet Schirra refused to fire the ejection seats and stayed put, drawing on his instincts, the lack of any liftoff call he would have heard from fellow astronaut Alan Bean, and the knowledge that using the ejection seats would have ruined the mission and risked life threatening injuries to him and Stafford. "Fuel pressure is lowering," he reported calmly, and as the seconds passed the threat of an explosion passed. Kraft recalled, "Two thoughts came quickly: *Why the hell didn't they eject* and *Thank God they didn't eject*."[34] Schirra simply recalled, shortly before his death in 2007, "I had my butt working for me."[35]

The incident emphasized a point that instructors have tried to teach student pilots

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[33] Ibid, 283.

[34] Ibid, 283 and Kraft, 242.

[35] Burgess and French, 70.

for decades. One instructor made the point by writing, “You can be a whiz at aerodynamics and know your equipment like an engineer, but it’s how you react when everything goes wrong that shows what kind of pilot you really are.” This point is not limited to pilots only, as “Business leaders face down everything from PR headaches to financial crises, and sometimes even threats to health and human life within their organizations. You can bring your A game to the boardroom and know your industry inside and out, but if you’ve never handled a major emergency, it’s hard to know how well you’ll fare when your first one hits.”[36] Schirra could have easily made the wrong decision in this emergency by judging that the *Titan* had left the pad, even by a few inches, and activating the ejection seats. If he was an automaton who had operated strictly according to the mission rule, he would have done so. But training and instincts told him to disobey the rule, and without this split-second decision the first space rendezvous would not have happened when it did.

He had another chance to prove himself when he and Tom Stafford finally did lift off on December 15. The first joint space mission with astronauts was underway. Schirra and Stafford now had the task of making up the 1,237 miles that separated them at orbital insertion from Borman and Lovell, which they did by traveling in a lower orbit, firing thrusters to keep the vehicle in the same plane as their target, and firing thrusters to gradually raise their orbit.[37] Their training for this unprecedented meeting benefited them in three ways. First, the visual display in the GMS helped them recognize their

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[36] Kim Green, “3 Things Pilots Know About Crisis Management,” November 24, 2015, *Fast Company*, http://www.fastcompany.com/3053896/lessons-learned/3-things-pilots-know-about-crisis-management (accessed May 29, 2016).

[37] Hacker and Grimwood, 286.

target and any potential errors in their approach.[38] Second, their time in the GMS helped them hone their cockpit communication. Stafford called out range and range rate to *Gemini VII* based on the onboard radar data while Schirra focused on the view out the window and the "8-ball" attitude indicator. During long hours in the simulator, *Gemini* and *Apollo* astronauts learned to count on each other and even sense slight changes in tone of voice during critical mission phases. Third, Schirra's time operating the hand controllers in the GMS helped him fly the final approach to his target. When he had flown in *Mercury*, he could only adjust attitude; now he could use two controllers to adjust attitude and translation. Like airplane pilots, he found that the key to success was to make small adjustments and avoid overflying the vehicle. "I did translation with my left hand, which is a very delicate maneuver—a bit like when the shuttle docks with the space station," he remembered. "I made tiny, tiny thrusts, and developed that technique to perfection."[39]

When Schirra pulled to within about 130 feet of *Gemini VII* and eliminated all lateral motion between his vehicle and the target, he had pioneered the concept of rendezvous. He then undertook stationkeeping with *Gemini VII* for more than three orbits, finding that his ship responded so crisply to his control that he pulled to within a few inches of his target and saw the faces of Borman and Lovell.[40] This was the moment that, more than any other in the *Gemini* program, illustrated that the U.S. had pulled ahead of the Soviets in piloted spaceflight. To this point, the Soviets had only

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[38] *Gemini VI-A* Technical Crew Debriefing, 57.

[39] Burgess and French, 72.

[40] Ibid, 73.

managed to fly two spacecraft within about three miles. Those vehicles could not maneuver to stop relative motion between them. “Jolly Wally” Schirra explained the difference between this and what he had just accomplished: “Did I tell you exactly what a rendezvous was? When a man looks across a street and sees a pretty girl, and waves at her, that’s not a rendezvous, that’s a passing acquaintance. When he walks across street through the traffic and nibbles on her ear, *that’s* a rendezvous!”[41] Schirra had not only done this, he had done so with a precision that reflected his training. “The only reason I can say that rendezvous looked easy is because we spent an exhaustive amount of time rehearsing this role,” he said at the mission debriefing.[42] When astronauts of the next half century traveled to the Moon, the *Hubble Space Telescope*, the *Mir* space station, or the ISS, they continued a tradition of training and execution that the *Gemini VI-A* crew had begun.

The week proved doubly successful. Schirra and Stafford pulled away and made a safe splashdown on December 16. Frank Borman and Jim Lovell splashed down on December 18 after an astounding fourteen days aboard *Gemini VII*. The latter mission bore more similarity to the work astronauts perform today in the ISS era than any other 1960s flight, because it emphasized medical experimentation over a long duration in weightlessness. Training for Borman and Lovell therefore involved not only learning how to operate their vehicle, but also preparing themselves physically and psychologically for the longest spaceflight ever. Could they live in a cabin the size of

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[41] Ibid, 57.

[42] *Gemini VI-A* Technical Crew Debriefing, 242.

the front seat of a Volkswagen automobile for two weeks and eliminate as much as possible the fatigue that the *Gemini IV* and *V* crews had felt? The two men prepared themselves as best they could for six months prior to launch by running and playing handball in Houston, until their move to the Cape for the final month. In Florida, they intensified their routine by spending every day running at least one mile, lifting weights, and working out in the crew gymnasium. Preparing for the flight also meant undertaking medical exams and limiting their diet for 10 days prior to launch so medical specialists could collect their body wastes. After Borman and Lovell spent fourteen days in orbit, doctors compared their preflight results with their postflight results.[43] The flight encouraged the doctors, as they found the astronauts slept well after the first night, reacted well to stress, and even lost less bone mass than the *Gemini IV* and *V* crews despite staying in orbit longer.[44] The preparation of Borman and Lovell served them well in proving that humans could function in weightlessness for the time needed to travel to the Moon and back.

As 1966 began, one task remained for *Gemini* astronauts to fulfill: docking. *Gemini VIII* crewmembers Neil Armstrong and Dave Scott planned to connect their spacecraft with an *Agena* for the first time. Scott also planned to make an EVA much more ambitious than Ed White's. He spent 84 hours training for a two-hour outing that would take him to the *Agena*, where he would remove a micrometeorite package and test a power tool. The scant 20 minutes in which White floated at the end of his tether paled

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[43] *Gemini* Mission Evaluation Team, *Gemini Program Mission Report, Gemini VII* (Houston, TX: MSC-G-R-66-1, 1966), 7-63 to 7-66.

[44] Hacker and Grimwood, Appendix D-1.

in comparison to these tasks Scott planned to pioneer.[45] The combination of a rendezvous, docking, and EVA containing significant work made for the most challenging mission yet attempted. This placed a thorough training regimen at a premium, but nobody could know that this was also the mission where the crew would place emergency training to the ultimate test. Grissom had confronted catastrophe while in the ocean five years earlier, and so had Schirra and Stafford while on the launch pad one year earlier. But no astronauts had ever come as close to death during a mission (Ted Freeman, Elliot See, and Charlie Bassett had already died in T-38 aircraft accidents) as Armstrong and Scott did on March 16, 1966.

The flight began as the most promising to date. Armstrong carried a reputation as having one of the keenest analytical minds in the astronaut corps, due to his seven years as an NACA/NASA test pilot prior to joining the "Next Nine." His 125 hours in the GMS preparing for this mission reinforced this reputation. "We achieved fifty to sixty rendezvous simulations on the ground, about two-thirds of which were with some sort of emergency," he remembered. "That means that some part of the equipment was either malfunctioning or inoperative during the rendezvous. We completed the rendezvous in all of them but two."[46] He also passed the real test, maneuvering the *Gemini* to the *Agena* and then taking his spacecraft's nose into the docking collar at just three inches per second. "Flight, we are docked!" Armstrong reported. "Yes, it's really a smoothie." About half an hour after the flight controllers heard this message, they lost

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[45] Burgess and French, 79.

[46] Hansen, *First Man*, 248 and *Gemini* Mission Evaluation Team, *Gemini Program Mission Report, Gemini VIII* (Houston, TX: MSC-G-R-66-4, 1966), 7-12.

contact with the *Gemini*/*Agena* combination as it moved across the Indian Ocean and out of range of the tracking network. The next words they heard, fifteen minutes after that, were from Scott: “We have serious problems here. We’re…we’re tumbling end over end up here. We’re disengaged from the *Agena*.[47]

Armstrong and Scott were thus on their own at the outset of a crisis, with only their training to guide them. It began innocently enough, as Scott looked at the instrument panel and found the vehicle in a thirty-degree bank angle rather than level. Armstrong fired the *Gemini* thrusters to eliminate the bank, but was unsuccessful. He thought the problem stemmed from the *Agena*, a natural reaction given the troubled development of this device. But when he asked Scott to turn off the *Agena* attitude control system, the bank still did not stop. Armstrong decided he had to undock with the *Agena*, which did not solve the problem either. In fact, the spacecraft spun by an increasing amount until it reached a full circle (360 degrees) per second. His vision blurred to the point that he knew time to solve the problem before losing consciousness, or before the spacecraft disintegrated, was running out. He drew upon his training in realizing that he did not have time to find out which of the many thrusters was sending the *Gemini* into its spin. He had no choice but to use the thrusters of the Reentry Control System to stabilize the vehicle. Since this took up much of the fuel reserved for reentry, he and Scott splashed down about four hours later.[48]

Though both men felt depressed about cutting short a three day mission and

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[47] Hansen, *First Man*, 257-258.

[48] Hansen, *First Man*, 258-265 and Burgess and French, 85-87.

losing Scott's EVA, Armstrong proved the value of having a highly trained astronaut accustomed to making split second decisions aboard *Gemini VIII*. The events of his life had prepared him for this, from bailing out of a *Panther* jet while flying a Korean War mission in 1951, to his recovery from an overshoot of his landing site while aboard the X-15 aircraft in 1962.[49] In this case, he took a step by step approach to solving the problem just as he had done during those 125 simulator hours. Three factors made this difficult. First, he faced the emotional moment of losing his mission and possibly his life. Second, he had not trained for a *Gemini* thruster to stick in the "on" position while docked with the *Agena*. The SimSups had not tested him on this point. Third, he faced severe time pressure in solving whatever problem had emerged. Despite all of this, he did just what his training had emphasized: mentally ask himself what options he had, narrow them until he had just one remaining, and carry out the option before it was too late. The fact that this option required him to abruptly end the mission should not overshadow the analytical thinking, honed during training, that he did in solving the problem. Most of Armstrong's colleagues shared this judgment.[50]

The problem solving kicked into even higher gear with *Gemini IX-A*. With Scott's EVA canceled, the task of proving an astronaut could perform useful work outside a spacecraft fell to Gene Cernan (he and Tom Stafford became the *Gemini IX-A* crew when scheduled crewmembers See and Bassett died in a T-38 aircraft accident on February 28, 1966). The *Gemini* team had grown so ambitious that despite having just

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[49] See Hansen, *First Man*, 91-95 and 178-183.

[50] Ibid, 269-273.

20 minutes of EVA experience, they planned to have Cernan freely maneuver in space rather than dangle from a tether. He planned to strap on a backpack provided by the Air Force called the Astronaut Maneuvering Unit (AMU), which contained two hand controllers he could use to maneuver away from the *Gemini* spacecraft. As an Air Force Captain explained, the use of this backpack foreshadowed the tasks that visionaries imagined astronauts performing, but did not actually perform until the post-*Apollo* era: "Maintenance, repair, resupply, crew transfer, rescue, satellite inspection, and assembly of structures in space are all operations of potential space systems. Many of these operations involve Extravehicular Activity and require men to maneuver in free space for short distances. The Astronaut Maneuvering Unit experiment is a fundamental step toward determining the basic hardware and operational criteria for these extravehicular activities."[51] What this Air Force Captain did not know was that training and execution of the most basic EVA maneuvering tasks needed much improvement before the backpack could enter the equation.

Cernan and his backup Buzz Aldrin spent 140 hours training to use the backpack, though still without using the neutral buoyancy technique that has proven most useful to spacewalkers in the years since. Their sessions in altitude chambers and the KC-135 aircraft prepared them for the task of donning the AMU and using the hand controller to propel their bodies via short bursts of thrust. They also took part in Air Bearing Facility simulations where they could maneuver their bodies in up to six degrees of freedom,

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[51] John W. Donahue, "Experiment D-12, Astronaut Maneuvering Unit," in *Manned Spaceflight Experiments Interim Report, Gemini IX-A Mission* (Washington, D.C.: NASA N67-16027, 1966), 55.

while seeing visual projections of the Earth and a target they could thrust toward. Each of these methods proved valuable both in preparing Cernan for the second *Gemini* EVA and instructing engineers in how they could help him. The AMU contractor gave him one method of approaching a target, but he found during the ground simulations that an "over the shoulder" technique was easier to learn and required less fuel.[52] He also found during the KC-135 flights that the restraints he used to position his body outside the *Gemini* spacecraft were insufficient, and this concern resulted in the addition of stirrups. Meanwhile, engineers found that the heat of the AMU thrusters might damage his pressure suit and added 11 layers of insulation to his suit.[53] These developments demonstrated why NASA spent money on the construction of a training environment that could yield lessons without the risks of actual spaceflight. Unfortunately, his actual EVA also yielded lessons at a much greater expense.

By the time Cernan managed to make his EVA, *Gemini IX-A* had already established itself as one of the most failure ridden flights of the program. On May 17, he and Tom Stafford went to the launch pad only to learn that the *Atlas* rocket carrying their *Agena* Target Vehicle had nosedived into the Atlantic Ocean. The Convair company furnished a backup *Atlas* that carried an Augmented Target Docking Adapter (ATDA) into orbit. But when Stafford and Cernan made their rendezvous on June 3, they found that the shroud had not come loose from this vehicle. "It looks like an angry alligator out here floating around," Stafford reported, learning the frustrating news that he could

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[52] Reginald M. Machell, *Summary of Gemini Extravehicular Activity* (Washington, D.C.: NASA SP-149, 1967), 6-35 to 6-39.

[53] Hacker and Grimwood, 329-330.

not undertake a docking. The *Atlas* rocket failure and ATDA shroud failure, combined with the tragic deaths of the astronauts originally slated to make the flight, brought embarrassment to the space agency. But the failures of Cernan on his June 5 EVA were easily the most glaring from a training standpoint.[54]

Cernan opened the hatch and climbed outside just as he had done in the KC-135, but here the similarity between the training experience and the actual experience ended. On the aircraft, he had been able to rest after only brief intervals of weightlessness. He did not have that luxury in space, which proved crucial because maneuvering his body proved more difficult than he or his instructors had expected. "All of our work had been built around the fact that in zero g, you would stay there unless you perturb your body position with some external force or motion," he pointed out in the mission debriefing. "This is not true. It was a continuous work load just to stay put in zero g," because every movement of an arm or leg exacted a force that set his body in motion.[55] Given that simply staying put required him to exert energy, moving his body to the back of the spacecraft where the AMU backpack was located made him exhausted. The flawed assumption about how much energy he would need to exert caused Cernan to make his bluntest assessment of *Gemini IX-A* in his 1999 memoir: "More than thirty years later, it can be safely said that we didn't know diddly squat about walking in space."[56]

When he moved to the spacecraft adapter and prepared the AMU for flight, he found that this flawed assumption conspired with other factors that made his work

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[54] Ibid, 330-337.

[55] Machell, 8-1

[56] Cernan with Davis, 129.

fruitless. First, the spacecraft did not contain a sufficient number of handholds and footholds to secure his body given the small forces that set his body in motion. Second, his stiff suit did not provide him with the flexibility to move as a construction worker would on Earth. Third, he did not have a defogging agent, so his faceplate fogged and restricted his visibility. Knowing he could no longer see well and felt exhausted, he and Stafford decided to end the EVA early and Cernan climbed back inside the spacecraft without flying the AMU.[57] Cernan's exhaustion taught the *Gemini* team a critical lesson about maneuvering in space, but his training could have imparted that lesson less painfully and at lower cost. Given that White had felt tired after only 20 minutes outside, the instructors should have recognized that producing 30 seconds of weightlessness at a time aboard a KC-135 would not adequately prepare an astronaut for an EVA. In his memoir, Cernan asked, "Why is floating in space and turning a few dials so difficult? Let me give you a couple of tests. Connect two garden hoses and turn on the water. Now, using only one hand, try to unscrew them. Or, hold a bottle of soda or beer at arm's length, and using a single hand, remove the twist-off top. For extra reality, run a mile before you start so you're nice and tired, do it while wearing two pairs of extra-thick gloves and close your eyes to simulate being unable to see. Stand on your head while doing some of these things to resemble tumbling in space."[58] Neither the 30 seconds of weightlessness at a time aboard the KC-135 or the Air Bearing Facility could capture these realities. But what training method could capture them?

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[57] Hacker and Grimwood, 337-339.

[58] Cernan with Davis, 136.

The irony is that despite the large government effort to meet President John F. Kennedy's lunar commitment by decade's end, the answer emerged from a very small and little known company in the private sector. In 1962, two entrepreneurs named Samuel Mattingly and Harry Loats had formed a company called Environmental Research Associates (ERA) in a northwest Baltimore suburb called Randallstown, Maryland. The two managed to secure a contract from NASA's LRC called "The Study of the Performance of an Astronaut During Ingress-Egress Maneuvers Through Airlocks and Passageways." When they built an airlock mockup for this contract, they did not have access to a zero-G aircraft and thought that taking it underwater might be a useful substitute to approximate maneuvering in weightlessness. They rented a pool at McDonogh School in Randallstown, which enabled them to do this beginning on July 18, 1964. Over the next two years, they employed a team of scuba diving enthusiasts to go underwater while wearing suits and while being weighed down so that they did not rise or fall, instead remaining neutrally buoyant. Mattingly and Loats made a KC-135 flight as well and found that this standard method of simulating the weightlessness of space was both more expensive and less realistic than their method.[59]

Despite the success of the neutral buoyancy method at the ERA company and a few other aerospace firms, not until the aftermath of Gene Cernan's EVA did an MSC employee take an interest in it. Don Jacobs traveled to Maryland in June 1966 and felt sufficiently impressed by an ERA demonstration that he arranged to extend the firm's NASA contract and shipped a *Gemini* spacecraft mockup to the firm. In July, Cernan

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[59] Neufeld and Charles, 147-151.

became the first astronaut to make the trip to McDonogh School and undertake an underwater EVA simulation. Mattingly recalled, "Harry (Loats) and I had him up in the stands, and we said, 'First question we've got to ask you, how does this compare with orbit?' And he said, 'It's at least 75 percent accurate.' I loved it." Cernan then returned to Houston and spread the word to fellow astronauts and MSC management: maneuvering underwater was the best way to train to position one's body and experience the fatigue of an EVA. His underwater session gave him confidence that he had not "screwed up" in space, as some of his colleagues believed. His difficulties could instead be traced to flawed assumptions about what spacewalking entailed and flawed training methods. ERA divers also simulated the upcoming *Gemini X* EVA and passed films of the sessions to crewmembers John Young and Mike Collins.[60] But Collins recalled, "Fortunately or unfortunately, John and I simply didn't have enough time to drop what we were doing, with only a month left to go, and chase this red herring underwater."[61] Future spacewalkers still needed convincing on this new method.

The program became steadily more ambitious with each flight despite the numerous glitches, and *Gemini X* was no exception. Young and Collins lifted off on July 18 to undertake another *Agena* rendezvous, but this time under unique circumstances that would test their training. The crew had spent more than 100 hours in the GMS preparing to navigate to the *Agena* using only star sightings rather than data from Mission Control. Collins used a sextant to measure the angle between selected

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[60] Ibid, 153-154.

[61] Collins, 192.

stars and the horizon, and entered the numbers into a computer program called Module VI that determined the vehicle's orbit. The crew would then have the data they needed to maneuver their spacecraft toward the *Agena*. Unfortunately, he obtained erroneous data due to his difficulty in determining the horizon and operating the sextant. The flight controllers found his data outside the range of acceptable deviation from the data collected in Mission Control, and the CapCom told Young and Collins to use the Mission Control data to navigate to the *Agena*.[62] But like many of the setbacks in the *Gemini* program, this one carried a lesson learned for training. Young remembered that he and Collins could not simulate this navigation technique "without bombing out a computer. We never really had a real good time line on how long it was going to take us to do that." Future crews would benefit from a simulator that could more adequately support this mission task, which in turn would help them develop a time line that would help them avoid the *Gemini X* crew overload.[63] By the time *Apollo* missions went to the Moon, crews had become adept at star navigation.

The mission contained still more developments that were instructive from a training standpoint. Young and Collins made three burns to maneuver the *Gemini* toward the *Agena*, but at just one mile away Young suddenly yelled, "Whoa, whoa, whoa, you bum!" The *Gemini* spacecraft had fallen off to the side of the target, as Young saw when his radar attitude indicator displayed an out-of-plane error of two and a half miles. One of Newton's laws of motion dictated the progress of *Gemini X*: an object

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[62] Hacker and Grimwood, 344 and Young with Hansen, 90-91.

[63] [*Gemini X* Technical Crew Debriefing, Box GH-134, *Gemini* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 214.

in motion will stay in motion unless acted upon by an external net force. Unless Young imparted that net force by firing the *Gemini's* thrusters, his ship would continue on its path swinging around the *Agena*. He had no choice but to undertake a whifferdill to return to the proper plane, which worried him: "Mike and I had done whifferdills in the simulator, and we knew it was going to take a darn good one to get us into the right position for our rendezvous."[64] He nonetheless pulled off a whifferdill that placed the vehicle back in the proper plane. Though he felt disappointed about consuming more fuel than any other *Gemini* Commander, his work performing this maneuver in the GMS had demonstrated the flexibility of a trained astronaut in correcting a mistake. Young and Collins docked with the *Agena*, then undertook a first by firing the *Agena's* engine while attached to enter a higher orbit. In this way, they reached the old *Agena* with which *Gemini VIII* had docked. The crew had achieved a dual rendezvous, and Young performed stationkeeping while at the old *Agena* so that Collins could maneuver to it and retrieve an experiment package during an EVA.[65]

Unfortunately, the EVA offered more evidence that the current method of training spacewalkers needed improvement. Collins pushed off the *Gemini* spacecraft and propelled himself eight feet to the *Agena*, grabbing hold of the docking adapter. The time he spent strengthening his hands in training after hearing of the difficulty Cernan had experienced helped him to hold on. But as he later wrote, he could not hold on for long: "I tried to stop, but the momentum in my lower body caused me to keep going and

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[64] Young with Hansen, 91.

[65] Ibid, 92-96.

peeled my hands right off the *Agena*! First my right and then my left slipped free, and then I was turning lazy cartwheels somewhere above and to the left of everything that matters." He looped back on his umbilical toward the *Gemini* and pushed off it again, but this time his left boot snagged on the spacecraft and sent him into a spin. He just barely managed to stick out his left arm and grab the *Agena*. Collins did manage to retrieve the experiment package, but due to his difficulty and time constraints he had to abandon his plan to install a replacement package and return to the *Gemini*. Once again, a well-conditioned astronaut had encountered trouble with seemingly simple tasks. If Collins had this much difficulty retrieving a package from a vehicle a few feet away, how could future astronauts fix satellites or assemble a space station? The root of his difficulty was body positioning, and this meant his successors needed a better training method than the KC-135 to prepare for this. Looking back several decades later, Collins was as blunt as Cernan about the training and execution of EVAs: "We were just stupid…We had not really thought it through."[66]

Only a few days after Young and Collins splashed down, the MSC director weighed in on the idea of underwater EVA training. "I have given a great deal of thought recently to the subject of how best to simulate and train for extravehicular activities and have reached the conclusion that both zero g trajectories in the KC-135 and underwater simulations should have a definite place in our training programs," Bob Gilruth wrote to Deke Slayton on July 25. He also explained that of these two methods, underwater training was "far better for the study of positioning, hand holds, and the

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[66] Ibid, 96-99 and Burgess and French, 109-112.

initiation and termination of all movements between points." In other words, he believed this would provide the means for future spacewalkers to avoid the problems that had most hampered Gene Cernan and Mike Collins. Gilruth's decision confirmed that a tiny company in Maryland had unleashed an idea that would substantially affect the national effort to send astronauts to space. But two problems still needed to be overcome before astronauts could routinely train for EVAs underwater. First, instructors needed to set aside time for them to take part in this. In the fevered push to complete the *Gemini* program by the end of 1966 and therefore stay on track to meeting Kennedy's end-of-the-decade lunar deadline, the instructors decided the *Gemini XI* crew of Pete Conrad and Dick Gordon did not have time to travel to Maryland prior to their flight.[67] Second, the astronaut corps and MSC management remained skeptical of the idea. Some astronauts considered the idea of training underwater beneath their dignity. Gilruth reported "mixed emotions" in Houston, because "some of our people didn't think the neutral buoyancy work was any good."[68]

But only two *Gemini* flights remained and the case against the current EVA training method was getting harder and harder to ignore. Pete Conrad and Dick Gordon made a highly successful *Gemini XI* flight in September, with just one exception. The effort to maneuver to an *Agena* using onboard calculations worked this time and Conrad docked with the target vehicle having minimized his fuel usage. He also pulled this off just 85 minutes after liftoff, becoming the first astronaut to make a rendezvous and

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[67] Neufeld and Charles, 154-155.

[68] Hacker and Grimwood, 356.

docking on his first orbit of Earth. The *Agena* engine later fired, taking the crew to a record altitude of 850 miles.[69] But Gordon became the third consecutive astronaut to overexert himself during an EVA. His objective was to tether the *Gemini* to the *Agena*, which required him to push off his spacecraft, remove the 30-meter tether and its clamp from a pouch, place the tether and clamp over the *Agena* docking bar, and then lock the clamp in place. He would need to stabilize his body, the problem that had bedeviled Gene Cernan and Mike Collins, to do this. In the KC-135, he stabilized himself by wedging his legs between an *Agena* model, which left both his hands free to deal with the tether.[70] But as with his two predecessors, training in 30 second intervals of weightlessness gave him a false sense of the actual experience. He could not stay stabilized by wedging his legs and had no choice but to hold onto the *Agena* with one hand while using his other hand to deal with the tether. He did connect the tether, but not before his body overheated and perspiration stung his eyes, making it difficult for him for see. Conrad decided to call off the rest of the EVA, canceling a planned test of a power tool at the back of the *Gemini*, and Gordon climbed back inside his spacecraft after just 33 minutes outside instead of the expected 107. "When I go back now and listen to the tapes, it scares me just to hear them!" Gordon exclaimed decades later.[71]

Never before had astronauts struggled so mightily with a task on three consecutive missions, but training for that task entered a new era in the fall of 1966. *Gemini XII's* Buzz Aldrin was the last hope to prove astronauts could perform useful

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[69] Ibid, 358-360.

[70] Machell, 7-22.

[71] Burgess and French, 116-118.

work without becoming exhausted before *Gemini* ended. He continued to undertake KC-135 training to experience weightlessness. But on September 12, he arrived at the McDonogh pool to undertake what Gene Cernan, Mike Collins, and Dick Gordon had not before their flights: underwater EVA simulations. In the pool, he did not have to worry about performing his work in 30 second intervals. He could practice positioning his body slowly and deliberately, which he knew would prove crucial in space in order to avoid the exhaustion that had plagued his predecessors. His input on how long it took him to perform work underwater guided mission planners in estimating how long it would take him to perform work in space. This method proved much more accurate than basing the estimate on KC-135 training.[72] His time underwater also forced him to confront the same problem that had confronted his predecessors in space: lack of traction. Fellow astronaut Scott Carpenter, an undersea researcher, explained, "Without weight, you don't have traction. And traction is important wherever you are if you want to do work: you have got to be stabilized. And the buoyancy of the water or the absence of gravity in spaceflight makes that very difficult because you have no traction."[73] The time that Aldrin spent in neutral buoyancy therefore helped him understand his need for hand and foot restraints that would give him traction, both while in the pool and while in space. His input, along with that of his predecessors, resulted in the number of restraints increasing from just nine on *Gemini IX-A* to 44 on *Gemini XII*.[74]

Gemini instructors made still greater efforts at ensuring that the McDonogh pool

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[72] Neufeld and Charles, 155 and *Gemini XII* Technical Crew Debriefing, 456-457.

[73] Burgess and French, 128.

[74] Hacker and Grimwood, 373.

represented a high fidelity training environment as the *Gemini XII* mission neared. Over the four weeks prior to launch, Aldrin participated in five sessions. During the last two, *Gemini XII* Commander Jim Lovell spoke to him via radio at the side of the pool as the two followed the flight plan established for their mission. Each step on the checklist Aldrin performed in the pool matched what he would perform on an actual EVA. Doctors also used these last sessions to collect biomedical data on Aldrin, an important task given the exhaustion and overheating that his three predecessors had faced. By the time he last stepped out of the pool on October 29, doctors had monitored his energy expenditure by measuring his heartbeat, breathing rate, and body temperature. He learned to control his work rate so that his heartbeat would not exceed 120 beats per minute, resting when necessary, and mission planners gave him a timeline for the mission consistent with this work rate he practiced in the pool. Instructors even filmed Aldrin underwater, so future spacewalkers would have a visual record of his EVA training.[75]

Lovell and Aldrin made the most successful flight of the *Gemini* program when they placed their training to the test in November. The first way that training enhanced their flight took place during their *Agena* rendezvous on November 11, the first day of the flight. Slightly over an hour after launch, Aldrin reported that the *Gemini* radar had achieved a lock on the *Agena*. But the radar reception grew so poor that the computer refused to accept any further readings for the last roughly 75 miles of the approach. The

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[75] Machell, 7-34, 7-35, and 7-36 and Otto F. Trout, Jr., Gary P. Beasley, and Donald L. Jacobs, *Simulation of Gemini Extravehicular Activity Tasks by Neutral Buoyancy Techniques* (Washington, D.C.: NASA TN D-5235, 1969), 16-25.

loss of radar meant the crew needed some other way to determine the range rate toward their target; in other words, how fast they were traveling relative to it. But rather than derail the mission, this incident only provided a lesson that a well-trained crew could serve as a backup for malfunctioning equipment. By chance, "Dr. Rendezvous" was sitting in the right-hand seat. Not only did Aldrin know what to do in this situation, he had helped to develop the chart for use in making a manual rendezvous. He made a sextant reading to determine the angle between the *Gemini* and *Agena*, consulted a chart, and fed the numbers that would take his ship to the target into the onboard computer. Lovell thrusted the *Gemini* based on these numbers and made an excellent rendezvous and docking, using only about 280 pounds of fuel. Only seventeen months earlier, McDivitt had made a futile rendezvous attempt after undergoing inadequate training. One of the best indications of the value of *Gemini* training came with the effort of Lovell and Aldrin to prepare for an equipment failure and then successfully place their preparation to the ultimate test.[76]

The success of Aldrin's three EVAs also reflected the greater attention to detail in training. The original plan for this last mission had been for Aldrin to test the AMU backpack that Cernan had not managed to test during *Gemini IX-A*. But mission planners nixed this idea so that he could focus on performing simple tasks without overexerting himself. During his first and third excursions, he stood outside his hatch to set up an ultraviolet astronomical camera, fix a handrail, retrieve a micrometeorite collection package, and take photos. But during his second excursion, he performed his

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[76] Hacker and Grimwood, 375.

most important work by climbing outside the *Gemini* and moving hand over hand to the *Agena*. To the relief of the medical specialists who monitored him, Aldrin did not feel exhausted as he placed his feet in restraints and went to work torquing bolts and cutting metal. When he climbed back inside two hours later, he knew from his favorable physical condition that he had mastered EVA to a greater extent than Gene Cernan, Mike Collins, and Dick Gordon. What accounted for this? The knowledge that came from his three predecessors and the addition of hand and foot restraints helped Aldrin, but instructors also took careful note of the value of neutral buoyancy training when viewed in light of his actual EVAs.[77] Only then could instructors feel confident about the value of this new method.

The evidence clearly favored the value of neutral buoyancy. The McDonogh pool was not a perfect analog for space, because in the pool Aldrin maneuvered with additional weights he did not have in space and in water that created a drag on his motions he would not feel in space. But the dynamics of his motions in space "were nearly the same in all cases" as in the pool, according to a report issued after the program ended. As long as future astronauts moved as slowly and deliberately as Aldrin did, the hydrodynamic effects of the water would not hamper the fidelity of the pool as a training device. The energy he expended while in the pool also closely matched what he expended in space. This indicated that future astronauts could prepare to perform assigned tasks without exhausting themselves, and feel confident that this preparation would help them while on real EVAs. He also managed to perform his tasks in space on

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[77] Ibid, 377-379.

a timeline that matched the timeline he had used in the pool. This provided a sense of relief for future mission planners, who could feel confident about astronauts' abilities to avoid falling behind on busy missions. Finally, he found that working with a full-scale mockup of the *Gemini* spacecraft and real EVA hardware while in the pool helped him prepare for the real experience. This indicated that future instructors should place duplicates of actual flight hardware in a pool to build astronauts' confidence that they could work with the equipment in space. Aldrin confirmed these lessons learned when he made an underwater simulation on December 2, about two weeks after his splashdown with Lovell.[78]

A half century after Lovell and Aldrin brought the *Gemini* program to a close, training of *Gemini* crews offers valuable lessons in understanding the history of human spaceflight. The training process for this program proved that astronauts could acquire the necessary skills to make groundbreaking flights on a regular basis. Unlike the team at Langley at the outset of the *Mercury* program, the team at MSC attempted to meet a deadline to send men to the Moon. The *Gemini* program thus sent 16 different astronauts (Tom Stafford, John Young, Pete Conrad, and Jim Lovell each flew twice) on 10 missions that took place over just 20 months. Could these men undergo sufficient training in such a fast-paced program? The results from each flight indicated that they could. Not every training related decision worked out for the best, as this chapter has indicated, but the *Gemini* mission reports consistently praised the level of training each crew received and the actions crews took in flight to help achieve *Gemini* objectives.

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[78] Trout, Beasley, and Jacobs, 23-24.

The lesson that crews could meet tight schedules and turn in quality performances boded well for the *Apollo* lunar voyages. The *Gemini* program also further solidified the idea of procedures simulators as the most vital tool in astronaut training. Each crewmember spent an average of 348 hours training in simulators, whether in the DCPS, the TDS, the rendezvous simulator at McDonnell, or the GMS. This was an increase from the average of 190 hours for the *Mercury* astronauts. The *Gemini* astronauts also spent a greater portion of their total training time in simulators (39 percent) than their *Mercury* predecessors (33 percent). Other methods of training proved crucial, such as checkouts of the actual spacecraft, EVA preparation, and physical conditioning for long-duration crews, but simulators remained paramount.[79]

The rationale for human spaceflight remained strong with the end of *Gemini*, because training empowered astronauts to take actions that automated spacecraft would not have been able to perform. Some of these actions fell into the category of responding to malfunctions. An automated spacecraft would not have been able to take the corrective action that Neil Armstrong took aboard *Gemini VIII* or Jim Lovell and Buzz Aldrin took aboard *Gemini XII*. As this chapter has indicated, every flight contained a surprise of some sort that tested the resolve of the crews, but through their training the astronauts still fulfilled every task asked of them by the end of the program. Some fell into the category of performing tasks on EVAs. When Mike Collins retrieved a micrometeorite package during *Gemini X*, for instance, he had proven the physical

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[79] C.H. Woodling, Stanley Faber, John J. Van Bockel, Charles C. Olasky, Wayne K. Williams, John L.C. Mire, and James R. Homer, *Apollo Experience Report: Simulation of Manned Spaceflight for Crew Training* (Washington, D.C.: NASA TN D-7112, 1973), 4.

flexibility of an astronaut in performing tasks an automated spacecraft could not. Some fell into the category of experiment operations. The crews made real-time adjustments on experiments, especially during the last missions, to achieve the greatest possible return from them. This would not have been possible aboard an automated vehicle.[80] Future astronauts would continue to carry out each of these actions through the ISS era. But for now, the Moon beckoned. Astronauts had proven they could rendezvous and dock with other spacecraft, perform work outside a spacecraft, and stay in space for up to two weeks at a time. The time had come to train them for the first voyages to another celestial body.

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[80] See Hacker and Grimwood, esp. 352.

CHAPTER VI

APOLLO: "IT'S LIKE YOUR CAR AFTER AWHILE"

Abe Silverstein found a name to capture the grandeur of his nation's quest to reach the Moon. When he flipped through a book on mythology in the summer of 1960, no person had yet flown in space but NASA officials had conceived a human spaceflight program to follow *Mercury*. Their early plans called for a spacecraft that would carry three astronauts on Earth orbital missions and, by 1970, on circumlunar missions. Engineers were already at work on the *Saturn I* rocket, the first in a family of rockets they expected to carry these astronauts into space (the *Saturn IB* would launch crews on earth orbital missions and the *Saturn V* would propel crews to the Moon). "I thought the image of the god *Apollo* riding his chariot across the Sun gave the best representation of the grand scale of the proposed program," Silverstein mused, and his name stuck.[1] After President John F. Kennedy breathed life into *Apollo* and gave it an end of the decade deadline to send men to the lunar surface, the program moved more quickly. By 1962, NASA had selected a contractor for a Command/Service Module that would take three astronauts into lunar orbit (North American Aviation in California) and a Lunar Module that would take two of them to the surface (the Grumman Aerospace Corporation in New York).[2] But what would the crew need to accomplish in their *Apollo* chariots? The definition of tasks that began in the early 1960s determined whether astronauts would be

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[1] Courtney G. Brooks, James M. Grimwood, and Loyd S. Swenson, Jr., *Chariots for Apollo: A History of Manned Lunar Spacecraft* (Washington, D.C.: NASA SP-4205, 1979), 15.

[2] Ibid, 87-116.

mere passengers or vital components on the way to the Moon. This, in turn, would determine their training.

In 1961, a NASA Statement of Work to prospective spacecraft contractors detailed the layout of the cockpit and the tasks of the three who would ride in it. At this point, the three were known as the Pilot, Co-Pilot, and System Manager. The Pilot would sit in the most prestigious left-hand seat, where he would determine the readiness of the spacecraft for launch, control the attitude and position of the spacecraft when necessary, assume responsibility for all decisions concerning the mission and crew safety, and direct all scientific studies on the lunar surface. He would accordingly have a hand controller by his side and would see vital displays such as an "8-ball" attitude indicator and computer readouts on his side of the instrument panel. In the center seat, the Co-Pilot would have the unique responsibility of navigating the spacecraft. In the right-hand seat, the System Manager would have the responsibility of monitoring and repairing systems while also conducting scientific observations. He would accordingly see displays on his side of the instrument panel that allowed him to quickly ascertain the health of the vehicle.[3]

NASA Administrator Jim Webb announced in 1962 that *Apollo* crews would voyage to the Moon and back by way of the Lunar Orbit Rendezvous method, which complicated the program and the tasks astronauts would have to perform. This method entailed crews traveling to lunar orbit aboard a Command/Service Module, before two of

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[3] Ivan D. Ertel and Mary Louise Morse, *The Apollo Spacecraft: A Chronology, Volume 1* (Washington, D.C.: NASA SP-4009, 1969), 122.

the three astronauts transferred into a smaller Lunar Module to descend to the surface. The ascent stage of the LM would then lift off from the Moon, reunite with the CSM and the one astronaut left behind, and the three men would return to Earth in the mothership.[4] The Pilot, Co-Pilot, and System Manager thus became known as Commander, Command Module Pilot (CMP), and Lunar Module Pilot (LMP), respectively. The Commander and LMP would have the added burden of operating a new vehicle and landing it on an alien world. The CMP would have to pilot his spacecraft and monitor its systems alone until they returned. Yet the other responsibilities outlined in 1961 stayed consistent.

The assigned responsibilities and layout of the CM and LM confirmed that the astronauts would be much more than passengers, and that their training would need to reflect this. The CM alone contained over 400 switches and displays, a drastic increase from *Mercury* and *Gemini*, and the astronauts would have to learn them in case of a malfunction that required their intervention.[5] But even in a completely nominal mission, the crew would take several actions demonstrating the mental and physical flexibility of highly trained human operators. Shortly after the *Saturn V* third stage fired to take the crew out of Earth orbit, the CMP would have to take the hand controller and dock his ship with the LM nestled inside the third stage. After a journey to the Moon filled with star sightings for navigation purposes, midcourse correction maneuvers, and housekeeping chores, the crew would enter lunar orbit. The Commander would then take the LM hand controller to guide the lander to a safe region on the lunar surface,

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[4] Ibid, 168.

[5] Hersch, 65.

looking out the window while the LMP closely monitored systems. After these two explored on the surface and lifted off in their ascent stage, the CMP would have to make a rendezvous with it. Finally, the Commander needed to be ready to take the Command Module through a manual reentry back into Earth's atmosphere. This required placing the vehicle in the right attitude, lighting an engine at just the right time to slow the vehicle, jettisoning the Service Module, and then pointing the Command Module in just the right direction so its heat shield could protect it.[6] The assignment of tasks once again reflected the organizational determination that astronauts had skills to offer that could set their missions apart from purely automated missions.

The assignment of tasks also carried implications for the selection of crews. As the Director of Flight Crew Operations at MSC (he had been promoted to this job in November 1963 and replaced as Chief of the Astronaut Office by Alan Shepard), Deke Slayton needed to find the right three men to send on each mission. The astronauts most coveted the Commander's seat, but Slayton only gave it to those with past spaceflight experience. He also valued experience for the CMPs, especially in rendezvous. Slayton valued this job so much that he established a pattern of grooming CMPs as future Commanders. He proved most willing to break in astronauts with no experience by giving them the LMP position. Although the LMPs would gain the prestige of landing and walking on the Moon, they would not have the flying or navigation responsibilities that their two crewmates would have.[7]

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[6] Brooks, Grimwood, and Swenson, 260-261 and Mindell, 91-93.

[7] Slayton with Cassutt, 164 and Brooks, Grimwood, and Swenson, 373-380.

But most importantly from a training standpoint, the assignment of tasks carried implications for the *Apollo* spacecraft simulators. NASA had awarded North American Aviation with the contract for the CSM on November 7, 1961, and once again the responsibility for manufacturing simulators fell to Link.[8] But the demands of simulation drastically increased from *Mercury* and *Gemini* to *Apollo*, because NASA officials called on Link and a few other companies to produce several types of simulators for the Moon program. These included part-task trainers that would build the astronauts' confidence in handling individual maneuvers from launch through reentry. These became available as early as 1963, six years before the first lunar landing. When crews had gained experience on these specialized devices, they would then tackle entire missions in a Command Module Simulator (CMS) and Lunar Module Simulator (LMS).[9]

The first and most dangerous step in a spaceflight was launch, and each *Apollo* crew trained for the journey into space aboard a holdover from the *Gemini* era: the DCPS. Three astronauts climbed inside this gondola and sat in front of a replica instrument panel containing all the displays they would see during a real *Saturn V* launch. The gondola vibrated and pitched just as it would during a real launch. The gondola also went through its motions in front of a spherical dome, so that astronauts could see an image of the Earth and a star field on a screen inside the dome.[10] The DCPS sessions benefited the crews by giving them experience in feeling the motions and

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[8] Ertel and Morse, 128.

[9] Robert C. Kohler and Lloyd Reeder, *Mission Training Program for the Apollo Lunar Landing Mission* (Houston: MSC-CF-D-68-28, 1968), 9-11.

[10] Woodling, et al., 33.

seeing the displays first of a normal launch, and then in experiencing the cues that called for them to abort a launch. If the Commander saw two cues indicating the *Saturn V's* performance had left acceptable bounds, he would have to fire the Launch Escape System tower. This tower contained a motor that would whisk the crew away from an exploding *Saturn V* during a real mission. Though the spacecraft did have an Emergency Detection System that could automatically activate the tower in an extremely time critical situation, engineers still valued the ability of astronauts in making a manual abort. The combination of instrument panel displays, window views, and physiological cues would give trained astronauts a chance to respond to what computer simulations had shown would be the most probable rocket failures. If the *Saturn* inertial platform failed, *Apollo* astronauts could even do something their *Mercury* and *Gemini* predecessors could not: control the rocket manually.[11] In addition to the DCPS, the men underwent sessions on a centrifuge in Houston to expose them to the G forces of a normal launch and launch abort.[12]

The demands on crewmembers would vary as launches progressed. The five engines of the first stage would fire for about two minutes and forty seconds, taking the *Saturn* from the launch pad to an altitude of 42 miles. Crews needed to be prepared for the most time critical malfunctions during this earliest part of their flight, because aerodynamic loading was highest and therefore structural breakup was most likely during this time. The Commander would only have a small window in which to

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[11] Charles T. Hyle, Charles E. Foggatt, and Bobbie D. Weber, *Apollo Experience Report: Abort Planning* (Washington, D.C.: NASA TN D-6847, 1972), 5-7.

[12] Woodling, et al., 3.

manually escape from 2,000 tons of TNT. But after this, the vehicle left the atmosphere and breakup became less likely. The window of time to deal with malfunctions would thus likely increase as the second stage propelled the crew to 109 miles and the third stage to an Earth parking orbit of about 118 miles. If a malfunction required an abort after leaving the atmosphere, the crew would need to prepare for an abrupt separation of their spacecraft from the rocket, an orientation to entry attitude, and splashdown in the Atlantic Ocean. If an emergency arose in the last two minutes of the launch, the crew would also need to prepare for separation but could call upon their spacecraft's propulsion system to propel them to orbit.[13] *Apollo* astronauts would need to adapt to these changing circumstances as the seconds passed, without feeling distracted by the noise and vibrations in the cabin, and felt the DCPS effectively gave them experience in doing this. Crews also trained for reentry into Earth's atmosphere aboard this vehicle, when engineers had configured it to replicate the motion and sights of the return home. By the time Gene Cernan used this simulator in training for the last lunar mission, *Apollo 17*, he remembered, "I felt very comfortable in flying the aborts as well as manual takeovers on the booster."[14]

The astronauts also made use of part-task trainers to prepare for a feat no human had accomplished: the landing on the Moon. After launch and orbital insertion, the plan called for the *Saturn* third stage to ignite and send a crew on a three-day journey to lunar

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[13] Ibid, 5-8.

[14] "*Apollo 17* Technical Crew Debriefing," January 4, 1973, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/a17/
as17Tech3.pdf, 17-9 (accessed July 30, 2016).

orbit. But how could a Commander feel confident about making the first piloted landing on another world? NASA researchers in California and Virginia each sought to give astronauts useful analogs for flight in a vacuum featuring one-sixth gravity. The assistant director of research at the NASA Flight Research Center in California, Hubert "Jake" Drake, organized a group to study this issue in 1960. The group even included Neil Armstrong, then a NASA test pilot, almost a decade before he made the first lunar landing. This group recommended three methods of simulating flight in this novel environment and astronauts utilized each of them, with varying success.[15]

The group initially felt a helicopter would be the most useful analog. If an astronaut wanted to practice flying the LM horizontally in order to avoid a rough landing site, he could take a helicopter and pitch the vehicle across a landscape just as he would with the LM. He could then hover above a landscape and make a vertical landing, just as he would with the LM. Astronauts from the "Original Seven" and "Next Nine" therefore made helicopter flights as part of their training beginning in 1963. These astronauts were experienced only in flying fixed-wing aircraft, so instructors gave them several hours of classroom work to introduce them to the aerodynamics of helicopters. There followed several hours of helicopter flight time in Pensacola, Florida with two astronauts and an instructor paired together. Yet there were two problems with the idea of using helicopters as an aid for LM flight. First, a helicopter could not simulate flight in one-sixth gravity unless engineers could exaggerate the vehicle's pitch and yaw

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[15] Hansen, *First Man*, 314-315.

angles by a factor of six. Second, helicopter controls did not match the LM controls.[16] John Young recalled that he and his colleagues continued flying helicopters through the lunar landings but "only to understand the trajectories, visual fields, and rates of motion of the LM. In a helicopter, you could pretty precisely duplicate the flight paths we wanted to make in the lunar descent, but the controls you used to do that were so different from the controls of the LM that it almost worked against your LM training to be flying helicopters at the same time."[17]

The Drake group also proposed tethering a simulated lunar lander to a gantry, so that it could maneuver beneath it to a landing on a cratered surface just as the LM would. This idea also came to fruition, but only due to the independent work of two NASA researchers at Langley: Donald Hewes and Hewitt Phillips. These two conceived the idea in 1962. Three years later, Langley engineers completed a 240-foot high, 400-foot long gantry called the Lunar Landing Research Facility (LLRF). The engineers attached the lander to the gantry with two long cables, which provided the lander with a lifting force equal to five-sixths of its weight. This meant that the vehicle's thrusters had to lift the remaining one-sixth of its weight, simulating flight in lunar gravity. The plan called for the cables to propel the vehicle downward at a speed of 35 miles per hour and for the pilot inside to decelerate until he had come to a safe landing. A black screen and floodlights at the far end of the gantry simulated the lunar sky, while the dirt simulated the lunar surface. 24 *Apollo* astronauts made landings at the LLRF from 1965 to 1969.

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[16] Ibid, 223.

[17] Young with Hansen, 142-143.

This method of simulation did have some advantages over helicopter flight. Since the vehicle was suspended to a tether, the risk of a crash was low. The simulation of the lunar lighting and surface also proved highly realistic. Neil Armstrong felt so impressed that he said the shadows on the Sea of Tranquility dust looked just like the shadows at the LLRF. But the astronauts knew that a free-flying vehicle could simulate a landing on the Moon far more precisely than this tethered device. Could such a free flyer be designed and built?[18]

The Drake group answered yes, and their foresight eventually produced the most effective training aid for *Apollo* lunar landings. Drake and Gene Matranga were both engineers who had worked on some of the most innovative flying machines, such as the X-15. Their experience guided them in conceiving a Lunar Landing Research Vehicle (LLRV) in 1961. Their vehicle featured a jet engine which would lift it to a desired altitude, at which point the pilot would throttle back the engine to support five-sixths of the vehicle's weight. The pilot would then make a landing by firing two hydrogen peroxide rockets to lift the remaining one-sixth of its weight. This idea promised a remarkable fidelity to a real Moon landing. Not only would the pilot simulate lunar gravity by throttling back the jet engine, he would throttle the rockets as he descended to move horizontally and slow the rate of descent. As he moved to find a safe landing spot and slowed to a gentle vertical landing, while remaining aware of the fuel he had available, he would be taking the same actions as he would on the Moon. NASA awarded a contract to build LLRVs to Bell Aerosystems of Buffalo, New York. Flying

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[18] Hansen, *Spaceflight Revolution*, 373-379.

the machine posed a major risk, because it featured a fly-by-wire control system that could imperil the pilot if the analog computers onboard malfunctioned. In case the computers, rockets, or jet engine suffered a failure, the vehicle had no wings and thus could not glide to a landing. Several test pilots did make 200 research flights from 1964 to 1966 without any serious accidents. Still, NASA officials did not want astronauts flying an LLRV due to the risk.[19]

Yet the thinking changed on this matter because, as Neil Armstrong recalled, "Having no flying machines to simulate lunar control characteristics was frustrating the Astronaut Office." NASA awarded Bell a contract in 1966 to build an advanced version of the LLRV on which astronauts could train, called the Lunar Landing Training Vehicle. The last major design decision on the actual LM had been made the previous year, so Bell contractors could build the LLTV with a high degree of fidelity to it.[20] The control panel, visual displays, control stick, and even the lightweight components matched the real vehicle that would touch down on the Moon. The LLTV also featured one other component that was not part of the real LM, but which would save lives in the years to come: a rocket ejection seat built by Weber Aircraft. When three LLTVs arrived at Houston from the Bell factory in December 1967, all that remained was to devise a training program for the astronauts who would fly it.[21]

The training program reflected the risk associated with the "flying bedstead" and

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[19] Hansen, *First Man*, 321-325.

[20] Thomas J. Kelly, *Moon Lander: How We Developed the Apollo Lunar Module* (Washington, D.C.: Smithsonian Institution Press, 2001), 84.

[21] Hansen, *First Man*, 321-327.

the high degree of skill required to fly it. By the beginning of 1968, Deke Slayton had a good idea of which astronauts he wanted to command lunar missions. He assigned these men to again receive instruction in helicopter flying over three weeks, to make tethered landings at the LLRF in Virginia for one week, and then to log fifteen hours in a ground simulator. Even then, the men received two months of instruction in LLTV flight from MSC test pilots Joe Algranti and Bud Ream before flying solo. For eleven astronauts (Frank Borman, Bill Anders, Neil Armstrong, Pete Conrad, Jim Lovell, Alan Shepard, David Scott, John Young, Fred Haise, Gene Cernan, and Dick Gordon), this preparation culminated in solo LLTV flights at Houston's Ellington Field that usually totaled twenty-two for *Apollo* Commanders and eleven for backup Commanders.[22]

The LLTV benefited the *Apollo* program in two ways: it helped convince the entire *Apollo* team that a manual landing was feasible and gave the astronauts confidence for a landing on a literally alien landscape. Would the Moon landings have to be completely automated? The LLTV flights strongly suggested that the answer was no, because the astronauts took control themselves from altitudes of several hundred feet and maneuvered the vehicle to avoid dangerous obstructions. An automated Moon landing might take the lander right into these obstructions, but trained humans could avoid them. When those eleven men flew the vehicle, they gripped the hand controller and felt for themselves the large pitch and roll angles they needed to give the vehicle to maneuver. They also knew when they were doing so that their lives depended on their

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[22] Ibid, 327-238.

ability to make a safe landing, unlike in any ground simulator.[23] Thus the eleven were unanimous in their praise of the vehicle as a tool for building confidence. Among the many compliments they offered, David Scott probably made the most effusive statement: "It gave me confidence that I knew what I was doing on the Moon. I didn't have to think about things. I didn't have to consciously program myself to do things. I was automatic."[24] In an environment as unforgiving as the Moon, on the first ever piloted attempts to land there, the men needed their flying tasks to feel as close to second nature as possible.

But the irony was that an astronaut came closer to death flying the LLTV than while flying the actual LM nearly a quarter million miles from home. Neil Armstrong took the vehicle to a height of several hundred feet on May 6, 1968, with the goal of making a landing before his twelve minutes of fuel ran out. When he was less than 100 feet above the ground at Ellington, he felt the ship turn into a thirty degree bank and lost control. Unbeknownst to him, propellant was leaking out of the vehicle. The propellant tanks lost helium pressure, which caused the rockets to shut down and meant Armstrong had no way to control the ship. The only alternative left was to activate the ejection seat. When he did so, the rocket propelled him high enough (from about 50 feet to several hundred feet) that his parachute had time to open and let him drift to a landing in a patch of weeds. By that time, the LLTV had already crashed and burst into flames. When Chris Kraft saw the film of the incident, he estimated that Armstrong would have died if

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[23] Warren J. North and C.H. Woodling, "*Apollo* Crew Procedures, Simulation, and Flight Planning," in *What Made Apollo a Success* (Washington, D.C.: NASA SP-287, 1971), 33.

[24] Mindell, 213.

he had waited two-fifths of a second longer to activate the ejection seat.[25]

Thankfully, the first responders to the accident had procedures to follow that were written for such an emergency. After undergoing training and drilling once a month, the responders were prepared to travel to Ellington in three vehicles. A crash truck carried four men dressed in heat resistant protective clothing, and contained a set of nozzles that could discharge the truck's 1,100 gallon water capacity to fight fires. An ambulance carried a driver and a flight surgeon, and was equipped with a resuscitator and a stretcher. Finally, a station wagon carried four more men and was equipped with a fire extinguisher, a first aid kit, and a de-arming tool for the ejection seat. The crash truck traveled to the LLTV on this day, while the ambulance and station wagon went to assist Armstrong.[26] Armstrong walked away from the weed patch with no injury more serious than a bitten tongue and spent the rest of the day in his office.[27] Yet the creation of the emergency procedures and frequent drilling reflected the understanding that the LLTV was an experimental vehicle that, unlike most forms of astronaut training, could take lives. A fraction of a second could have resulted in a different person taking the first steps on the Moon.

Yet another crash later that year cast the decision to continue flying the LLTV into serious doubt. On December 8, 1968, test pilot Joe Algranti had to eject and land by parachute after a malfunction in the control system. An accident investigation board

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[25] Hansen, *First Man*, 329-331.

[26] [LLTV Emergency Procedures], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 1-16.

[27] Hansen, *First Man*, 329-330.

issued a report calling for design and management changes, but also calling for the program to continue. Bob Gilruth and Chris Kraft wanted to stop before an astronaut was killed in the LLTV. Yet in 1969, Armstrong was again flying the LLTV as the *Apollo 11* Commander. When Kraft exclaimed in his office, "It's dangerous, damn it!" Armstrong coolly responded, "I know you're worried, but I have to support it. It's just darned good training." If he had felt the trainer lacked value, he would have acceded to the wishes of Gilruth and Kraft. But he successfully urged that flights continue. One more crash was still ahead, as test pilot Stuart Present had to eject after an electrical system failure on January 29, 1971. The loss of three vehicles, each of which cost $1.8 million, caused dismay at MSC. But any fair assessment of the LLTV must also mention that the vehicle landed safely hundreds of times. The ratio of those successful flights to the three crashes was not out of the ordinary for an experimental aircraft. Since all three pilots had training in reacting to emergencies, the program also did not kill anyone. Above all else, all six men who manually piloted a LM the last few hundred feet to the Moon felt a greater degree of comfort after flying the trainer. Gene Cernan became the last to fly it on November 13, 1972, in advance of *Apollo 17*.[28]

The astronauts required still more part-task trainers for rendezvous and docking. Engineer John Houbolt had weathered tremendous criticism of his idea to send humans to the Moon via a lunar orbit rendezvous mission profile, due to the risk in trusting one spacecraft to find and link up with another while nearly a quarter million miles away from home. The *Gemini* program proved that crews could maneuver to another vehicle

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[28] Ibid, 327-334.

in Earth orbit. This experience guided the *Apollo* team in forming requirements for the new program: the active vehicle should fly 15 miles below the target, use a transfer angle of 130 degrees to catch up with the target, and make the rendezvous with the sun behind it. Rendezvous in lunar orbit did pose new challenges, however. Crews would have to cope with mascons, meaning regions of the Moon's crust that contained large gravitational anomalies and could alter a spacecraft's flight path. Crews would also have to fly behind the far side of the Moon for half of each orbit, when they would be out of contact with Mission Control. Above all else, the two crewmembers in the LM would know that their vehicle could not return to Earth, because it did not have a heat shield. Their only ticket home was to maneuver to the CSM. Although the radars and computers in the two spacecraft would carry the greatest burden in making the meeting possible, what role could the crew play and how could they train for it?[29]

The two astronauts in the LM would have to monitor computer data, solve malfunctions, and manually brake their ship to make a successful rendezvous. The plan called for the ascent engine to lift them off the Moon and propel them into an orbit 45 miles high. The engine would then shut down, but the Commander would use the hand controller to pulse the vehicle's thrusters and refine velocity. As was the case during *Gemini*, the astronauts would keep their eyes on the computer display during the long coast to their target so they would be prepared to intervene. They might notice the need to make an engine burn to place their ship in the proper rendezvous plane, or the need to

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[29] Frank O'Brien, "The *Apollo* Flight Journal: Lunar Orbit Rendezvous," *Apollo Lunar Surface Journal*, http://history.nasa.gov /afj/loressay.htm (accessed August 5, 2016).

use a chart to compute their position manually in case of a loss of radar data. The latter had happened during *Gemini XII*, so the astronauts knew the importance of preparation in case their technology failed. Two hours and forty minutes after entering orbit, the thrusters would fire on the lunar backside for the Terminal Phase Initiation maneuver. This burn would match the trajectories of the LM and CSM. Forty-five minutes later, the most intense phase of crew participation would begin. The Commander would have to make four burns to manually slow the LM by 30, 20, 10, and 5 feet per second, when less than two miles separated him from his target. After making sure the trajectories and speeds of the two vehicles were perfectly matched, he would fly in formation with his crewmate in the CSM and take photos. The astronaut in the mothership would then gently thrust forward, at less than a foot per second, until the CSM docking probe slipped into the LM drogue.[30] Trained astronauts would provide the knowledge and flexibility to increase the chances of success, so they would need to train for this part of their flight as well.

The earliest part-task trainer for *Apollo* rendezvous came from Langley. After the space agency selected Lunar Orbit Rendezvous as the method by which crews would travel to the Moon and back, an expert engineer in guidance and control named Arthur Vogeley designed a Rendezvous and Docking Simulator that was ready for use in 1963. This facility featured a mockup of an *Apollo* spacecraft hung from the roof of Langley's West Area aircraft hangar. Engineers attached the vehicle to a moving crane that moved hydraulically along a 210-foot track. By strapping inside the cockpit and flying the

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[30] Ibid.

spacecraft along the track, several astronauts gained their first taste of the skills required to rendezvous. With their hand-eye coordination and attention to detail, the men proved that Houbolt's idea was not as outlandish as some NASA officials initially believed. "We trained an awful lot of astronauts," Vogeley explained, "who all appreciated the realism of the simulator's visual scene. It gave us a lot of satisfaction to show that NASA could do that sort of thing in a unique piece of ground equipment that only cost about $300,000. I think we got our money's worth."[31]

Another holdover from the *Gemini* era, the TDS, built *Apollo* astronauts' confidence for this phase. *Gemini* crews had trained for rendezvous by maneuvering their simulated ship across a rail assembly toward a simulated *Agena*. Engineers replaced them for the *Apollo* era with a simulated LM to serve as the active vehicle and a simulated CSM to serve as the target. When two men stepped inside the LM and began their pursuit, they especially benefited from a realistic presentation of the visual experience of rendezvous. The astronauts looked up at the target through an overhead window, where they could look through the Crew Optical Alignment Sight. This device contained a pattern of reticles which the Commander needed to make sure were aligned with the reticles on the target vehicle. He needed to shift his attention from this sight to the "8-ball" attitude indicator on his instrument panel, all while he placed his hand-eye coordination to the test by using the hand controller to guide the LM during these last moments of the rendezvous. He saw the ship that would take him home bulge in his window, then felt the CSM probe slip into his vehicle's drogue. The astronaut standing

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[31] Hansen, *Spaceflight Revolution*, 372-373.

next to him called out range and range rate figures to assist him. The simulation room was painted black so that while the two went through their tasks, the lighting conditions mimicked the space environment. Since this phase of the flight required a busy balancing of tasks within a short time frame, especially for the Commander, the astronauts would not have felt confident without sessions on this simulator. The astronauts thus built their confidence through 1.5 hour sessions that featured normal sequences as well as malfunctions. The sights and sounds also heightened the fidelity of the training experience to a point that fixed base simulators could not match.[32]

Although these part-task trainers prepared crews for the most dynamic phases of a mission (launch, lunar landing, rendezvous and docking, and reentry), the primary CMS manufactured by Link contractors provided what Mike Collins called "the heart and soul" of training. Riley McCafferty remembered attending the first major mockup review of this simulator at Binghamton, New York in 1963, just two years after North American won the contract for the actual vehicle. "As I remember that particular review, believe it or not, the consoles at that time were at least 75 percent like they are now," he recalled. The layout, height, and size of the instrument panel were thus largely consistent with the interior of the spacecraft that eventually took astronauts to the Moon. McCafferty became project engineer for the simulator in 1965, meaning he and his colleagues would inspect the three of them as they were shipped from the Link factory and ensure they remained consistent with the design of the real vehicles they were supposed to mimic. Link delivered the first CMS to Houston near the end of that year,

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[32] Williams, 19-21.

then two more to Florida's Kennedy Space Center (KSC) the following year. By the summer of 1966, McCafferty had assigned a group of engineers to assist him in supporting these three simulators for the most complex machine in the history of flight.[33]

Frank Hughes, who had just joined NASA as one of those engineers when Link made the first delivery to Florida, remembered the excitement of seeing the simulator for the first time: "We all walked up and looked at this box, what you call the CMS…That day, after a couple of hours, we walked around and talked. This one guy was my boss, his name is John Mitchell. He walked me around and introduced everybody—he was a great guy. Then he said, 'Okay, we're going to have you guys start studying the *Apollo* systems. Here's the book.' They just had one book for all these people, and we're all in one room, one office room." After receiving this introduction to his new employer, Hughes recalled seeing the simulator powered for the first time in June 1966. "It was just like the whole device, a piece at a time, came alive," he reflected. With only three years remaining before Kennedy's end-of-the-decade deadline and the first *Apollo* crew scheduled to launch the following year, Hughes and his colleagues learned the more than 400 switches and displays as rapidly as possible. "Every switch, you reach up and knew where it was, because it's like your car after awhile," Hughes said.[34]

When Hughes first gazed at the simulator in 1966, he saw a machine that could simulate a half-million mile journey to the Moon and back by taking advantage of the digital era of computers. About 175 contractors worked to develop the simulator

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[33] Interview with McCafferty, 1-2.

[34] Frank Hughes, Interviewed by Rebecca Wright, March 29, 2013, Houston, Texas, http:/www.jsc.nasa.gov/history/ /oral_histories/HughesFE/HughesFE_8-29-13.htm (accessed August 9, 2016).

software, and simulating all the motions and possible malfunctions of the vehicle on a round trip to the Moon required them to create 750,000 words of memory in four large computers. No technological development proved more important to astronaut training than the digital computer, because these units were the engines driving the most important tool in an astronaut's arsenal. With this foundation in place, the 200 Link contractors assigned to simulator hardware could focus on developing a machine that matched the Command Module and could prepare astronauts for a lunar mission.[35] How could they do this?

Their most important task was to reproduce controls, because this was how astronauts would interact with their spacecraft. The Link contractors made sure that the force required for an astronaut to change the position of a switch was the same as in the real spacecraft. They made sure the hand controller duplicated the genuine article in force profiles. They also programmed a digital computer to accept, or "interpret," the same program as the Guidance and Navigation computer that would be in the real spacecraft and respond to astronaut inputs the same way. When a SimSup instituted a malfunction into the spacecraft, the simulator displays would alter just as they would in a real emergency.[36] For instance, in turning around the CSM and docking it to the LM on the first day of a mission, the CMP had to manually activate his ship's thrusters and align it optically with a sight in his ship and a target cross on the LM. A SimSup could fail a thruster, and if the CMP could not work around the problem to achieve a safe

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[35] Woodling, et al., 10.

[36] Ibid, 11.

docking, the sequence would have to be repeated. The SimSups could arrange this by reloading memory to match the state of computer software at the beginning of the docking sequence.[37] The Command Module Simulator thus had both high fidelity and flexibility, two essential ingredients in giving crews the confidence to fly to the Moon and back.

The Link contractors also paid close attention to reproducing the aural and visual experience of spaceflight. Crews could hear the sounds of booster thrust, loss of cabin pressure, the firing of pyrotechnic devices, and the firing of thrusters via a loudspeaker in the simulator. SimSups could even manually control the amplitude of the sound with a decibel control potentiometer. Crews could also see simulated images out their windows, which accounted for 30 to 40 percent of the total simulator cost. Since the CMPs would need to navigate the spacecraft by recognizing the positions of stars, the contractors simulated about 1,000 stars by using small steel balls set into the surface of a celestial sphere. The balls even varied in brightness based on size and coating. *Apollo* visual simulations of the Sun, Earth, and Moon also advanced in capability beyond those of *Gemini*. The simulator engineers used arc lights, film, and large mirrors, supplied by the Farrand Optical Company, to project images of these bodies. Astronauts could even see their positions, brightness, and size change as the simulator "moved" through space. When astronauts trained to rendezvous and dock with other vehicles, a cathode ray tube produced an image of a spacecraft out their windows with a position accuracy of plus or

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[37] *Apollo Program Summary Report* (Houston: JSC-09423, 1975), 6-4 and Tomayko, 276.

minus one degree.[38] Motion picture and video game developers had not yet introduced computer graphics into their industries, but the need to meet a major national goal provided the urgency to create compelling visual images in *Apollo* simulators.

The hardware used in the simulator also matched the real spacecraft to a remarkable degree. In some cases, the Link contractors could not simulate hardware such as instrument panel displays and procured real parts from North American. But in most cases, they produced their own parts from a "model shop" in Binghamton. The parts did not require the sophisticated design of real spacecraft parts, so the contractors saved money by making parts from initial design sketches. NASA did furnish some simulator parts in Houston as well, such as optical sights, suit hoses, backpacks, and stowed items. This effort to produce realistic hardware enhanced fidelity because contractors assigned all 445 items of stowed equipment to a specific location and the astronauts could train to stow them. The couches in the spacecraft provided proper body restraint and matched the reach pattern that astronauts would need to manipulate switches in the real vehicle. The crewmembers could also wear fully pressurized suits, so they could train to do so while wearing rigid gloves.[39]

But most importantly, the simulator made landing on the Moon a more reachable goal because it increased the mental proficiency of astronauts (and flight controllers, in integrated simulations). In the 1990s, a group of researchers estimated that 70 to 80 percent of accidents in commercial and military aviation were directly related to human

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[38] Woodling, et al., 12-25.

[39] Ibid, 12-14.

error. In 2007, one researcher estimated that nearly two-thirds of accidents at NASA were related to this as well. The *Apollo* program did contain accidents, including one that took the lives of the *Apollo 1* crew during a launch pad test and one that nearly took the lives of the *Apollo 13* crew en route to the Moon. But an astronaut never made a life threatening error as a result of inadequate training. How can one account for this, given the prevalence of human error in fields like commercial aviation? The astronauts were part of a program that cost about $20 billion, which the entire nation felt motivated to achieve to honor a late president's memory. The money and time spent in training them, and in supplying them with highly trained flight controllers who could communicate with them during missions, thus dwarfed other high tech fields.[40]

Yet the method of training *Apollo* astronauts also deserves consideration as a reason for the lack of mistakes. After the CMS entered operation in 1966, the astronauts learned Command Module systems through a combination of briefings and simulator sessions. For one hour each, experts instructed them through briefings on the electrical system, the environmental system, the communication system, the propulsion system, the guidance system, Delta-V maneuvers, and the reentry of the Command Module. The briefings let the astronauts knew what switches to throw or keyboard entries to make during a normal mission, but also how to analyze the malfunctions that were so likely with the most complex flying machine in history. For instance, the men had to know how to switch to a backup or alternate mode. The astronauts then went into the CMS

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[40] Immanuel Barshi and Donna L. Dempsey, *Risk of Performance Errors Due to Training Deficiencies* (Houston: JSC-CN-35755, 2016), 4.

and placed their knowledge to the test for three hour sessions at a time. With this first phase of training under their belts, each of them went back to the simulator to train for more intricate maneuvers. These sessions especially tested their problem solving abilities. They needed to know how to rescue the LM during the lunar orbit rendezvous by firing the service module engine, for instance. The CMP even needed to know how to operate the spacecraft alone during the transearth flight, if tragedy had left his two crewmates unable to return. The effort to familiarize astronauts in the Command Module ended with integrated simulations, where a crew *and* flight controllers undertook full dress rehearsals of a mission in five phases: launch, orbital activity, lunar descent and ascent, joint CSM-LM activity, and reentry.[41]

This method successfully mitigated concern about crew error. Two NASA researchers argued in a 2016 study that two factors mainly contribute to training deficiencies in high-tech fields: organizational issues and a mismatch between a person's learning capacity and the demands of a task.[42] But while training for an *Apollo* mission, astronauts were part of an organization containing high quality instructors who taught them how to operate the spacecraft. These instructors mandated that each of them spend 60 hours attending briefings and a minimum of 200 hours in the simulator, eliminating concern that training might not cover an event that could occur in flight. The instructors were also flexible. Because they knew astronauts had different learning rates, they did not mandate a number of hours to specific exercises. They encouraged the astronauts to

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[41] Kohler and Reeder, 23-40.

[42] Barshi and Dempsey, 6.

train until they had achieved proficiency, not until they had simply checked off a box or earned a certain grade. After each simulator session, the astronauts stepped outside for debriefings, where they could ask questions and speak about any problems with the simulator or their performance. Astronauts also managed to eliminate any concern of a mismatch between their learning capacity and the demands of a task. They had been selected in the first place because they had already proven themselves as among the best in operating complex aircraft at high speeds. Their training on the specific procedures of a lunar flight lent itself to long-term retention, because they took part in briefings and simulator sessions over a span of several years and right until launch.[43]

The most significant difference between training in *Mercury* and *Gemini* simulators and in the *Apollo* CMS was the proficiency required in the guidance and navigation system. The MIT Instrumentation Laboratory had produced a guidance computer for each spacecraft that was less powerful than a 21st century handheld calculator. The device contained only 36,000 words of memory and 2,000 words of RAM, and operated at a 12-microsecond clock speed.[44] Yet the computer served its purpose by making thousands of calculations per second and thus directing the positioning of the vehicle on its voyage to the Moon and back. The astronauts needed to augment that capability by serving as highly trained operators, however. For each mission phase from launch to reentry, a crewmember needed to activate the corresponding computer program and select the right options within each program.

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[43] Kohler and Reeder, 9 and 23-40.

[44] John Tylko, "MIT and Navigating the Path to the Moon," *Aero-Astro Magazine*, http://www.web.mit.edu/ aeroastro/news/ magazine/aeroastro6/mit-apollo.html (accessed August 11, 2016).

Crews would need to make 10,500 computer keystrokes to navigate to the Moon and back. The CMP for each mission would also need to use a sextant to measure the angles between heavenly objects, such as stars, the Earth and the Moon. The computer would more precisely compute the spacecraft position based on the sextant readings. Gaining proficiency in understanding and operating the *Apollo* guidance system consumed 40 percent of the astronauts' training time, between briefings by MIT personnel and those hundreds of simulator hours. This was one of the biggest reasons for the drastic increase in simulator time compared to *Mercury* and *Gemini*.[45]

The grueling training load required still more hours in the Lunar Module Simulator. In 1964, just a year and a half after Grumman had won the contract to manufacture the first vehicle to land humans on another world, Link began work on the LMS. By the fall of 1966, one of these simulators had arrived in Houston and one at the Cape.[46] This device only had to simulate the small fraction of the mission when two crewmembers separated the lander from the mothership, descended to the lunar surface, and lifted off to return to the mothership. Even during this small fraction, the onboard computer would carry much of the responsibility in guiding the astronauts to a safe landing, liftoff, and rendezvous. It would control the digital autopilot, the descent engine, the Reaction Control System (RCS) thrusters used to keep the vehicle in the proper attitude, the indicators the crew would see on the instrument panel, and even the astronauts' inputs to the hand controller. What, then, did the astronauts need to train to

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[45] Warren J. North, "Astronaut Training at the Ph.D. Level," *New York Times*, July 17, 1969.

[46] Kelly, 198.

accomplish? The human brain was still the most advanced computer in existence and in this case, the brains of two crewmembers trained to recognize malfunctions could verify the computer programs and landing phases. If necessary, they could troubleshoot any problem by flipping switches or even calling for an abort that would send them back to the mothership. Even if all went according to plan, the LMP would still need to punch keys to issue commands to the computer. The Commander would have the even greater responsibility of flying the vehicle. Since he could not be sure the digital autopilot would guide the vehicle to a safe area on the crater filled Moon, he would grab the hand controller and fly the final few hundred feet himself (although he would send signals to the computer in moving the hand controller). He would then stop the engine when the probes attached to the four landing legs touched the lunar surface.[47]

The astronauts thus had responsibilities that could make the difference between life and death, both during the landing sequence and aforementioned liftoff and rendezvous sequence, and this called for a simulator in which crews could prepare for them. This placed another heavy burden on the Link contractors, because the digital requirements for the LMS were almost as intensive as for the CMS: 600,000 words of memory in three computers.[48] The visual requirements were also demanding and unprecedented, because the astronauts needed a simulated view of the Moon as it grew closer and closer until landing. To do this, NASA and Link once again turned to the Farrand Optical Company. The contractors at this company manufactured an optical

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[47] Mindell, 190-191.

[48] Woodling, et al., 10.

probe and mounted it on a boom, which maneuvered across a sixteen foot diameter plaster of Paris model of the lunar surface. As the lander made its simulated descent to the Moon, its motions sent signals to a computer that directed this optical probe accordingly. Thus the probe zoomed in on the model, transmitting a view of it, until the Commander could look out of his triangular window and visualize being a few feet above a desolate landscape. He would even be able to see the shadows that the lander cast on the surface, a vital cue near the end of the landing. By the time the *Apollo 11* crew trained for their landing, craftsmen had images from the *Lunar Orbiter*, *Surveyor*, *Apollo 8*, and *Apollo 10* spacecraft to guide them in creating a three dimensional lunar surface model. Neil Armstrong and Buzz Aldrin could train in the LMS while seeing broad features at the Sea of Tranquility represented to an accuracy of about 50 feet via this model. As they descended close to the specific landing site on Tranquility's southwest corner, the accuracy increased to 10 feet.[49]

This method of optically simulating lunar landings was highly advanced for the 1960s and even inspired one of the most prominent engineers at Farrand in his later endeavors. Al Nagler worked at Farrand from 1957 to 1973, where he designed the infinity optics displays that *Gemini* and *Apollo* crews saw outside their simulator windows. When he saw the 110 degree wide view outside the LMS, this so inspired him that he went to work developing a wide angle lens for his Tele Vue Optics company in the 1970s. He and his colleagues succeeded in developing television lenses and a Nagler

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[49] Woodling, et al., 27.

eyepiece that has aided astronomers around the world in observing outer space.[50] Nagler's story indicates that the advanced technology used to simulate and fly missions benefited the world by inspiring spinoffs. By making his lunar commitment, President Kennedy had required the brightest technological minds around the country to make advances that they probably would not have otherwise made until later than the 1960s. Many of these advances not only helped astronauts reach the Moon, but also diffused to the general public.

Astronauts learned to operate the Lunar Module in a series of steps which, like Command Module training, proved highly effective. The men listened to briefings on the electrical system, the communication system, the environmental system, the RCS thrusters, the Descent Propulsion System, the Ascent Propulsion System, the Stabilization and Control System, the Abort Guidance System, and the Primary Guidance System. Then they applied their knowledge in brief simulator sessions that covered one of those specific areas at a time. Usually only one of them needed to sit inside the LMS during this first phase of training. Two astronauts sat together for the more complex sessions of the second phase. These sessions gave them experience not only in making a landing as planned, which would be complex enough, but also in recognizing when they would need to take over manually to find a safe landing site or make an abort that would send them back to lunar orbit. The sessions also gave them experience in preparing the LM for its launch from the Moon and, if necessary, controlling it manually to a safe orbit. From there, the astronauts graduated to the

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[50] Michael E. Bakich, "The Life and Times of Al Nager," *Astronomy* Vol. 41, Issue 4 (April 2013): 52-57.

integrated simulations. During these full dress rehearsals, two members of the crew could sit inside the LMS while their one crewmate sat inside the CMS. Wires enabled the two simulators to interact with one another and with Mission Control, just as the real spacecraft would have to interact with one another at the Moon.[51]

Nearly fifty years after the *Apollo* Moon landings, one aspect of how astronauts trained for them and made them deserves special consideration: the two men in the cockpit depended on each other to make safe landings. The Commander kept his eyes out the window during the last few hundred feet as he manually flew the vehicle, while the LMP kept his eyes on the numbers he saw on the instrument panel displaying the ship's altitude, velocity, and fuel quantities. He called out the numbers as the LM approached the Moon, so that the Commander could know them without taking his eyes away from the window, until he saw a blue light marked "Lunar Contact" illuminate. This meant that a probe attached to one of the landing legs had touched the surface, so he called out "Contact light" and the Commander knew to shut down the engine just then.[52] More recently, airline companies have advocated strongly in favor of Cockpit Resource Management Training, meaning training to improve pilots' interpersonal communication and teamwork skills. After an incident in 1977, when two Boeing aircraft collided on a runway and killed hundreds of people, NASA researchers held a workshop in 1979 in which they endorsed this idea. By the 1990s, it had become

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[51] Kohler and Reeder, 10 and 41-50.

[52] Mindell, 191-192.

standard in the airline industry.[53] The *Apollo* astronauts did not have this specific training that more recent pilots have had, but over hundreds of simulator hours they learned to trust each other when their lives would be on the line nearly a quarter million miles from home. Even though the Commanders were more experienced in spaceflight than the LMPs, all Commanders willingly accepted the input of their partners.

While the astronauts focused on learning how to operate their two spacecraft, the SimSups and flight controllers had their hands full preparing for and conducting integrated simulations. Dick Koos knew that the precedent from *Mercury* still applied, that flight controllers would have access to more information than the astronauts, and the volume of information would increase drastically from *Mercury* to *Apollo*. This called for a series of simulations designed to test the controllers' ability to interpret the wealth of telemetry and make decisions. Koos, the SimSup hired by NASA on the basis of his experience with computers, thus went to work on the computers required to make these simulations possible. "When the *Saturn* flights began, to get that telemetry into the control center, you had to simulate that with a computer in the control center called the Ground Support Simulation Computer (GSSC)," he remembers today. "The interface (between the GSSC and the *Apollo* simulators at Houston and the Cape) became much more complex and we had to develop that. The trajectory the flight controllers saw was both from the *Apollo* guidance computer and from the *Saturn* computer. They compared them. Those were their two sources of information for the launch trajectory. We had to

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[53] Robert L. Helmreich, Ashleigh C. Merritt, and John A. Wilhelm, "The Evolution of Crew Resource Management Training in Commercial Aviation," *International Journal of Aviation Psychology* Vol. 9, Issue 1 (1999): 19-32.

make all that synchronized. Working that interface out and getting those telemetry requirements from the *Apollo* simulator was basically what I worked on. We had to get IBM, who developed computers for us, and Link, which developed the simulators for us, together to develop that interface. We simulation guys really owed a lot to IBM."[54]

When the equipment became available, the flight controllers worked twelve hour days in carrying out integrated simulations. They spent some of these days with math models and a simulated astronaut. But when the prime and backup crews of an *Apollo* mission had reached that last phase of their training, the controllers responded to telemetry and made recommendations to the real astronauts they would have to support in flight. The *Apollo 7* astronauts began this procedure by taking part in 18 days of simulations in which their CMS was wired to Mission Control. The *Apollo 9* astronauts took part in the first simulations in which the CMS, LMS, and Mission Control were all wired together, since this was the first piloted mission to carry a Lunar Module. The total number of days devoted to integrated simulations gradually increased until reaching a high of 35 for the *Apollo 14* mission.[55] During the first few days of training for each mission, the simulations went according to plan, without any glitches. This allowed the astronauts and controllers to learn to work together and perfect carrying out procedures. But a team of SimSups had been busy for several months writing scripts of malfunctions. When those peaceful first few days ended, the SimSups began programming them into the simulators. The astronauts saw them as readouts on an instrument panel, the

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[54] Author Interview with Koos.

[55] Woodling, et al., 8.

controllers as telemetry on their computer screens. "Nothing is sacred; no quarter is given and none asked," wrote Flight Director Gene Kranz about the SimSups relentlessly trying to test his controllers.[56]

The roster of SimSups expanded from *Mercury* and *Gemini* to *Apollo*, reflecting the far greater complexity of simulations needed for the moon program. Jay Honeycutt remembered that he was one of about forty of them, working out of the MSC Flight Operations division, by the time *Apollo* began. These forty split up into those who focused on the trajectory of spacecraft, the tracking of spacecraft, CSM systems, and LM systems. When an integrated simulation began, about ten of them sat in Mission Control behind a glass partition from the flight controllers they were trying to train. Thus there were four teams of SimSups, who worked together in devising as many as twelve cases of malfunctions per day. There were also multiple teams of flight controllers assigned to each mission.[57]

The SimSups developed an understanding of the qualities that made for a good flight controller. Harold Miller, one of the original members of the simulation task group at Langley, cited four qualities. First, the best controllers had intelligence and a great memory. The average age of *Apollo 11* flight controllers was only 28 years. When they supported the first Moon landing, only a handful of years had passed since most of them had earned their college bachelor's degrees.[58] Yet after their classroom instruction,

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[56] Kranz, 261-262.

[57] Jay F. Honeycutt, Interviewed by Rebecca Wright, March 22, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/HoneycuttJF/HoneycuttJF_3-22-00.htm (accessed September 12, 2016).

[58] Rick Houston and Milt Heflin, *Go, Flight! The Unsung Heroes of Mission Control, 1965-1992* (Lincoln: University of Nebraska Press, 2015), 179.

they knew their assigned jobs and could recall what the mission rules called for them to do at any point in the mission. Second, the best could think very quickly on their feet. When the SimSups injected malfunctions into a simulation, the controllers would have a limited amount of time in which to respond to them. In order to interpret the information they saw on their computer screens, consult with a team of engineers in the Staff Support Room (SSR) if necessary, and then express themselves quickly and precisely to the Flight Director and CapCom, they needed this quality. Third, the best had tremendous confidence in their abilities. Like the astronauts, they had no qualms about taking actions with potentially life or death consequences. Fourth, the best had a sense of humor. If a controller made a wrong response to a malfunction and the entire team heard about his mistake during the subsequent debriefing, his sense of humor helped him to take the news good naturedly while assuring himself that he would never let it happen again. The onus of determining who possessed those qualities and was ready to support a mission fell to the Flight Directors.[59]

The greatest burden during the simulations fell to the Flight Director, because he had to understand the assignments of each of his nearly 20 controllers, listen to them, and make a decision. The Flight Directors had access to communication loops for each of his controllers, as well as his own Flight Director loop and the air to ground loop. Kranz believed that the many simulations were crucial to allow him and his colleagues to learn to focus amid the information overload. "The training process really allows you to remain focused on one or two loops, and you're listening for key words," he argued.

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[59] Ibid, 33.

"The training process alerts you to the tone of the crew's voices and the tone of the controllers' voices. In addition to that, you've got key words that you've used throughout the training process that will get additional attention."[60] Among *Apollo* Flight Directors, Kranz, Cliff Charlesworth, and Glynn Lunney already had experience in the job from *Gemini*. But Gerry Griffin, Milt Windler, Pete Frank, Phil Shaffer, Don Puddy, Neil Hutchinson, and Charles Lewis all needed an indoctrination to the job through the training SimSups could give them. "I felt like an idiot and looked like an idiot," Frank remembered about one of his first simulations. "There's these guys that someday you're supposed to be down there running this thing telling them what to do. Here they're seeing you do this and you don't know what you're doing."[61] Yet each of the aforementioned Flight Directors gradually proved themselves under the mental strain of simulations.

Despite the thousands of hours astronauts and controllers spent preparing for a round trip to the Moon that would cover nearly a half million miles, the trip would not have been worthwhile without a focus on the destination. Here was where *Apollo* training differed from *Mercury* and *Gemini* training: the need to train for a visit to another heavenly body. Although President Kennedy had only challenged the nation to land a man on the Moon by decade's end and had said nothing about what an astronaut should accomplish once on the lunar surface, MSC personnel gave thought to the exploration and scientific discovery such an astronaut could accomplish just one year

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[60] Ibid, 211.

[61] Ibid, 102.

after the challenge. Eugene Shoemaker, one of the pioneers of astrogeology who was then working for the U.S. Geological Survey (USGS) in Flagstaff, Arizona, credited Max Faget (MSC Director of Engineering) as the key figure in Houston who envisioned an emphasis on lunar science during *Apollo*. Shoemaker traveled to Houston in the summer of 1962 to meet with Faget. "Max wanted me to come and work for him, straight out, to build up a geology group, to do research, to train the astronauts, and to build up the whole thing for science on the Moon," he remembered. Shoemaker actually went to work at NASA Headquarters in Washington, D.C., but while there he proposed the training program that the space agency eventually adopted, whereby Ph.D. geologists from the USGS and MSC would instruct the astronauts in their discipline.[62]

Shoemaker knew that all members of the astronaut corps at this time were pilots, and that the only way to make the most of their exploration skills was to cross train them in geology. The most dangerous task of a lunar mission was the landing on the surface, which would require the astronauts to exercise the piloting skills they had honed for their entire adult lives. But if they also possessed the skills to undertake the less dangerous but complex surface exploration through cross training, they would aid the efficiency of *Apollo* through their ability to thrive in all aspects of missions.[63] Past explorers on Earth had developed multidisciplinary skill sets as well. For instance, Meriwether Lewis had a background as an Army soldier when he embarked on his 1803 expedition to the American West with William Clark. Yet he received private tutoring as a field

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[62] Phinney, 28.

[63] Phinney, 2.

naturalist, biologist, botanist, and navigator prior to his journey.[64]

A USGS document from 1950 makes clear the value of education and training in becoming an effective field geologist. The USGS required a minimum of 30 semester hours in geology for those who wished to study the landscape and natural resources of the United States in a professional capacity. But the geologists who wrote the report argued that undergraduate work alone "is rarely adequate…the intellectual discipline, the intensive training, and the research habits instilled by the graduate school environment are of paramount importance to a Survey geologist." The authors believed that the best geologists of the future would hold advanced degrees and become well rounded through knowledge of diverse subjects such as mathematics, physics, chemistry, minerology, and biology.[65] The *Apollo* astronauts were in a different situation, because they would only spend a maximum of three days at their field site and only a maximum of about 22 hours outside their spacecraft. They would then haul their rocks back to Earth, where professional geologists could study them for the rest of their lives in the comfort of a laboratory environment. At least one astronaut wondered why, given that this was the case, the space agency needed to place such a heavy emphasis on the astronauts' skills as field geologists. Yet the geologists who instructed them advanced a compelling argument that making a substantial contribution to lunar geology required more than simply filling a container with rocks. It required the astronauts to observe the context in which they found their samples, because the rocks had sat undisturbed for up to 4.5

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[64] Kelly, 273.

[65] Harold M. Bannerman and William T. Pecora, "Training Geologists: A United States Geological Survey Viewpoint," *Geological Survey Circular* Vol. 73 (March 1950): 1-6.

billion years.[66] If astronauts brought trained minds to process the information they were seeing at the site of exploration, they could help unravel the mysteries of cosmic history dating back that far.

Geologists thus began instructing astronauts in January 1963, shortly after the "Next Nine" astronauts joined the "Original Seven." The geologists lectured to both groups and accompanied them on a trip that month to Flagstaff, where the astronauts studied Meteor Crater and observed the Moon by telescope. Gene Shoemaker received encouraging comments about the field trip. He felt persuaded to set up an arrangement whereby personnel from the USGS and MSC would split astronaut training duties. The USGS geologists such as Al Chidester, Dale Jackson, and Donald Wilhelms would give astronauts an introduction to the subject through lectures in Houston. MSC geologists such as Uel Clanton, Ted Foss, Elbert King, and Wendell Mitchell would also give them classroom instruction, but focus on the more specific subjects of mineralogy and petrology. Personnel from both organizations would then work together to arrange field trips. Slayton required all of his astronauts to attend the trips unless flight preparations or unavoidable commitments excused them.[67] Although the two groups clashed on who should have ultimate authority, their members did develop a syllabus for future astronaut groups. Series I training would require 58 hours of classroom instruction and four field trips. Having received an introduction to the subject, the astronauts would undergo training more specific to lunar exploration through still more classroom work and field

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[66] Andrew Chaikin, *A Man on the Moon: The Voyages of the Apollo Astronauts* (New York: Viking, 1994), 406.

[67] Phinney, 3, 22, and 54.

trips during Series II and III.[68]

The first attempt to implement the syllabus, in February 1964 after the selection of the third group, provided one critical lesson learned. All 29 of the astronauts who took part in geology training had dreamed since childhood of becoming aviators. Their education and work reflected their desire to work with flight machinery, not rocks. At the first meeting in the classroom set up at Ellington Air Force Base, an instructor asked, "Who has, at some time in their education, taken at least an introductory course in geology?" None of the 29 raised their hands.[69] Their interest in this new subject varied widely, but in general the astronauts found the classroom instruction the least productive form of training. The astronauts simply wanted the information they needed to make intelligent observations of the lunar surface, and sitting through two hour sessions on general subjects such as the "law of uniformity," the "law of superposition," and the "law of original horizontality" did not appear necessary to them.[70] The instructors understood the astronauts' criticism of classroom instruction. Elbert King wrote, "The quality of the lectures was uneven—some were good, some were awful…We could not afford to waste their (the astronauts') time with poorly prepared or badly presented material—this was made abundantly clear."[71]

The astronauts and instructors each learned the lesson that field trips were a

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[68] Donald A. Beattie, *Taking Science to the Moon: Lunar Experiments and the Apollo Program* (Baltimore: The Johns Hopkins University Press, 2001), 159.

[69] Phinney, 54.

[70] [Flight Crew Training Report No. 68, February 17-22, 1964, Box 081-11, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas.

[71] Elbert A. King, *Moon Trip: A Personal Account of the Apollo Program and its Science* (Houston: University of Houston Press, 1989), 27-28.

much more productive form of training. The first one sent them to Arizona’s Grand Canyon in March. After arriving at the rim, a USGS instructor described the geological features of the magnificent vista, the processes that formed them, and the rocks the astronauts could expect to find. The men then split up into groups of two or three astronauts and one instructor and set off on a 6.5 mile hike to the bottom of the canyon. The groups traveled back up the next morning, but this time the instructors required the astronauts to place their knowledge to the test by identifying the units of rocks on the trail they followed. In April, another trip took the men to the Marathon Basin in southwest Texas. This outing gave the astronauts experience in observing the volcanic flows that had shaped the rocks in this location, just as volcanism had shaped the Moon for billions of years. The third trip took them to Flagstaff in May, where the men undertook additional field work in a region shaped by both impact craters and volcanic flows and flew in a light aircraft to study the stratigraphy of the region from a bird’s eye view. The final trip took them to New Mexico’s Philmont Ranch in June.[72] The instructors ramped up the intensity of the training for this outing, as the astronauts had to sketch, describe, take notes, and make strike and dip measurements of more complex geological features than at the previous locations.[73]

The field trips contained several advantages that set them apart from classroom instruction. First, they gave the astronauts practical experience in the type of work those fortunate enough to land on the Moon would perform, as opposed to simply sitting in a

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[72] [Flight Crew Training Report No. 70, 74, and 78, March 2-7, March 30-April 4, and April 27-May 2, 1964, Box 081-11, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas.

[73] Phinney, 220.

classroom. The classroom work did not include tests, and even if they did the instructors could not really know if their students had become proficient geologists until they could prove their worth in the field. As a second advantage, each instructor spent time with only two or three astronauts so that they could easily evaluate the strengths of each one and encourage each of them to ask questions about geology. As a third advantage, sites such as the Grand Canyon impressed upon the astronauts the grandeur of field geology.[74] The field trips also served as a case study in the coordination between several agencies needed for hands-on, practical training of astronauts. Geologists from the USGS and MSC worked together to instruct them, while the National Park Service allowed both instructors and astronauts to use desired field sites.[75] The campsites where the men spent the nights contained "all the amenities of home," according to lunar scientist Richard Allenby.[76]

The astronauts graduated from Series I of their geology training after their Philmont Ranch trip, and with this under their belts they could learn more specifically about the Moon from their instructors. Their classroom instruction during Series II emphasized the debates on how lunar features formed, which they hoped to solve by taking informed minds to make close-up observations. For hundreds of years, scientists who had observed the Moon via telescope had wondered whether it had been shaped more by ancient volcanism or by impacts. The instructors thus required the astronauts to

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[74] King, 28.

[75] Phinney, 57.

[76] [Richard J. Allenby to Homer Newell, October 14, 1965, Box 075-14, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas.

study lunar features as seen in photos from telescopes and the first successful *Ranger* lunar probe so their students could understand the state of scientific thinking about the regions they hoped to explore. The Series II field trips expanded on this goal by sending astronauts to a combination of sites, some shaped by volcanism and some by impacts. In October 1964, a group traveled to Oregon's Newberry Crater and made traverses across it with the goal of finding enough data to determine by which of the two methods the crater formed. Trips to New Mexico's Jemez Mountains and Hawaii gave the astronauts experience exploring diverse volcanic phenomena such as rhyolite domes, welded tuffs, ash flows, gas and lava vents, and lava tubes.[77] Buzz Aldrin consequently remembered, "Of all the places on Earth where we trained, the Big Island (Hawaii) felt most like the Moon.[78] Series II ended with trips to the Nevada Test Site and Meteor Crater in early 1965, where the astronauts trained to observe the impact craters that scientists knew also accounted for much of the Moon's surface.[79]

The training grew still more specific and practical with Series III. Classroom instruction this time taught the astronauts how to probe the lunar surface through physical methods (such as seismic, gravitational, or magnetic) to measure its properties. Some of the men in the classroom eventually carried out these methods on the Moon, when time was at a premium and they needed the informed minds that training gave them to guide their work. Another advantage of Series III was that the instructors took

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[77] Phinney, 62.

[78] Buzz Aldrin with Leonard David, *Mission to Mars: My Vision for Space Exploration* (Washington, D.C.: National Geographic Society, 2013), 96.

[79] Phinney, 62.

the astronauts to more distant field sites that were also more analogous to the Moon. A trip to the Katmai Peninsula in Alaska allowed them to observe volcanic landforms so fresh that they were in nearly pristine condition. A trip to the Askja Caldera in Iceland took them to one of the most Moon-like sites on Earth, due to the lack of vegetation cover. The instructors were so intent on giving these Series III trips practical value that they told the astronauts to play the "Moon Game." This meant that the instructors dropped two astronauts in a deserted location and asked them to pretend they had just left their Lunar Module. The two had to plan their traverses, operate geophysical instruments, and collect samples, while making observations of the context in which they found their samples via a radio-microphone. The instructors recorded their words so they could evaluate the astronauts' observational skills. When a group returned from a trip to Zuni Salt Lake, New Mexico and Pinacates, Mexico in December 1965, the geology training for the first three groups of astronauts had ended until they were assigned to missions.[80]

Earlier that year, the corps entered a new era as NASA selected a new group comprised of professional scientists. NASA personnel had considered this controversial question for the past few years: did the space agency need to focus solely on cross training pilots, or should professional scientists have seats on *Apollo* spacecraft? On July 6, 1962, an Ad Hoc Working Group on *Apollo* Experiments and Training recommended that at least one member of the lunar landing missions "should be a professional scientist and that the other members should have had extensive training in

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[80] Ibid, 62-63.

suitable scientific subjects. The scientific objectives of the program require a scientist with education at the Ph.D. level and with from 5 to 10 years of experience." The group explained that scientists with strong backgrounds in field geology would benefit the *Apollo* program because, "The investigation of the Moon's surface, and with it the origin of the solar system, cannot be done competently except by people who have a very good grasp of all that is known and understood in these fields."[81]

But there was one problem with this reasoning: in order for the crews to reach the lunar surface and return safely, they would need piloting skills. The pilots in the astronaut corps had experience making decisions where a mistake could have meant death, whereas scientists had never operated with this kind of pressure. "If an alarm came on, there would be no time to ask some professor to carry his share of the load," Gene Cernan explained.[82] One professional scientist who became an astronaut in 1967 remembered Frank Borman's more blunt declaration at a meeting: "To hell with the scientific community!"[83] Cernan and Borman were both typical among the pilots in the astronaut corps in expressing their dislike of the idea of taking scientists on lunar missions or into the astronaut corps at all.

The space agency resolved the controversy by selecting scientists into the corps, but placing them at the back of the flight line so that the pilots would occupy the seats on the first lunar missions. After the selection of the third astronaut group in 1963, Robert

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[81] "Draft Report of the Ad Hoc Working Group on *Apollo* Experiments and Training on the Scientific Aspects of the *Apollo* Program," July 6, 1962, Box 55, Folder 7, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

[82] Cernan with Davis, 84.

[83] Brian O'Leary, *The Making of an Ex-Astronaut* (New York: Pocket Books, 1971), 131.

Voas held discussions with Bob Gilruth and other top MSC officials and concluded that the agency should select professional scientists. Administrator Jim Webb approved the plan, then the NASA Associate Administrator for Space Science and the head of the Space Science Board of the National Academy of Sciences devised a set of criteria by which to consider and select them. On October 19, 1964, the announcement went out that NASA would select scientists the following year.[84] Of the more than 1,300 who applied, the selection boards at NASA and the National Academy of Sciences whittled the names to six in June 1965: Owen Garriott, Ed Gibson, Duane Graveline, Joe Kerwin, Curtis Michel, and Harrison "Jack" Schmitt. Only Kerwin and Michel had piloted jets, so the other four spent slightly more than a full year learning to fly planes at Williams Air Force Base in Arizona.[85] When asked today if his experience piloting jets proved to be an asset once selected as an astronaut, Kerwin answers yes. "The thinking was, you had to be willing to put yourself at risk in a real flight situation, no panic," he explains. "The actual physical skills were not as important."[86]

The space agency went through with yet another selection of scientists in 1967. During this era when NASA consumed up to 4.5 percent of the national GDP, headquarters personnel had conceived an ambitious agenda beyond the initial *Apollo* lunar landings. A program called *Apollo Applications* would use the *Apollo* hardware to send crews to an Earth orbiting space station and to the lunar surface for stays of up to two weeks. Given this optimistic atmosphere, the first landing of astronauts on Mars

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[84] Slayton with Cassutt, 143.

[85] Ibid, 152-153.

[86] Joe Kerwin, E-Mail Correspondence with Author, December 30, 2016.

appeared likely by the 1980s. Headquarters personnel made the mistake of thinking that lawmakers would keep the NASA budget at mid-1960s levels and that the MSC therefore needed new infusions of astronauts. They projected that six crews would launch each year through the mid-1970s.[87] Each crew would require pilots to make rendezvous maneuvers and lunar landings, so NASA selected 19 more pilots in 1966. Each crew would also benefit from the expertise of scientists in performing microgravity experiments, making geological observations, and even undertaking laboratory analysis on lunar rocks during two week missions, so NASA selected eleven additional scientists the following year. None of them had pilots' licenses, but all had doctoral degrees in areas ranging from nuclear physics, to geochemistry, to astronomy, to medicine, to electrical engineering, to chemical engineering.[88]

Despite the willingness of the space agency to accept the demand for scientific representation in the astronaut corps, three factors worked against the scientists in receiving seats on missions. First, the astronauts from the first three groups who had stuck around for *Apollo* were ahead of them in line. Second, Deke Slayton clearly favored selecting astronauts with pilot pedigrees for the most important seats. He wrote, "I didn't have anything against scientists, or doctors, but I wasn't quite sure what I was supposed to do with them on flight crews…People don't realize it takes two or three people to make sure the spacecraft gets where it's supposed to go, performs all the planned maneuvers, then return safely."[89] But third and most importantly, the grandiose

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[87] Slayton with Cassutt, 201.

[88] Ibid, 202.

[89] Ibid, 143.

projections at NASA Headquarters did not match the reality of the late 1960s. The bold political environment of President Kennedy's 1961 speech had given way to an environment in which President Lyndon Johnson and the majority of legislators felt comfortable reducing NASA's budget given the fiscal challenges of the Vietnam War and social programs. The budget cuts shut down the *Saturn IB* and *Saturn V* production lines in 1967. The remaining rockets would be able to support ten *Apollo* lunar landings and a few missions to an earth orbiting space station, but otherwise the future of human spaceflight was murky by the time the group of eleven scientists reported to MSC on September 18. Slayton had to tell them "they just weren't needed" on that first day, but five of them eventually earned assignments to *Apollo* support crews (a job that required standing in for flight crews during meetings and tests and serving as CapComs). None of the members of this group flew in space until the 1980s. Even among the first group of scientists, only Jack Schmitt managed to walk on the Moon.[90]

Schmitt did have an influence on *Apollo* beyond his flight, because as the only Ph.D. geologist in the astronaut corps he provided his input into geology training. The scientists in his group and the group of 19 pilots underwent their own indoctrination to geology through classroom instruction and field trips from May 1966 to September 1967. He felt that the process needed improvement, because the geologists teaching the astronauts tried to inundate them with arcane concepts rather than simply making sure they could do their jobs. "The guys were bored," he observed of his fellow students. The USGS and MSC geologists boasted that they would give the astronauts the

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[90] Ibid, 201-203 and Brooks, Grimwood, and Swenson, 378.

equivalent of a master's degree in geology by the time they launched, but Schmitt countered, "That wasn't the point. The point was to get the maximum of good information, good samples and good documentation as you could in a very short amount of time and to get them interested to learn the things that would be helpful in that whole process. And so I went to Al Shepard and suggested that the astronauts ought to take more control of the training program in science with the primary purpose to make it mission-relevant." By the time *Apollo* crews were ready for mission specific training, Schmitt had organized a revised program. He picked geologists who had reputations as enthusiastic teachers to give lectures to the astronauts, and recalled, "My memory is that the astronauts started not only to enjoy the sessions more but also began to see some relevance to them.[91] Schmitt understood a point that the first field trips had illustrated: that as the effort to cross train pilots in geology became more practical, it became more effective. The pilots were more doers than thinkers, and as such they derived more benefit from instruction in specific mission tasks than from trying to learn arcane geological terms in a classroom.

While the astronauts underwent geology training throughout the mid-1960s, MSC engineers also considered how to replicate the lunar surface environment in Houston. By 1963, the engineers had constructed a "Moon Room" in one of the buildings at Ellington Air Force Base. This 20 by 40 foot room contained a floor covered with dark volcanic rock from craters in California and walls painted black. An adjustable light in one corner of the room simulated the Sun. Astronauts donned their

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[91] Phinney, 64-65.

suits and visited this facility so they could test their ability to perform work under projected lunar lighting conditions. By 1964, engineers had constructed an even more useful analog for a lunar environment: an outdoor rock pile 328 feet in diameter, which contained a mock LM set up around two large craters, several smaller craters, and a concrete ridge. Visits to the rock pile gave the suited astronauts a chance to test their ability to climb down the ladder from the LM hatch to the surface, their boots in walking, their bulky gloves in grasping objects, and their hand tools in performing geological work. The plan called for each crew to set up an *Apollo* Lunar Surface Experiments Package (ALSEP), so the astronauts also trained here to set up experiments.[92]

The rock pile became a more high fidelity training tool when the *Ranger*, *Lunar Orbiter*, and *Surveyor* probes returned the first close-up lunar photos. After a *Surveyor* achieved the first landing of an American spacecraft on the Moon in 1966, the vehicle returned photos indicating that the dust was finer grained and the surface was more heavily cratered than previously believed. Geologist Mike McEwen thus planned a revised rock pile containing 188 craters ranging from 3 to 60 feet in diameter and blast furnace slag that could simulate the fine dust. Engineers also constructed large arc lights that would shine during the night to simulate the Sun. By early 1968, astronauts could train on this new moonscape. Uel Clanton, one of the instructors, summarized the value of this tool when he remembered, “That was one of the more popular training areas. We worked it, the astronauts, the people involved in manufacturing and testing the

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[92] Ibid, 35-36.

spacesuits, all worked the rock pile. It was not like the Moon, but it was about as a good a simulation as you could get for the Houston area."[93] When *Apollo* crews moved closer to launch, they could train at yet another high fidelity facility at KSC, dubbed the sand pile.[94]

Despite the presence of these creative outdoor sites, crews spent the bulk of their time training for their lunar surface stays indoors at MSC Building 9. The suited astronauts walked through all of the tasks they planned to perform here, with the instructors observing them to make sure mission planners had developed a realistic timeline. The walkthroughs in Building 9 built the confidence of astronauts, mission planners, and geologists that the *Apollo* missions could meet the lofty expectations placed upon them. "I don't see any way of getting away from that," Armstrong said during his debriefing. "You're going to do a number of those one-G walkthroughs, and you're going to develop your timeline and the procedures. There isn't another way to do it right now that's a good way."[95] Prior to the last *Apollo* mission, Gene Cernan and Jack Schmitt trained in this building for a mission that would include about 22 hours outside their LM. Their mission dwarfed *Apollo 11* in complexity, as it featured three EVAs and a Lunar Rover journey to the base of a mountain, but Schmitt praised the walkthroughs as "extremely useful" just as Armstrong had.[96]

Astronauts on the lunar surface would each experience one condition that these

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[93] Ibid, 36-37.

[94] Ibid, 37-38.

[95] "*Apollo 11* Technical Crew Debriefing," July 31, 1969, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/a11/a11 TechCrewDebrfV1_1.pdf, 24-27 (accessed July 1, 2016).

[96] "*Apollo 17* Technical Crew Debriefing," 17-15.

sessions could not simulate, however: one-sixth gravity. Common sense told them that they would have an easier time working in reduced gravity than zero gravity. If they dropped an object in one-sixth gravity, the object would fall to the ground as it would on Earth. They also would not have to worry about the task of restraining themselves to a spacecraft that had proven so problematic during *Gemini*, because they would be walking (and eventually driving a rover) on solid ground. But the instructors understood that the program would benefit from their desensitizing the astronauts to reduced gravity, and testing their ability to use geologic tools, so crews could feel confident about making the most of each minute of their work. Three methods could simulate this condition on Earth: parabolic flights using the KC-135 aircraft, neutral buoyancy pools, and a harness arrangement that would support five-sixths of a person's weight.[97]

The MSC and USGS geology instructors were the first to simulate lunar gravity aboard the KC-135. A loud buzzer sounded in the aircraft as the pilot flew over the top of a parabola, creating zero gravity for 15 to 20 seconds. But the pilot then changed the shape of the parabola to create one-sixth gravity for another 15 to 20 seconds.[98] During this time, the geology instructors tested the loping gait required to walk and the equipment the astronauts would have with them. Uel Clanton remembered flying about 400 parabolas, probably the most of any instructor. The sessions aboard the KC-135 combined with the sessions on ground training facilities informed the design of *Apollo* suits and equipment. The suit contractors at the ILC Dover company in Frederica,

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[97] Ibid, 38.

[98] David Scott and Alexei Leonov with Christine Toomey, *Two Sides of the Moon: Our Story of the Cold War Space Race* (New York: St. Martin's Press, 2004), 268.

Delaware already had to worry about offering the astronauts protection from the temperatures of lunar daytime, cuts from jagged rocks, and micrometeoroid impacts. But the instructors' experiences maneuvering in one-sixth gravity demonstrated that they also needed to worry about the suit's mobility. An astronaut could not hope to do useful geological work without stooping and bending, so the contractors added rubber joints at the shoulders, elbows, hips, and knees. Clanton also monitored a contract with Martin Marietta in Denver, Colorado for the development of hand tools. If he had trouble bending over to use a drill, for instance, the contractors modified the drill.[99]

Each lunar landing crew then performed hundreds of parabolas prior to their missions and the astronauts generally concluded that this was the best method of simulating one-sixth gravity. Neil Armstrong and Buzz Aldrin both made this argument during their *Apollo 11* debriefing. The two each noted drawbacks of this method, such as the lack of realistic lunar surface characteristics in the KC-135 cabin and the expense required to make just one flight. The lesson from the *Gemini* program, that aircraft flights could only replicate reduced gravity for less than a minute at a time and therefore could not simulate the fatigue that longer tasks created, also still applied. But the flights eliminated the uncertainty about how to maneuver in reduced gravity in all six degrees of freedom, and the astronauts thus considered the training essential. "One-sixth G is relatively easy to operate in," Aldrin said after *Apollo 11,* but this did not stop all future crews from making KC-135 flights of their own.[100] The astronauts of all later lunar

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[99] Phinney, 38-39.

[100] "*Apollo 11* Technical Crew Debriefing," 24-26 and 24-27.

missions made only positive comments about the experience in their debriefings.[101]

The astronauts also trained for this sensation in a neutral buoyancy pool at MSC, where the instructors weighed them down in such a way as to simulate one-sixth gravity. Yet this method did not work nearly as well in training for lunar surface EVAs as it did for EVAs in flight. Lunar surface EVAs would require a motion more like walking, and the drag created by the water meant that astronauts could not adequately replicate this motion in a pool. Ken Mattingly, one of the 19 selected in the class of 1966, wrote a memo the following year in which he described this experience as more like "swimming in scuba than walking in the KC-135 during one-sixth G parabolas." He also commented that the weight placed on his suit "resulted in an uncontrolled center of gravity and moments of inertia."[102] Pete Conrad responded to a question about water immersion training during his *Apollo 12* debriefing by stating, "I think that's a waste of time, and it doesn't do the job."[103] Thus the question remained: how could crews train to maneuver in one-sixth gravity without the limitations of drag in a pool or time in an aircraft?

MSC instructors devised an ingenious answer by hooking astronauts to harnesses that they adjusted to support five-sixths of their weight. The first type of harness was a vertically suspended system, meaning that a suspension system over their heads supported the harnessed astronauts as they moved across a test surface in six degrees of

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[101] "*Apollo 12-17* Technical Crew Debriefings," 1969-1972, *Apollo Lunar Surface Journal*, http:/www.hq.nasa.gov/alsj/frame.html (accessed July 1, 2016).

[102] Phinney, 40.

[103] "*Apollo 12* Technical Crew Debriefing," December 1, 1969, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/a12/a12-techdebrief.pdf, 24-6 (accessed July 1, 2016).

freedom and jumped to heights of 12 feet and more. The second type of harness was an inclined plane, pioneered at the LRC near the LLRF facility. This device contained a suspension system that supported astronauts on their sides in an inclined attitude about 9.5 degrees from horizontal. The harness method had the advantage of simulating movements in all axes over long periods, but contained limitations as well. The system restraints limited the astronauts' maneuverability, forced an unnatural body posture, and provided so much stability that they did not fall as often as they would on the lunar surface.[104] Although no method of simulating one-sixth gravity was perfect, the various devices built the astronauts' confidence in maneuvering on the lunar surface. Alan Bean observed after *Apollo 12*, "I noticed that I got on a nominal walking pace very rapidly once I got on the Moon."[105] Even an alien landscape could breed familiarity for well-trained astronauts, and this was exactly what the entire *Apollo* team wanted given the amount of taxpayer money each minute on the lunar surface would cost. The path to that surface proved arduous, with tragedy mixed in along the way.

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[104] Amos A. Spady, Jr., *Comments on Several Reduced-Gravity Simulators Used for Studying Lunar Self-Locomotive Tasks* (Washington, D.C.: NASA TN D-5802, 1970), 1-11 and Phinney, 40.

[105] "*Apollo 12* Technical Crew Debriefing," 24-7.

CHAPTER VII

APOLLO: “WITH THE HUMAN EYE, IT’S A PIECE OF CAKE”

The NASA team could not set their sights on the Moon immediately. A series of unpiloted flights paved the way for the first flight of *Apollo* astronauts. The plan then called for a three man crew to verify the performance of the spacecraft over up to 14 days in Earth orbit, hopefully in early 1967.[106] Deke Slayton found the choice of who should command this first mission an easy one. Knowing the job that Gus Grissom had done in the development of the *Gemini* spacecraft and in flying the first mission, he picked Grissom to also command the first *Apollo* mission. He also picked two rookies, Donn Eisele and Roger Chaffee, to round out the crew. But Eisele injured his shoulder during a KC-135 flight, placing him behind the training curve, so the nation’s first spacewalker Ed White replaced him.[107]

Excitement reached a crescendo in 1966 for several reasons. Grissom, White, and Chaffee received their introduction as the *Apollo 1* crew, North American delivered their CSM to the Cape, the Command Module Simulator entered operation, and the *Gemini* program came to a triumphant conclusion. The crew proved themselves worthy of the excitement. As North American contractors tested every spacecraft system in Downey, California, Grissom impressed his colleagues with his meticulous approach to monitoring the work. He encouraged his crewmates to share their ideas at any time.

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[106] Brooks, Grimwood, and Swenson, 208-209.

[107] Slayton with Cassutt, 164.

Chaffee also impressed with his willingness to study glitches and even confront contractors on the factory floor with design sketches to solve them. But the crew quickly became frustrated. Their spacecraft suffered from myriad problems, ranging from wiring, to communications, to propulsion, to the environmental system, to the RCS thrusters. Grissom had ideas on how to solve the problems, but could not go to the top of the chain of command and push for design changes as he could at McDonnell during the *Gemini* program.[108] The other source of frustration stemmed from training and taught the *Apollo* team a critical lesson about simulating missions.

By all accounts, the CMS did not meet expectations during its first year of operation. Riley McCafferty is the best authority on this matter, because he served as the project engineer for the simulator. As mentioned previously, the four digital computers were the most important element driving the simulator. But when McCafferty and his team of engineers tried to operate the software on those Digital Data Processor (DDP)-224 computers, "It just wouldn't run all the time; it wouldn't run right." The simulator often stalled with the *Apollo 1* crew inside.[109] Frank Hughes and Stanley Faber have similarly negative recollections of the state of the simulator during the latter months of 1966.[110]

But the greatest frustration with the simulator stemmed from the need to modify it in a timely manner. The need to make sure a simulator kept up with the updates to a spacecraft was not new, but proved much more difficult in *Apollo* than *Mercury* or

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[108] Leopold, 215-219.

[109] Interview with McCafferty, 16-17.

[110] Interview with Hughes and Interview with Faber.

Gemini. Since the CSM contained many more parts than those previous vehicles and testing had revealed numerous problems, the modifications totaled as many as 75 to 100 per week. When these happened, the plan called for a contractor to submit a modification request to a Simulator Control Panel. The request listed the change to the actual spacecraft, the simulator change required to match the spacecraft, the effect on training if the change was not implemented, and the effectiveness of the spacecraft and simulator. The Simulator Control Panel evaluated the request and approved it. The Link contractors supplied more information: how the hardware or software needed to be modified, an estimate of what the requested parts would cost, the man-hours required to implement the modification, and a schedule of all pertinent milestones. This long process meant the spacecraft could undergo changes more quickly than the simulator.[111] During the last months of 1966, Grissom felt the simulator had fallen so far behind the spacecraft that it could not usefully train him. "I always had 150-200 mods outstanding, just not getting to them," Riley McCafferty remembered. "And Grissom would come down and just tear my heart out, you know…I'd be looking at it and I'd say, okay, this change will be so and so and such and such, and by the time I got that change designed…the spacecraft changed again."[112] The need for more time to update the simulator should have provided a lesson for the entire *Apollo* team, but for the time being it did not. The launch date of February 21, 1967 went unchanged.

After the new year began, Grissom expressed his frustration in a way no other

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[111] Woodling, et al., 39-40.

[112] Interview with McCafferty, 16.

astronaut has ever done. On January 22, the *Apollo 1* crew traveled from California to spend time with their families in Texas. Unfortunately their stay only lasted one day, because on January 23 they had to fly to the Cape for a week of launch countdown simulations. But on the morning he left home, Grissom walked into a courtyard and pulled a large Texas lemon from a tree. When he made it to Florida, he hung the lemon on one of the simulators located at the Kennedy Space Center. The moment symbolized the inadequacy of the training sequence. Yet Grissom's increasing disgust did not prompt a reconsideration of that sequence. His spacecraft was waiting for him, sitting atop a *Saturn IB* booster at Launch Pad 34. His crew climbed inside for simulated countdowns throughout the following week, which culminated in a "plugs out" test on Friday, January 27. This would test the ability of the spacecraft to operate on internal power, rather than power supplied by cables, throughout the countdown until T-0. After that, the crew would train for an emergency evacuation from the spacecraft. Grissom, White, and Chaffee looked forward to the end of the day, because they would then return to Houston.[113]

When the crew climbed inside the vehicle that afternoon, none of their colleagues doubted their ability. For almost a year, the three had studied their particular spacecraft as it had evolved in Downey, monitored the exhaustive systems checks, read the discrepancy reports, and had even sat inside the vehicle while suited up in altitude chambers and at the launch pad. Despite the frustration concerning the simulator, the crew had spent enough time inside to know the locations and proper positions of the

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[113] Leopold, 234-235.

more than 400 switches and displays.[114] Of the many books that their fellow astronauts have written, none has argued that Grissom, White, and Chaffee were less than worthy choices to make the first piloted *Apollo* mission. In retrospect, the three should have decided to scrub the test when communications troubles stopped the simulated countdown at T-10 minutes. Some of the test conductors at the Cape argued for this, but to no avail. The crew waited for the hold to end until 6:31 p.m., when Grissom noticed fire spreading underneath his couch. One of his colleagues promptly made a startling transmission: "Fire! We've got a fire in the cockpit!"[115]

In the horrifying seconds that followed, the three men implemented their spacecraft egress training. Rather than panicking, the men recalled what they had been taught to do and set to work in the manner of the experienced test pilots they were. There were no fire extinguishers aboard the vehicle. Grissom instead tried to fight the fire by dumping the cabin pressure. He reached his gloved hand through flames and at least made an effort to activate the valves, according to engineers who examined the cabin afterwards. He also removed the headrest on White's couch so that his crewmate could grab a torque wrench and begin to ratchet open the inner hatch. White did make some progress in retracting the locking bars, with Grissom's assistance, but the hatch did not allow for quick escape. The most difficult job belonged to Chaffee in the right-hand seat. Instinct would have told him to leave a burning spacecraft as soon as possible. Yet he stayed in his seat, as he had been trained, to maintain communications with the

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[114] Brooks, Grimwood, and Swenson, 214.

[115] Leopold, 249-250.

CapCom until his two crewmates could finish opening the hatch. “We’re burning up!” he exclaimed, eighteen seconds after the first report. Those listening at the Cape and Houston heard a brief shout of pain, then only silence. Thick smoke and carbon monoxide had quickly entered the cabin and caused the astronauts to breathe toxic fumes. When Pad Leader Don Babbitt finally opened the hatch at 6:36 and said, “I can’t tell you what I see,” the realization dawned on everybody listening that the crew was dead.[116]

Fifty years later, what lessons do the deaths of Grissom, White, and Chaffee carry? The one consoling lesson is that the crew reacted to the emergency as they had been trained. All accidents involve human limitations in some way, and the ensuing investigation revealed that several limitations applied in this case: frayed wiring prone to electrical arcs, a pure oxygen atmosphere that quickly spread flames, and a hatch that could not be opened in less than 90 seconds. But there is a difference between limitations in terms of design failures and those in terms of operator failures, as when a pilot makes a controlled flight into terrain. The astronauts had trained for spacecraft egress eight times in the past, and did so perfectly while facing death. Thus they do not belong to the statistic cited earlier about direct human error causing a high percentage of accidents.[117] But the tragedy also carried a lesson for the future training of astronauts. The *Apollo* team sought to demonstrate the resolve needed to meet the end of the decade deadline to land men on the Moon, now less than three years away. But an excessive

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[116] Ibid, 250-258.

[117] Barshi and Dempsey, 4.

focus on meeting the deadline would compromise safety. Future crews needed assurance that their simulators had been updated to match their spacecraft. This required engineers to eliminate the sense of "go fever" that had caused the *Apollo 1* launch to be scheduled for February 1967, despite the disappointing state of both the spacecraft and simulator, and take the time to make sure future crews would receive high fidelity training.

As the head of the Simulation Branch at MSC, Stanley Faber remembered well what the gift of time meant for *Apollo*. The fire caused all flights to be delayed until an investigation board could release a report and North American contractors could modify the spacecraft to repeat any future accidents. Personnel in Houston and the Cape thus had the time to improve the simulator without the pressure of more flights. Faber explained, "When we had…the major accident there, the program management…got a little more logical and set a much more logical target date for the launch of the 101 spacecraft (the production number of the CSM that the *Apollo 7* crew rode on the first piloted flight after the fire)…In that break between the fire and the 101 flight, we completed the mandatory portions of the simulator." This included the successful installation of the DDP-224 computers that controlled the simulator.[118] Nothing proved more crucial than this, because the instructors now knew they could place astronauts inside without fear of the simulator stalling and reset it to allow them to train repeatedly for their most critical tasks. "The simulations settled down; the flight software got a lot

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[118] Interview with Faber.

better," confirmed Hughes of the months following the fire.[119] The comments of Faber and Hughes bring to mind Chris Kraft's observation about the significance of the *Apollo 1* tragedy. "I hesitate to say this, but I have to say it," he said decades later. "I don't think that we would have gotten to the Moon in the Sixties if we had not had the fire. That's a terrible thing to say, but I think it is true."[120] The logic behind this observation was that the aftermath of the tragedy gave the *Apollo* team time to reevaluate and improve their work before risking any more lives.

The improvement came not only with the simulations involving astronauts, but also the simulations involving the flight controllers who would have to support them. The sequence of *Apollo* missions devised by Owen Maynard called for two unmanned *Saturn V* test launches over the upcoming year, so the controllers needed training to support the maiden flights of the mightiest rocket ever flown successfully. Dick Koos remembers using the GSSC to simulate *Saturn V* launches. "Not all of the things we wanted to do had been programmed yet," he explains. "But we did have the capability of doing engine outs and creating whifferdills in launch trajectories when we did simulations." The controllers learned the correct responses to any foreseeable malfunctions from the hours they spent in the control center, whether it was to burn an engine longer than planned to compensate for the loss of another engine or even to set off charges to detonate the vehicle if the *Saturn V* veered off target and threatened people below.[121] On November 9, the rocket made its first launch on the *Apollo 4*

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[119] Interview with Hughes.

[120] Leopold, 275.

[121] Author Interview with Koos.

mission. The *Saturn's* 7.5 million pounds of thrust sent a CSM more than 11,000 miles away from Earth, before the spacecraft plunged back to the Pacific Ocean at almost 25,000 miles per hour. This flight proceeded almost flawlessly, but during the *Apollo 6* mission the controllers especially learned the benefit of Koos's simulations. On April 4, 1968, the *Saturn* suffered a severe pogo effect during first stage flight, the loss of two out of five engines during second stage flight, and the failure of its one third stage engine to fire once in Earth orbit.[122]

Despite the disappointing *Apollo 6* flight, Cliff Charlesworth's flight control team delivered an exemplary performance in responding to the glitches. "We simulated two engine outs and that was what happened during the real flight of *Apollo 6*," Koos explains. "The flight controllers had seen that so many times, they knew what to do. They knew to command the *Apollo* spacecraft's Service Propulsion System (SPS) to complete the trajectory (to compensate for the failures of multiple *Saturn* engines). Charlesworth thought the *Saturn* would probably break up, because simulations gave it such a weird trajectory that it wouldn't stay together." But the *Saturn V* survived the real flight intact and vindicated Koos's decision to simulate the engine loss scenario for the controllers ahead of time. "I came in the next day to Charlesworth's office and he said, 'I thought you were back in that sim room all the time (during *Apollo 6*),'" Koos remembers today. "This shows the level of fidelity that the simulations had."[123]

In the meantime, the training of astronauts paused only briefly in the wake of the

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[122] Brooks, Grimwood, and Swenson, 232-233 and 248-249.

[123] Author Interview with Koos.

tragedy. Slayton decided in March 1967 to name Wally Schirra, Donn Eisele, and Walt Cunningham as the crew of *Apollo 7*. This crew would finish the job of their deceased colleagues by taking the CSM on its first piloted flight. These three also discovered what the gift of time meant for them: a much more thorough training regimen than would have been the case without the tragedy. The astronauts spent one hour each weekday performing physical exercise. The process of learning the spacecraft began with systems briefings, as Schirra, Eisele, and Cunningham (as well the backup crew of Tom Stafford, John Young, and Gene Cernan) listened to North American instructors explain every aspect of their ship for five hours every weekday. The sessions were so lengthy because the instructors believed this provided for "maximum retention and learning."[124] Among the most notable briefings covered the possibility of a fire in the spacecraft. In the aftermath of *Apollo 1,* the crew learned from an MSC engineer about the new fire suppression equipment in the CSM. They also reviewed "burn test" films and the procedures they would utilize to egress where Grissom, White, and Chaffee had been unable. Another notable briefing concerned a first in American spaceflight: the use of a television camera to broadcast from a spacecraft.[125] The RCA company provided a slow-scan, black and white camera that the crew learned to operate, and the three went on to win an Emmy for their *Apollo 7* telecasts.[126]

Training entered a new phase in April, as the crew logged their first simulator

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[124] Kohler and Reeder, 3.

[125] Kohler and Reeder, 15 and [*Apollo 7* Training Summary, Box 081-12, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 175 and 63.

[126] Bill Wood, "*Apollo* Television," *Apollo Lunar Surface Journal,* http://www.hq.nasa.gov/alsj/ApolloTV-Acrobat7.pdf (accessed August 31, 2016).

time. Schirra, Eisele, and Cunningham logged hundreds of hours in the CMS over the following year and a half, about one-third of their total training time. The SimSups were so exacting that they logged each malfunction that they threw at the astronauts. They did not expect the astronauts to have all the answers, especially for the glitches they inserted for study purposes. Schirra had to become the guinea pig who responded to the *Saturn IB* colliding with the tower right after liftoff or the first stage of the rocket failing to separate from the upper stage. The SimSups kept a long list of all the problems he solved, watching his prompt and correct responses to everything from fuel cell leaks, to oxygen tank leaks, to computer display failures, to RCS failures, to the main parachute failing to deploy automatically. The list of malfunctions he did not discover totaled only six. Eisele and Cunningham had similarly strong records.[127] Every session took three to four hours out of their days, but after this they often headed from Houston to Downey aboard their T-38 jets.[128] The duration of systems briefings, simulator sessions, and cross country flights confirmed that *Apollo* training would leave less time at home for the astronauts than ever.

The men spent time with families, made hunting and fishing trips, and attended sporting events on weekends, but even this narrow opportunity dwindled as the crew moved closer to flight. The astronauts were aware of the string of troubling news that came prior to the first piloted *Apollo* flight, from the Tet Offensive in Vietnam, to the assassinations of Martin Luther King, Jr. and Bobby Kennedy, to riots in inner cities and

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[127] *Apollo 7* Training Summary, 300-318.

[128] Ibid, 259-290.

universities (some of the astronauts even considered volunteering as pilots in Vietnam after the fire put *Apollo* flights on hold). They were also aware that amid all this troubling news, the NASA budget dwindled in fiscal 1968 to its lowest point in five years. This eventually meant that many astronauts would be denied their trips to the Moon. But they could not fixate on these issues, because training required them to live a largely sheltered existence in Houston, Downey, and the Cape. Nobody put it better than Cernan in his memoir: “The immense and growing pressures for us to succeed left little time to read a newspaper or listen to a television news broadcast. Bedtime reading was a mission plan. Stealing time to see our families on a weekend made us feel like thieves.”[129]

Yet the trips to Downey proved useful in continuing a paradigm that began in *Mercury*: providing astronaut input into spacecraft design. Beginning in May 1967, Schirra, Eisele, and Cunningham regularly observed a North American contractor team that looked far different than it did before the tragedy. The team had replaced flammable materials in the cabin, implemented an oxygen/nitrogen atmosphere when the spacecraft was on the launch pad instead of pure oxygen, and redesigned the hatch so that astronauts could exit in five seconds. Besides eliminating the conditions that had led to the fire, the team improved its overall attention to detail just as the investigation board had recommended. Contractors supervised subcontractors more closely with an eye toward receiving components on time. A Configuration Control Board had been formed to approve proposed changes to the CSM, so that manufacture of the ships could

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[129] Cernan with Davis, 171-172.

proceed in a more orderly manner. A Crew Safety Review Board had also been formed to evaluate the ships from an astronaut's point of view.[130]

But the team at Downey also entrusted the *Apollo 7* prime, backup, and support crews to support them. The astronauts combined to spend several hundred hours there, so they could attend major systems tests and climb inside the spacecraft cockpit. The most critical occasion to sit inside came when the engineers placed the vehicle in an altitude chamber that could reproduce most of the hostile conditions of space. The time spent in Downey proved worthwhile, because it allowed the astronauts to make suggestions for improvement. For instance, John Young wrote a report in which he praised the crew checklist but also argued that computers, inverters, pumps, fans, and radios operated longer than necessary. Reports also circulated that water from the environmental control system leaked on the cabin floor, some headsets did not work well, and the quality of the drinking water suffered from chlorination. These reports were hardly surprising for such a new and sophisticated spacecraft, but the important change from before the fire was that engineers at North American Rockwell (the company had merged with Rockwell Standard in September 1967) valued astronaut input and had an orderly process by which to heed suggestions concerning such inadequacies. The astronauts also shared their messages with their peers by circulating reports and attending weekly pilots' meetings. Young concluded his report with the opinion "that S/C 101 is a pretty clean machine," a far cry from the vehicle in which

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[130] W. David Compton, *Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions* (Washington, D.C.: NASA SP-4214, 1989), 113.

Grissom, White, and Chaffee had died. North American Rockwell cleared up the 13 problem areas that a customer acceptance review had revealed and shipped the spacecraft to Cape Kennedy on May 30, 1968.[131]

After this, the astronauts' travels took them far beyond Downey. The crew went to Morehead Planetarium in North Carolina and the Griffith Planetarium in California to observe and learn all of the stars they would sight to align the CSM guidance computer.[132] Another trip concerned the end of the mission, as the crew needed to prepare for their egress from the spacecraft and ocean recovery. Schirra, Eisele, and Cunningham practiced egress in an MSC water tank in August, then traveled to the Gulf of Mexico for a higher fidelity egress simulation a few days later.[133] The first question they wanted to answer concerned their ability to right the ship if it flipped over after splashdown into a nose down position. These three and their peers found they could quickly reach the switch that signaled air bags to inflate and bring the vehicle right side up. The astronauts also prepared for an emergency wait of up to 48 hours for their recovery. Although some of their *Mercury* and *Gemini* predecessors had become seasick while their ships bobbed in the ocean, the first *Apollo* astronauts to go to the Gulf found they could remain healthy for that entire wait. They did this by relying on a three man life raft with sun bonnets, water, a first aid kit, two desalting kits, a beacon for communications, and a dye marker with which to mark their position. If water splashed into the spacecraft, they could use the urine collection hose to vacuum the water and

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[131] Brooks, Grimwood, and Swenson, 263-265.

[132] Ibid.

[133] *Apollo 7* Training Summary, 267-275 and 41-47.

dump it overboard. After the simulations, a Billy Pugh net lifted the astronauts from their life raft to a helicopter circling overhead.[134]

In August and September, the crew made it to the Cape for emergency evacuation training. The newly redesigned hatch allowed Schirra, Eisele, and Cunningham to escape from the vehicle in five seconds in case of an *Apollo 1*-like emergency. This fact and the evacuation drills the crew undertook at the Cape made a repeat of the tragedy highly unlikely. But what if a catastrophe forced them to leave the entire pad immediately? The primary method of doing this was to scramble across the *Saturn IB* swing arm, climb into the elevator, and descend the 218 feet from the crew access level to the ground. This would take about half a minute. If the crew needed a faster escape method, they could scramble into baskets that could take them via slide wires to a bunker over 1,000 feet away. If a *Saturn IB* explosion threatened them, the astronauts would have no time to think, only time to implement the correct procedure. Thus Schirra, Eisele, and Cunningham placed their knowledge to the test at their launch site (Pad 34). They could take comfort in the knowledge that since the fire, the pad featured structural improvements, improved firefighting equipment, and improved access to the spacecraft and escape routes.[135]

During the few weeks remaining before launch, the crew stayed in the loop for the most critical decisions affecting the flight. The three men suited up and climbed inside their spacecraft for a countdown demonstration test on September 17. After

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[134] Shayler, *Space Rescue*, 308 and Brooks, Grimwood, and Swenson, 213.

[135] Shayler, *Space Rescue*, 93 and *Apollo 7* Training Summary, 21-29.

returning to Houston, they shared their input concerning the spacecraft, the *Saturn IB*, the launch pad, Mission Control, and their training at an October 3 Flight Readiness Review.[136] Occasions such as these illustrated that the job of astronaut still involved much more than climbing inside a cockpit and flipping switches. Engineers at NASA and North American Rockwell valued their opinions on technical issues. Thus this crew had spent the past year and a half not only preparing for spaceflight, but also participating in design reviews of their vehicle, the development of the checklist they would follow, and the development of the flight rules they would follow. On the morning of October 11, the time had come for Schirra, Eisele, and Cunningham to finally place the memory of the fire to rest and demonstrate what a well-trained trio of astronauts could accomplish.

The *Apollo 7* crew indicated the value of training through the teamwork they exercised during eleven days in orbit. Whereas *Gemini* missions had only required two astronauts to work together, this one required three. These three were highly diverse. Schirra was a naval aviator who had flown in space twice before and viewed *Apollo 7* as a test flight of the spacecraft. He believed that any exotic scientific experiments would only detract from that goal. Eisele was an Air Force aviator who had not flown in space before. Cunningham was a civilian who had not flown either, but had worked for the RAND Corporation while pursuing a doctorate in physics. But after their simulator hours, the three learned each other's strengths and proved compatible when placed to the ultimate test. The two younger astronauts confirmed this in recalling the flight. Eisele

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[136] *Apollo 7* Training Summary, 7-17.

explained, referring to Schirra, “We both checked each other and we did it on a simulator. One or the other would start to do something, start the wrong way or forget to do it when you should, and we’ve always just kind of overlapped each other that way.”[137] Cunningham explained, “We could do the job regardless of who we were flying with. Nobody did any psychological evaluations before they put us together. The media thought that somehow there was some big fancy selection process that matched crews psychologically. We didn’t have time for that nonsense.”[138] The duration and intensity of the training sequence made crew compatibility in flight a realistic possibility.

The most important phase of the flight came during the first two days, when the crew rendezvoused with their *Saturn IB* upper stage. Right after insertion into orbit, the spacecraft separated from the *Saturn IB* upper stage and Schirra fired the RCS thrusters to move back toward it. This was not an especially easy task for Schirra, because he was used to flying sleek fighter planes as a naval aviator. The control stick felt differently in his hands while flying the CSM, because “*Apollo* was a big, unwieldy vehicle, like flying a big transport plane, which fighter pilots don’t really revere.” But like all skilled test pilots who trained extensively on simulators, his senses were attuned to the movement of the vehicle. This allowed him to pulse the thrusters while staying in plane with the rocket stage, until his ship was just four feet away from it. He had just simulated one of the most critical maneuvers in a voyage to the Moon: the CSM extracting the LM from its housing in a spent rocket stage and then docking with it.

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[137] Burgess and French, 220.
[138] Ibid, 185.

Without this, a Moon landing could not happen.[139]

The crew then moved into a slightly different orbit than the rocket and tested their ability to make a rendezvous using the large SPS engine at the back of their ship. The SPS fired successfully, as it did eight times during the mission, which gave engineers confidence that it could send future astronauts into and out of lunar orbit. But the crew needed to place their training to the test as well. The long hours in the simulator proved useful when the crew activated the proper program in their guidance computer and computed the maneuver that would be needed to reach the rocket in just a few minutes. The three men thus proved they could compute the maneuver onboard just as the flight controllers could from the ground. They also proved they could take corrective action in case their judgments disagreed with the computer. The computer sent a signal to place the spacecraft in an attitude about 10 degrees out of plane in yaw. Schirra considered this excessive, so he reduced the yaw angle by about a half before the computer executed the Terminal Phase Initiation program that would send them to a rendezvous. Meanwhile, Eisele used a sextant to track the target as his ship moved toward it. About 30 hours into the flight, the crew had made a safe rendezvous within their propellant limits. From a training standpoint, the point here was that a skilled crew offered benefits to a mission beyond that of an unmanned mission. The *Apollo 7* crew had demonstrated this by making corrective movements in attitude and translation and tracking their target. As in *Mercury* and *Gemini*, launching a crew highly trained in

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[139] Ibid, 211-213.

these actions increased the chances of mission success.[140]

As the eleven days continued, Schirra, Eisele, and Cunningham continued to prove the benefits of their presence. When the astronauts carried out their tests of the environmental, electrical, thermal control, and guidance systems, they did what no purely automated vehicle could do: observe the tests with trained eyes and provide detailed verbal feedback, both at the time and in postflight debriefings. For instance, Eisele navigated the spacecraft by making star sightings. He found this more difficult than expected, because wastewater dumps produced frost particles that made star identification difficult and the Earth's horizon was too indistinct an object with which to gauge the star sightings. But he still learned what he could accomplish and offered suggestions for future improvement. The crew's presence was also useful because the tracking stations on the ground did not allow flight controllers continuous contact with them. "It was the first time that we ever had this spacecraft up and we were in contact with the ground 5 percent of the time," Cunningham pointed out.[141] This left the crew often on their own in solving problems; although there were no major ones, they could notice easily correctable ones like moisture forming on coolant lines and fuel cells with high temperatures. Schirra also praised Eisele in recalling, "He saved the computer a couple of times, when the ground screwed it up. One time the computer went down, he fixed it between ground stations. I love that!"[142] When historians write about *Apollo 7*,

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[140] *Apollo* Mission Evaluation Team, *Apollo Program Mission Report, Apollo 7* (Houston, TX: MSC-PA-R-68-15, 1968), 6-2 to 6-3.

[141] Burgess and French, 213-214.

[142] Ibid, 220.

they usually fixate on the crew's ill-tempered interactions with Mission Control. But far more important is that Schirra, Eisele, and Cunningham splashed down on October 22 having proven the value of the human element in an *Apollo* spacecraft.

This came just in time for one of the boldest actions in the history of spaceflight. The original plan called for Jim McDivitt, Dave Scott, and Rusty Schweickart to fly *Apollo 8*, during which they would become the first crew to test the Lunar Module in space. Frank Borman, Mike Collins, and Bill Anders would then become the first crew to ride the *Saturn V*, ascend to an altitude of four thousand miles, and test the LM again. Collins learned in July 1968 that he needed neck surgery, so Jim Lovell replaced him on this crew.[143] But the technical hurdles of preparing the LM to fly by the end of 1968 proved too much to overcome. When the Grumman team shipped McDivitt's LM to the Cape that summer, inspectors had found over 100 defects. It quickly became clear that if *Apollo 8* was going to fly by the end of the year, it would have to do so without a LM. What could the *Apollo 8* crew do with only a CSM at their disposal? As manager of the *Apollo* Spacecraft Program Office, George Low had a courageous answer: fly nearly a quarter million miles from Earth to the Moon, make ten lunar orbits, and return. This would give the *Apollo* team experience in navigating to the Moon and back, firing the SPS engine to send a spacecraft into and out of lunar orbit, and sending it back to Earth to reenter the atmosphere at over 24,000 miles per hour. By 1969, the LM would hopefully be ready to land another crew on the Moon. Low decided to tout this idea in early August and quickly won the acceptance of the highest NASA officials from

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[143] Collins, 268-290.

Houston, Huntsville, the Cape, and Washington D.C. A December launch date to send *Apollo 8* to the Moon appeared feasible from a hardware standpoint, all of these people believed, but could a crew adequately train for this challenge in time?[144]

The answer was yes, although with a change of plans in store. When the conversations began, Deke Slayton immediately thought a crew could be ready by December. But he knew that of the upcoming crews, McDivitt, Scott, and Schweickart had the greatest familiarity with the LM and there would be no LM on *Apollo 8*. Thus he called McDivitt into his office on August 10 and explained that he wanted him to stick with the LM mission he had been training for, which would now become *Apollo 9*. McDivitt agreed, which cleared the way for Borman to accept the *Apollo 8* mission instead two days later. The first astronauts to voyage to the Moon would be Borman, Lovell, and Anders, if all went according to plan.[145] The three men had already spent about one year logging a tremendous amount of simulator time, meaning neither they nor Slayton had concerns about their knowledge of the CSM. But the new mission required the three to attend a new series of briefings while also preparing for new maneuvers in the simulator in just four months. The speedy pace stands in stark contrast to the training of astronauts in the nearly fifty years since.

Borman, Lovell, and Anders could not have met the December deadline alone. The first key to their training was to develop a flight plan, which required the best minds in Kraft's Flight Operations branch to design the mission. These people met in Kraft's

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[144] Chaikin, 56-59 and Brooks, Grimwood, and Swenson, 256-260.

[145] Slayton with Cassutt, 214-216.

office on August 19 and determined the basic details: the *Saturn V* would launch on December 21, sending the spacecraft to a 66-hour voyage to the Moon. The vehicle would slip in front of the Moon's leading edge and, after an SPS engine burn, move into orbit at an altitude of 69 miles. The vehicle would make 10 orbits over 20 hours, then the engine would hopefully fire again to take the crew to a December 27 splashdown.[146] The flight operations personnel quickly gave the crew a flight plan which detailed every action they would have to take, from sleeping, to eating, to housekeeping chores, to star sightings, to engine firings, to the unprecedented observations of the Moon. Meanwhile, support crew astronauts Ken Mattingly, Jerry Carr, and Vance Brand coordinated the checklists that the prime crew would follow and worked out the details of spacecraft stowage. With all of this in place, the instructors set to work reproducing the mission on the simulator at the Cape. The software specialists reconfigured the simulator computers, while the SimSups devised new malfunctions by which to test the crew. This teamwork allowed Borman, Lovell, and Anders to begin simulations for their new mission on September 9.[147]

No crew had ever trained as relentlessly as these three did over the next three months. They spent 10 hours a day in the simulator, six days a week. Even aside from this, they flew their T-38 jets from the Cape to Houston for meetings. The workload proved so strenuous that they did not have time for as much physical conditioning as

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[146] Chaikin, 68-71.

[147] *Apollo* Mission Evaluation Team, *Apollo Program Mission Report, Apollo 8* (Houston, TX: MSC-PA-R-69-1, 1969), 7-15.

they would have liked.[148] Yet all crew members agreed that the time proved worthwhile. Borman noted at the mission debriefing that the crew did not need to spend nearly as much time with the actual spacecraft as their predecessors, because the money poured into the simulator made it the primary learning tool. "The visual was a problem throughout most of our training cycle but, nevertheless, the CMS was adequate for providing the proper training," he argued. "The instructors here in Houston and at the Cape were good."[149]

Those instructors subjected the crew to a series of malfunctions broken into stages: launch, translunar injection, midcourse corrections, lunar orbit insertion, transearth injection, reentry, and splashdown.[150] If Borman noticed that he had lost one of his ship's fuel cells during the coast to the Moon, for instance, he would have to remember the mission rule and call off the insertion into lunar orbit. For some malfunctions, he could go around the Moon instead and return to Earth on a free return trajectory (where the spacecraft utilizes the gravity of the Moon as a slingshot effect to return it to Earth without its own propulsion). For others, he would have to fire the SPS engine to turn around and come home. In still other cases, he might notice a malfunction after his ship had passed around the far side of the Moon and out of radio contact with Earth. In this case, he would have no immediate help from Mission Control and would have to "initiate such inflight action as he deems essential for crew safety." One

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[148] Ibid.

[149] "*Apollo 8* Technical Crew Debriefing," January 2, 1969, *The Public's Library and Digital Archive*, http://www.ibiblio.org/ apollo/Documents/Apollo8-TechnicalDebriefing-Martin-1.pdf135, 135 (accessed September 5, 2016).

[150] Author Interview with Koos.

situation he did not have to face in simulations was a catastrophic engine failure that left his crew stranded in lunar orbit. Although the SimSups knew this was a realistic possibility, this would not have been a helpful simulation. The astronauts only faced emergencies they could solve through the knowledge and moxie they gained during those 10 hour workdays.[151]

The crew spent several days studying the Moon as well. No human had ever seen the Moon from 69 miles away, which meant the three men had the potential to contribute to lunar geology through their words and photos. They could also determine if certain sites were suitable landing areas for future *Apollo* crews. This prompted them to "schedule as much refresher and supplemental training in lunar geology as the test-flight nature of *Apollo 8* would allow," and indeed their training summary shows over a dozen days devoted to these sessions. Anders had the primary responsibility for taking photos, so he attended the most sessions. When December arrived, he had a "critical item checklist" of landmarks to find and the geological knowledge to describe them intelligently. Five *Lunar Orbiter* spacecraft had already returned thousands of photos, so the astronauts studied them but also looked forward to the much higher quality photos they would take.[152] On December 10, the three flew to the Cape for the last time and isolated themselves in their crew quarters. This limited their exposure to people who might carry illnesses. After several simulator sessions, briefings on their spacecraft and

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[151] "*Apollo 8* Final Flight Mission Rules," December 15, 1968, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/ a410/ A08MissRules.pdf (accessed September 5, 2016).

[152] NASA Manned Spacecraft Center, *Analysis of Apollo 8: Photography and Visual Observations* (Houston, TX: NASA SP-201, 1969), 1 and [*Apollo 8* Training Summary, Box 081-13, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 46-68.

Saturn V, and jogs on the beach, Borman, Lovell, and Anders were ready for the Moon.[153]

All three believed that the first voyage of humans to the Moon matched their training to a high degree, although their trip did provide lessons learned for future crews. When the *Saturn V* first stage engines ignited on the morning of December 21, the astronauts felt a greater degree of noise and especially motion than they had in the DCPS. Their dominant sensation was of the sudden movements of the vehicle that jerked them side to side in their harnesses. Anders briefly felt that he would be catapulted against the instrument panel, while thinking that the simulations had not prepared him for the violence of this ride. The three also felt the noise from the engines increase in their headsets. They heard the "tower clear" call, but could not communicate for about 35 seconds thereafter. If the CapCom had called for an abort, the crew would not have heard him.[154] Thus the first launch of humans on the *Saturn V* strongly suggested the need for more realistic simulations. The more that future astronauts would feel prepared for the noise and motion of the experience, the less prone they would be to make a mistake. Borman mentioned the shortcomings of his launch training in the mission debriefing and paved the way for future crews to receive more realistic simulations.[155]

The outbound voyage matched the simulations much more closely. Just short of three hours after launch, the single third stage engine fired to send the spacecraft beyond

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[153] Chaikin, 78-79.

[154] Chaikin, 86 and *Apollo 8* Mission Report, 7-16.

[155] "*Apollo 8* Technical Crew Debriefing," 135.

Earth orbit. This translunar injection burn did feel like the simulator, because the engine only pushed the men back in their couches with slightly more than 1 G and all felt comfortable taking on their roles they had rehearsed so heavily. Borman fixed his eyes on the "8-ball" attitude indicator and grabbed the hand controller in case he needed to manually control the rocket's steering. Lovell looked at the computer readout and called out the increasing speed. Anders fixed his eyes on the health of the fuel tanks. The presence of three skilled crewmembers ready to respond to any malfunction indicated the flexibility of a human mission to the Moon rather than a completely automated one.[156] For the next three days, Lovell managed to make 27 sets of star sightings. Because he encountered many of the same difficulties as his predecessors, his simulator time was an asset without which he may not have been successful. "When the sextant optics were working, we were able to develop techniques that were required in flight," he said of his preparation. Sure enough, on the way to the Moon he measured the angle between stars and the Earth's horizon within a few thousandths of a degree of perfection. Shortly after midnight on Christmas Eve, the SPS engine came to life to slow down the ship enough that it could enter orbit around the Moon. Anders went to work taking photos, while Lovell took navigation sightings on landmarks. The simulator could not prepare Lovell for landmark tracking, he lamented. This task proved especially difficult when he was on the far side, the side that always faces away from Earth, because maps of that side were very uncertain. Yet like the explorer he was, he eventually managed to locate his

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[156] Chaikin, 89.

assigned landmarks.[157]

But the larger issue with *Apollo 8* concerns the question of why it was worthwhile to have a trained crew observe it from 69 miles high. Why had these three sat in geology lectures since 1963, and then made a frenzied push to learn about the Moon over the last few months? Why not just continue sending probes like the *Rangers, Lunar Orbiters,* and *Surveyors* that had already returned photos of the Moon? The first reason was the power of the human eye. The human eye possessed a dynamic range and ability to discriminate colors that no camera could match. The three men had an average eye resolution of about 100 feet from their altitude and could also use a telescope that magnified objects ten times. The second reason was the power of the human mind. Thanks to the understanding of geology they had received through training, the men could look at a mountain, valley, or crater and make an assessment of its importance. If a feature looked surprising, for instance, they could make an immediate judgment to follow up with more study. They could also use words to describe these features to scientists back on Earth. Because Borman, Lovell, and Anders could do this, their ability surpassed an automated vehicle that simply carried out preprogrammed instructions. Even aside from this, *Apollo 8* photos contained a resolution one to four times better than *Lunar Orbiter* photos.[158]

The results from *Apollo 8* reinforced these points. Although frustrated by the smears that covered three of their five windows, the crew achieved about 90 percent of

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[157] *Apollo 8* Mission Report, 7-17 to 7-19 and "*Apollo 8* Technical Crew Debriefing," 136.

[158] NASA Manned Spacecraft Center, *Analysis of Apollo 8: Photography and Visual Observations*, 1 and 13.

their photographic objectives while also describing their visual observations in just 20 hours. The astronauts' eyes told them that the smooth maria in the southern Sea of Tranquility, where a future crew planned to land, contained numerous craters but did not pose any showstoppers for a landing vehicle. The men did see many more craters than expected based on *Lunar Orbiter* photos, so they made the judgment to follow up on this unexpected development by studying their colors, textures, and possible origins, and even naming several of them. Since debate still swirled in this era about how the Moon and its craters had formed, this work made a step toward providing scientists with data that would take the debate in one direction or another. Several of the Moon's features reminded them of the sites on Earth they had studied during training, especially in the western United States where vegetation was so scarce, indicating that their geological preparation there had assisted them in their efforts to help these scientists. After taking their legendary Earthrise photo and reading from the Book of Genesis for about one billion television viewers, the astronauts returned to a safe splashdown on December 27. Their mission was still not over, because their spacecraft had just become the first to return photos and film of the Moon to Earth (which permitted more uniform processing and a better dynamic range than images transmitted by unmanned vehicles) and scientists went to work writing essays about their findings. *Apollo 8* thus showed that there were compelling reasons to send people to study the Moon at close range. The more training these people received, the more compelling those reasons became.[159]

But as 1969 began, one question still needed an answer: could the LM take a

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[159] Ibid, 1-7.

crew to the lunar surface? Of all major *Apollo* components, the LM had proven to be the most innovative and the most plagued by problems in manufacturing. Grumman engineers had grappled with propulsion system leaks, engine instability, stress corrosion, cracked batteries, and even ruptured tanks.[160] Even when it had flown on the unmanned *Apollo 5* mission in January 1968, a programming error resulted in the guidance computer aborting a descent engine burn. The plan now called for *Apollo 9* astronauts Jim McDivitt and Rusty Schweickart to climb inside a LM while in Earth orbit, separate from Scott in the CSM, and make the first piloted test flight of this ungainly ship containing walls one-eighth of an inch thick. The two men knew that the ship contained no heat shield and therefore they would not be able to return to Earth if they could not redock with the CSM. What was the best way to prepare for such a hazardous mission, more so from a hardware point of view than even *Apollo 8*?

The best way was to meet the contractors entrusted with developing that hardware on which their lives would depend and monitor their progress. McDivitt and Schweickart learned of their assignment to fly aboard the LM in 1966. Since then, they had made regular visits to the Grumman plant as engineers assembled their ship (LM-3) and then tested its systems as astronauts operated the controls in the cockpit. The contractors even set up trailers in the parking lot near the Assembly and Test clean room so the astronauts could live on site. This meant that if McDivitt and Schweickart questioned any aspect of the LM design, they could easily ask or argue with the engineers who had built it. They could also observe firsthand any issues that arose

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[160] Kelly, 126-144.

during testing that might endanger their flight. Tom Kelly, the chief engineer for the LM, expressed his admiration for the dedication of the *Apollo 9* crew in understanding the vehicle. "Their curiosity, persistence, and endurance knew no bounds," he wrote.[161] This reflected the test pilot's classic mentality to not simply climb aboard a vehicle, but to understand it before flight so as to evaluate it as thoroughly as possible. McDivitt and Schweickart were in the astronaut corps because they had backgrounds as pilots who did just that, and their long flights from Texas to New York in advance of *Apollo 9* allowed them to continue that tradition.

The simulations for *Apollo 9* were the most complex in the brief history of spaceflight, because for the first time astronauts would be flying in two vehicles. Riley McCafferty is once again the best source in explaining the difficulty of readying both the CMS and LMS to support *Apollo 9* training. The LMS was supporting a crew for the first time, meaning the engineers who worked under McCafferty's leadership especially struggled in solving the problems with this machine. The software specialists needed to prove the simulator computers could support complex maneuvers, while the hardware specialists needed to prove they could modify the simulator to keep it consistent with LM-3. On top of that, the engineers needed to wire both simulators to allow radio communication from Houston to the Command Module, from Houston to the Lunar Module, and from the Command Module to the Lunar Module. "I guess my whole crew, during that period of time, averaged 50-55 hours a week across the board," McCafferty recalled. But he also argued, "Nobody really made mistakes because they got tired, or

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[161] Kelly, 196-198.

made mistakes because they'd been working so long. They stayed keyed up all the time." Yet he estimated that the crew lost two hours of simulator time per week due to technical difficulties during January and February 1969 and wanted to avoid repeating this for any future crews.[162]

The value of the simulators was at a premium by this point, because each new flight contained new maneuvers that no previous crew had accomplished. The *Apollo 9* crew needed to not only repeat the training that their predecessors had already received in launch, navigation, troubleshooting of systems, reentry, and splashdown, but also become trailblazers in two new tasks. After launch, the CSM *Gumdrop* (crews named their ships for the rest of *Apollo*) would separate from the third stage of the *Saturn V* and move back around toward the LM *Spider*, nestled inside the rocket. David Scott would grab the hand controller and guide his ship to a docking with *Spider*. A tunnel linked the two ships together, so the crew could move back and forth between them. All three men also trained for the first rendezvous of two spacecraft both containing astronauts. McDivitt and Schweickart would fly *Spider* to just over 100 miles away from Scott in *Gumdrop*, to a point below and behind it, then perform a series of maneuvers that moved the ship's trajectory progressively higher and to the front of their target. With *Gumdrop* growing larger and larger in their windows, the two men would slow their relative motion with it until hearing the clang of their ship's drogue engaging with *Gumdrop's* probe.[163]

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[162] Interview with McCafferty, 2-3.

[163] Interview with Hughes.

But as with all aspects of *Apollo*, simulating the desired outcome was only the first step in preparing for a mission. The men also simulated situations where *Spider* could not make these maneuvers. If *Spider* could not do so within a minute of when it was scheduled, Scott would have to rescue his crewmates using *Gumdrop* propulsion. During the daytime portion of an orbit, he could clearly see the target he needed to chase. But he also took part in nighttime simulations, when he could only see a flashing light to assist him. Other simulations covered the possibility of the two ships being unable to dock with each other. The lives of McDivitt and Schweickart would then depend on their ability to make an EVA in just forty-five minutes to rejoin Scott, so the two practiced donning their suits and making the transfer. Finally, Scott took part in emergencies where he had to leave his crewmates behind and return to Earth alone. This required him to quickly switch between the three seats, dividing his attention between all sides of the instrument panel, before settling into the left-hand seat for reentry and splashdown.[164]

While admitting their frustration with the simulator breakdowns, the crew considered the last two months of their training the most beneficial because of the integrated simulations they were able to perform.[165] The sessions were as high fidelity as possible, because they included flight controllers, tracking station personnel, and contractors who had built the hardware in two rooms across the hall from Mission Control: the Spacecraft Analysis Room (SPAN) and Mission Evaluation Room (MER).

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[164] Scott and Leonov with Toomey, 216-218.

[165] *Apollo* Mission Evaluation Team, *Apollo Program Mission Report, Apollo 9* (Houston, TX: MSC-PA-R-69-2, 1969), 10-2.

From SPAN, chief engineer Tom Kelly saw data from *Spider* and tried to gather as many experts as possible to solve life threatening malfunctions. When he had received enough advice, he made Grumman's official recommendation to the senior NASA person in the room. Given that two astronauts would have to depend for the first time on arguably the most hazardous component in the whole program, the people who had lived with the hardware for the past several years had become vital and needed this training in real-time problem solving. Kelly believed that by the last integrated simulation in mid-February, he belonged to "a finely honed mission support team."[166]

The *Apollo 9* flight plan also called for Schweickart to step outside *Spider* and make an EVA. He would wear a backpack attached to his suit called the Portable Life Support System (PLSS), which would protect astronauts on the lunar surface. But since this backpack was a complex unit that provided oxygen, water, and radio communications, Schweickart planned to test it before the *Apollo 11* crew went to the Sea of Tranquility. Whereas Buzz Aldrin had trained for the last *Gemini* EVA at a pool in Baltimore, Schweickart became the first to train for an EVA at a pool in Houston called the Water Immersion Facility (WIF). Engineers moved this pool from Ellington Air Force Base to Building 5 at MSC and equipped it with external viewing ports, a decompression chamber, a ladder, a hoist, lighting, and heating. When NASA had hired six scuba personnel needed for operations, the pool opened in June 1967.[167] Schweickart spent 12.5 hours in this facility, which prepared him to follow a timeline while

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[166] Kelly, 201-202.

[167] Neufeld and Charles, 156.

maneuvering from a LM mockup to a CSM mockup, and do so while minimizing fatigue. He also made 71 parabolas aboard the KC-135 aircraft so he could feel true weightlessness prior to launch. He tested the PLSS backpack in a vacuum chamber as well, so he could feel assured that it would protect him during his mission. Finally, in February after he had accomplished all this, he took part in a one-G simulation of the EVA. His thorough preparation illustrated that the space agency had quickly cast aside the unrealistic training methods and expectations that had characterized most of the *Gemini* EVAs. The underwater method pioneered at a little known company in Maryland had become fully incorporated at a federal government agency, where it has remained ever since.[168]

The *Apollo 9* flight succeeded as well as the most optimistic person could ever have hoped, and once again the crew provided reminders of what trained astronauts could accomplish to solve problems. After liftoff on March 3, Scott tried to align *Gumdrop* with *Spider* for docking but found that he had lost translation capability to the left. The crew needed to know enough to discover that propellant valves were closed. After opening them, Scott guided *Gumdrop* to a gentle docking and terminated all motion between the two ships in just ten seconds. When McDivitt and Schweickart floated across the tunnel into *Spider*, they could put their test pilot skills to work on a new machine. They reported on the smooth firing of the descent engine when docked with *Gumdrop*, an experiment which would unexpectedly prove useful when the lives of

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[168] *Apollo* Mission Evaluation Team, *Apollo Program Mission Report, Apollo 9* (Houston, TX: MSC-PA-R-69-2, 1969), 4-2 to 4-3.

the *Apollo 13* crew depended on it. The most critical moment came during day five, when *Spider* undocked and flew free of *Gumdrop*. Scott visually inspected the ship carrying his two crewmates and found the landing gear had fully extended. McDivitt and Schweickart grappled with roughness during the manual throttle-up of their engine, a guidance system that caused over control of the vehicle, and a computer that incorrectly calculated the maneuver to send them back to *Gumdrop*. Yet as they had been trained, the astronauts reported on the first two issues and solved the third by retargeting the computer. The two men jettisoned their descent stage, thrusted their ascent stage toward *Gumdrop*, achieved radar lock, and rejoined Scott after six hours away. Given the groundbreaking nature of this flight and the complexity of the hardware involved, the need for problem solving came as no surprise. Because these test pilots were there to respond and describe, future crews benefited from them.[169]

When the *Apollo 9* crew splashed down on March 13, only one hurdle remained before the first Moon landing. Tom Stafford, John Young, and Gene Cernan now planned to take the CSM *Charlie Brown* and the LM *Snoopy* to lunar orbit on the *Apollo 10* mission. The first astronauts to fly the LM above the Moon would be Stafford and Cernan, but they would descend to only about 47,000 feet before flying back to rejoin Young. This crew provided a useful case study in the training of experienced astronauts. The three men had five *Gemini* flights between them and they had already served as the *Apollo 7* backup crew. Not only had they logged hundreds of hours on *Gemini* and *Apollo* simulators, they also had the camaraderie of having worked together for years.

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[169] Ibid, 10-2 to 10-28.

While deficient interpersonal communication has factored into several aircraft accidents over the years, this crew made that possibility very unlikely.[170] The experience also allowed for them to streamline their training. These astronauts could do away with planetarium visits, centrifuge runs, and spacecraft fire briefings. They also halted major simulation activity two weeks before their May launch, so they could relax and focus on physical conditioning at the Cape. Stafford, Young, and Cernan all felt this approach placed them in a desirable physical and mental state before going to the Moon.[171] "We weren't starting at the bottom with these fellows, we were starting midway or 30 percent of the way up the ladder," Riley McCafferty explained. "The crews were progressively getting in better shape as we flew. *Apollo 10* was in better shape than *Apollo 9*, *Apollo 9* in better shape than *8*, right on down the line."[172]

Training for this mission made especially clear that the idea of integrated simulations had gathered tremendous momentum as the best way to prepare for flights with two piloted vehicles. When Stafford and Cernan flew free in *Snoopy*, they would need to coordinate their actions with Young and Mission Control in achieving a lunar orbit rendezvous with *Charlie Brown*. How could the men manage this task without being able to see each other? Stafford and Cernan were adamant that the only effective way to prepare for this was to work together in separate simulators while also hearing the CapCom in their headsets. Stafford called a flight with two different vehicles "a

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[170] Chaikin, 152-153.

[171] *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 10* (Houston, TX: MSC-00126, 1969), 9-1 and "*Apollo 10* Technical Crew Debriefing," June 2, 1969, *Apollo Flight Journal*, http://www.history.nasa.gov/ap10fj/pdf/a10-tech -tech-crew-debrief.pdf, 20-1 to 20-15 (accessed September 14, 2016).

[172] Interview with McCafferty, 6.

completely different world" in this respect, and explained this was why "we pushed to have the simulators in Houston integrated." Cernan made an even more emphatic assessment: "Running rendezvous closed loop with one simulator and not tying into any other simulator became, after a period of time, to be almost negative training. You don't ever really get a feel for what the guy in the other spacecraft is doing and what his problems are or what his timeline is like until you start operating integrated." As the astronauts moved to the Cape shortly before launch, they decided to prepare for rendezvous in no other way.[173] Yet the men had no way of knowing during their simulations that two incidents in space would test their judgment and training as much as any in the whole program.

The first came during the engine burn that sent them out of Earth orbit on May 18. For the first three minutes, Stafford, Young, Cernan felt the vehicle vibrate at the 20 hertz level they had expected from simulations. But the vibration then jumped to an estimated 50 to 70 hertz. The instrument panel blurred to the point that Stafford could not read it. About three and a half years earlier, he had sat atop a *Titan* rocket and observed Schirra make a judgment call that saved a *Gemini* mission. Now the opportunity to make a judgment call fell to him. He did not have a precise vibration figure on the panel, which he could not read anyway, and did not have a mission rule that called for him to twist the abort handle if the figure reached a certain level. He also said during the mission debriefing, "We'd never seen it before and never heard about it." Thus Stafford could not simply regurgitate what he had already done in a simulator. He

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[173] "*Apollo 10* Technical Crew Debriefing," 20-1 to 20-2.

had the more difficult job of judging whether the vibration imperiled the structural integrity of the vehicle and, if necessary, aborting before this could happen. All three astronauts mentally prepared for an abort and even considered it likely at first. But Stafford judged that the burn could continue and his instinct proved correct. The engine shut down after three minutes of the unusually high vibration, he saw that the vehicle was on course, and engineers later determined that the vibration was within design limits.[174] A less well trained and savvy astronaut might have chosen to end the flight, but Stafford and his crew continued to the Moon.

After entering lunar orbit on May 21, Stafford and Cernan climbed into *Snoopy* the next day and undocked with *Charlie Brown*. The descent engine took the two men from 69 miles above the Moon to just 8.9 miles, where they took photos and described the features along the path to the southern Sea of Tranquility. Since the Moon had no atmosphere, the astronauts could travel at this low altitude while traveling just 3,700 miles per hour, compared to the 200 mile altitude and 17,500 mph speed of Earth orbit. This radically different experience called for a new training method, and the most useful analog appeared to be aircraft flight (commercial airplanes typically fly a few thousand feet below *Snoopy's* lowest altitude). Stafford and Cernan thus simulated the LM trajectory in T-38 flights, while describing geological features out their windows. They also listened to briefings on lunar geology and spent hours studying maps. The training proved beneficial, again due to the power of the human eye. Since the two men knew what to look for and could see small details below them, they could report that

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[174] Ibid, 5-3 and *Apollo 10* Mission Report, 9-3

astronauts landing on the Sea of Tranquility could expect a smooth area on the near end of the targeted site but a much rougher far end. Like those who had explored the Earth in generations past, they could pave the way for their successors by reporting observations. Young said it best when he declared, "You can see down into the shadows of those craters in Earthshine on the Moon…Now, you've never seen a picture come back from the Moon that saw down into the shadows of the craters—not one. With the human eye, it's a piece of cake."[175]

One of the scariest moments in *Apollo* came during *Snoopy's* second pass around the Moon, when Stafford and Cernan were almost ready to jettison the descent stage and fire their ascent engine to return to *Charlie Brown*. A few seconds before this was slated to happen, the LM went into a violent spin. Pitch and yaw rates quickly increased until *Snoopy* tumbled at about sixty degrees per second. Not since *Gemini VIII* had any astronaut needed to make a quick response to a tumbling spacecraft, and Stafford and Cernan were much lower than that crew had been. If they could not eliminate the motion, the vehicle would drift into gimbal lock and their ability to navigate would be compromised. Most ominously, only forty seconds remained until their ascent engine was scheduled to fire, and if the vehicle was aimed in the wrong direction at that time the engine might send them off target from *Charlie Brown* or plunge them right into the lunar surface. "Son of a bitch! What the hell happened?" Cernan blurted. But like Neil Armstrong before him, Stafford had several factors working to his advantage: years of experience piloting new and occasionally temperamental flying machines, hundreds of

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[175] Brooks, Grimwood, and Swenson, 310 and Burgess and French, 375-377.

hours maneuvering the LM simulator, and the clarity of mind to understand what would be most helpful in alleviating a crisis. First, he flipped the switch to jettison the descent stage. "I blew off the descent stage because I knew we'd get a better torque-to-inertia ratio," he explained. "This was because all the thrusters were on the descent stage." He then took the hand controller and, using the RCS thrusters, damped out the unwanted motion.[176] According to Cernan, only a few seconds remained before he and Stafford would have been unable to find their ticket home.[177]

Stafford's response became even more impressive when engineers traced the problem to a mundane issue that was not simulated in advance. The abort guidance system the crew planned to test during their upcoming engine burn had two control modes: "attitude hold" and "automatic." Cernan knew the switch in the cockpit should be set to "attitude hold," so he flipped the switch there. Stafford did not realize his companion had done this, so he flipped the switch again, to the "automatic" mode that sent the ship into the violent gyrations. The cause of this near disaster therefore connected to a training-related issue: cockpit communication. In 1997, one researcher listed the barriers to pilot communication that had caused mishaps like *Apollo 10*'s: noise, multiple communications at the same time, fatigue, distractions, incomplete messages, ambiguous wording, lack of credibility, lack of rapport, use of jargon, and boredom. Stafford was troubleshooting a minor problem when the snafu happened, so this emergency best fits into the category of distraction. The point of training was to

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[176] Brooks, Grimwood, and Swenson, 310-311 and Burgess and French, 380-381.

[177] Cernan with Davis, 218.

eliminate all of these barriers, and indeed future crews did not make this mistake again.[178]

The two easily correctable scares notwithstanding, the safe return of the *Apollo 10* crew meant the precursor missions could end. This meant that the crew of *Apollo 11* would make the first Moon landing: Neil Armstrong, Mike Collins, and Buzz Aldrin. These astronauts set a new record for training time. From their selection in January to launch in July, the men averaged 42 hours per week on specified training activities while averaging about 20 more hours per week on routine tasks such as reading, doing paperwork, and traveling. Sundays were the only day of the week free from formal activity, and even then those routine tasks occupied much of their time. Collins ended with 928 training hours weighted heavily toward time in the CMS, while Armstrong and Aldrin logged 1,298 and 1,297 because they needed to spend time in the CMS and LMS while also preparing to walk on the Moon.[179] Yet as grueling as their preparation was, this crew only needed to train for three tasks that had never been done before: the descent from 47,000 feet to a complete stop on the lunar surface, the two and a half hour moonwalk, and liftoff to rejoin Collins. Since the landing was the most technically difficult of these feats, training for this task proved the most vexing and the most remarkable.

Armstrong and Aldrin worked with Flight Operations division personnel on the

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[178] Burgess and French, 381-382 and Robert Baron, "Barriers to Effective Communication: Implications for the Cockpit," *Airline Safety*, http://www.airlinesafety.com/editorials/BarriersToCommunication.htm (accessed September 16, 2016).

[179] Hansen, *First Man*, 374-375.

most critical task affecting the landing: the formation of mission rules. When the document was published in May, the men had their guidebook on what actions to take in the simulator and eventually above or on the Moon. The rules covered the minimum capabilities that they would need to land in the electrical, environmental, guidance, and propulsion systems. Some of the rules were simple and easy to remember; for instance, a propellant leak or a loss of radar data while the LM *Eagle* was descending meant the men would have to quickly jettison the descent stage and fire their ascent engine to return to the CSM *Columbia*. Some of them were more complex, such as electrical system rules. If *Eagle* lost one battery, the men should continue the landing. If the vehicle lost three batteries, they should typically return to *Columbia*. But if this happened during a late phase in the descent, after *Eagle* had dropped below 1,000 feet, they should continue the landing. If this happened after landing, they should liftoff at the earliest opportunity.[180] The complexity of the rules illustrated why astronauts needed to log hundreds of hours of simulator time. A crew that went without it could not be trusted to take the proper course of action.

What is especially clear from the time Armstrong and Aldrin spent preparing for the landing is that their sessions were a learning process for all who supported them. Armstrong logged 383 hours in the LMS, while Aldrin logged 411. Armstrong added 34 hours in the LLRF at Langley and the LLTV in Houston, the two motion base simulators that allowed him to practice landings in one-sixth gravity.[181] These sessions allowed the

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[180] "*Apollo 11* Final Flight Mission Rules," April 16, 1969, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/office/pao/ History/alsj/a11/A11MissionRules.pdf (accessed September 17, 2016).

[181] Hansen, *First Man*, 378.

two to learn how to respond when malfunctions arose and tested their knowledge of mission rules. When the descent reached the last few hundred feet, Armstrong took over manual control and learned how to pilot *Eagle* away from hazards on the lunar surface. The training also honed their judgment. For instance, Armstrong understood that an abort during the landing would be a risky proposition because it required shutting off one engine and igniting another while close to the lunar surface. He later said that he might have been willing to override a mission rule and continue the landing with this knowledge in mind.[182] Riley McCafferty remembered feeling impressed with the skills that these particular astronauts possessed, which made the jobs of the simulator personnel easier. Armstrong had proven his skill as a test pilot and had even been involved in the development of the LLTV. Aldrin and Collins already understood the spacecraft computers well. Because he worked with such a skilled crew, "we could really make an hour in the simulator worth an hour in the simulator."[183]

Armstrong and Aldrin also learned to work with each other. The two needed to form the working relationship that all pilots and first officers on airplane flights need, except in this case to undertake one of the riskiest tasks in the history of flight. These two men had somewhat different backgrounds, in that Armstrong was a test pilot who had flown planes for civilian research purposes and Aldrin was an Air Force test pilot and Ph.D. scientist. The Commander maintained to the end of his life that the two trusted and worked well with each other, but one incident during training illustrated that

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[182] Hansen, *First Man*, 378-387.

[183] Interview with McCafferty, 8-9.

the two needed to learn each other's traits.[184] Armstrong reacted too slowly to an emergency and crashed onto the simulated lunar surface. Aldrin confronted his Commander about the incident late that night, feeling that the crash had been a sign of weakness on their part. Armstrong interpreted the situation differently. He knew he could have aborted the landing, but since this was only a simulation he decided to test the flight controllers' ability to respond to the emergency. This fit with his general approach to simulator time, in which he "tried actively to encourage simulator problems so I could investigate and learn from them." Armstrong thus had an unusually analytical style of training to which Aldrin needed to adjust.[185]

But training for the landing affected far more than the astronauts. The simulator personnel who worked under Riley McCafferty learned what they could accomplish in a short time period. After the *Apollo 10* crew returned their photos and film from the Sea of Tranquility, these engineers installed a new visual model of the landing site, completing it only about six weeks before the *Apollo 11* launch. These engineers also repaired malfunctions with their simulator in time to allow this launch to happen with a fully trained crew in July. McCafferty remembered that this was a daunting task, because the crew could not delay their scheduled travel to wait for engineers to repair a simulator. Yet he remembered that Armstrong remained patient and sympathetic. If a simulator was down during a scheduled session, he switched to other training activities and returned whenever the CMS or LMS was ready. "That's really the thing that made

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[184] Hansen, *First Man*, 359.

[185] Ibid, 378-381.

Apollo 11 for us on time," McCafferty argued. "Without his help and without his understanding, his flexibility, we couldn't have done it."[186] Far fewer people today remember McCafferty's name than Armstrong's, but McCafferty and those who worked for him met the tight deadline that allowed the first Moon landing to succeed before decade's end.

Flight controllers also went through a dramatic learning process. In June, Gene Kranz and his flight control team began integrated simulations with Armstrong and Aldrin. Although this idea dated back to *Mercury,* the controllers quickly learned that Moon landing simulations differed drastically from past simulations. The sequence from the descent engine burn at 47,000 feet, where Stafford and Cernan had left off, to landing took only twelve minutes. This left them with little time to make a decision whether to press ahead with a landing or to abort, and to make matters worse there was a communications delay of about three seconds to simulate speaking with the crew at the Moon. Kranz devoted an entire chapter in his memoir to the many simulations when the LM crashed and he had to hear the dreaded words that the crew had been killed. "By the final training run (of the first day of integrated sims) I felt like the coach of a sandlot ball club behind 21-0 in the third inning," he recalled. Chris Kraft even gave him a phone call because he felt concerned about the team's performance. But ten more days of this remained and Kranz's team eventually improved their decision making. Kranz could have recommended delaying the launch to allow his team more time to train, but recommended a July launch. By then, controllers had gone through a learning process

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[186] Interview with McCafferty, 7-8.

that taught them mission rules and how to implement them in time.[187]

In turn, flight operations personnel had learned from the simulations what rules should be changed or added. The initial rule book went through revisions on June 20, July 3, and July 11. As it turned out, one rule change saved the *Apollo 11* mission. As described in the introduction, Dick Koos decided to simulate a 1201 computer program alarm during the July 5 session. This malfunction caught flight controller Steve Bales and the rest of the team off guard and resulted in a wrong decision to abort, so the rule book went through one last revision to reflect what program alarms a crew could encounter and still continue the landing. In a remarkable coincidence, Koos had simulated this malfunction that would really happen on the first Moon landing during the last session for Kranz's team. Kranz inserted the revision on the day of launch, July 16.[188]

Armstrong and Aldrin spent less than 14 percent of their training hours preparing for their moonwalk, because this was a much less technically demanding part of their mission than landing. This was also because the two men had only about two and a half hours to spend outside on the Sea of Tranquility (mission planners did not know how long the supply of water for the cooling of their suits would last, resulting in the decision for a brief EVA). Yet mission planners still had a plethora of tasks for them to accomplish: collect a contingency soil sample, inspect the LM from outside, test their bearing and locomotion in the one-sixth gravity, deploy three experiments and an

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[187] Kranz, 256-271.

[188] Hansen, *First Man*, 384.

American flag, receive a phone call from President Richard Nixon (although this was not included during training sessions), and only then make their geological observations and collect rock samples. Geologists wanted the astronauts to take numerous photos of the landscape and their equipment, so this would also have to factor into the mission timeline. No previous exploration in history had included such a meticulously detailed timeline of tasks packed into such a short time, or had cost as much money, and Armstrong and Aldrin needed to train to make sure they could fulfill the planners' expectations.[189]

This training took several forms. In these days before any instructor could know with certainty the best way to maneuver in one-sixth gravity, Armstrong and Aldrin evaluated the Water Immersion Facility and KC-135 aircraft as means of simulating that motion. Their suited walkthroughs with all the equipment they would have with them, either indoors, at the rock pile, or at the sand pile, prepared them best in following the packed timeline. The June 18 walkthrough proved especially crucial because the geologists who would be supporting *Apollo 11* sat in the backroom of Mission Control and heard the astronauts communicate with them on their science objectives.[190] Armstrong and Aldrin also received numerous briefings. One covered their suits so they could understand the operation of the complex garment that would keep them alive: torso, helmet, gloves, outer boots, backpack, remote control, hoses, cables, and liquid cooling system. Another covered the three experiments they would have to leave on the

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[189] Ibid, 375-377 and 476-528.

[190] Phinney, 100-101.

surface: the Lunar Ranging Retroreflector, the Passive Seismic Experiment, and the Solar Wind Composition Experiment. Besides understanding the idea behind the experiments, the astronauts learned how to carry and deploy them through thick gloves. Their training also took the form of one geology field trip, to the Quitman Mountains in western Texas on February 25. The two communicated their findings and collected as many useful specimens as possible, then held a discussion with the MSC and USGS geologists mentioned earlier. The geologists considered themselves lucky that Armstrong would take to the Moon his longstanding interest in geology.[191]

Yet another form of training concerned the possibility of life on the Moon. Though geologists considered this extremely remote based on observations from telescopes and unmanned vehicles, Armstrong, Collins, and Aldrin would be isolated from the rest of the public for three weeks after their return just in case they carried a lunar microbe with them. A helicopter would lift them from their spacecraft in the Pacific Ocean to the *USS Hornet*, where the astronauts (dressed in their Biological Isolation Garments) would climb into a small trailer called the Mobile Quarantine Facility. The trailer would house them on the flight back to Houston, where they would spend two more weeks isolated in the Lunar Receiving Laboratory while scientists determined they were free of lunar germs.[192] The astronauts thus received a briefing on the possibility of back contamination and on the facilities they would live in while isolated, with an emphasis on communications, oxygen and decompression, sanitation,

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[191] Hansen, 375 and [*Apollo 11* Training Summary, Box 081-13, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, and Phinney, 100-101.

[192] Chaikin, 180-181.

emergency egress, and crew safety.[193]

The unprecedented training sequence contributed to the success of *Apollo 11* in two major ways. First, Armstrong demonstrated the flexibility that highly skilled and trained pilots could offer to a Moon landing on July 20. He heard the two computer alarms during the powered descent, but knew from his training that this should not result in an abort if the rest of the vehicle appeared to be in good health. Dick Koos's simulation had taught the flight controllers that the alarms should not prevent the landing anyway, and CapCom Charlie Duke told him this. But more dauntingly, the computer directed *Eagle* toward a crater the size of a football field that was surrounded by large boulders. If this had been an unmanned mission, the vehicle would have been in serious trouble. But Armstrong had the training to respond to this situation, most applicably in the LLTV. He took over manual control at an altitude of 500 feet and translated forward by an unexpectedly large amount (1,500 feet), so he could fly past the crater. As in his LLTV flights, he looked for a clear area until he found one, arrested forward and sideways motion so the vehicle descended straight down over that area, and shut the engine off after Aldrin called "Contact light." He heard Duke say during the last hundred feet that only thirty seconds of descent fuel remained, but he had landed in the LLTV with about fifteen seconds remaining and so did not feel overly concerned. Though it is impossible to know what would have happened if Armstrong had gone without LLTV or LMS training, he would have undoubtedly lacked the confidence to

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[193] Kohler and Reeder, 8.

take the actions that he did in responding to a crisis.[194]

Second, he and Aldrin took the first step toward demonstrating the flexibility of astronauts as explorers. The United States had not sent a pair of robots to the lunar surface, but two humans who had the skills that training gave them. The two found that the training most helped them by giving them physical familiarity with one-sixth gravity and mental familiarity with the timeline. These factors allowed them to make unprecedented contributions to exploration, though Soviet and American probes had already landed on the Moon. About one hour after taking his "one small step" onto the Sea of Tranquility, Armstrong began the work of scooping 48 pounds of rock and soil into sample containers. Even this total, by far the lightest of any *Apollo* mission, was over 66 times the amount ever returned from the Moon robotically. The two also photographed rocks before and after lifting them, a geological technique no robot could match. After the mission, geologists recognized most of the specimens as basaltic rocks, the kind found in areas on Earth where lava has solidified. The rocks dated to 3.7 billion years old, suggesting volcanic activity at that point in Tranquility's past. Armstrong also proved a point when he observed a crater about sixty-five yards east of *Eagle's* resting point. He had the intuition to understand that this crater would interest the geology community, the mobility to stride there, and the intelligence to describe what he saw at close range. Less than half an hour later, he had to climb back up the ladder into *Eagle*. But the ease with which he had performed this task whetted the appetite of geologists

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[194] Hansen, *First Man*, 441-475.

who anticipated more ambitious missions.[195] Armstrong really had taken just “one small step” in understanding the Moon.

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[195] Ibid, 512-521.

CHAPTER VIII

APOLLO: “I WILL NEVER BE ABLE TO SAY ENOUGH TO MY PEOPLE”

The job of lunar geologist proved short-lived. With the NASA budget in a steady decline, geologists understood that their opportunities to learn about the Moon through a trained human presence were limited. Moon landing crews through *Apollo 20*, according to the current plan, thus needed much more thorough instruction in geologic exploration. Neil Armstrong and Buzz Aldrin did provide several lessons learned to guide future training. One called for more field trips while controlling the news media to avoid a repeat of the incident where reporters had hounded Armstrong and Aldrin in the Quitman Mountains. Another called for a more realistic simulation of lunar surface properties, which Armstrong had found remarkably fine grained. Another called for a more realistic timeline of activities, because Armstrong needed more time to collect samples than anticipated. Finally, the success of the first two moonwalkers in carrying out basic photo procedures called for more elaborate photo documentation of the Moon by future crews, who would have to train accordingly.[1]

The MSC and USGS geologists tasked with training crews implemented each of these lessons and more for *Apollo 12* astronauts Pete Conrad, Dick Gordon, and Alan Bean. Conrad and Bean made six field trips without any media coverage to distract them. The trips proved more beneficial than the one their predecessors had taken, because these astronauts followed what they planned to accomplish on the Moon with

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[1] Ibid, 376 and Phinney, 102.

much more precision. Conrad and Bean planned to make two outings in the Ocean of Storms, during which they would travel to a *Surveyor* spacecraft that had landed there two years earlier and follow a traverse route to several craters the geologists wanted them to sample. The astronauts thus followed a specific traverse route during their trips. They did this along with the CapCom who would speak to them on the Moon and the geologists who would monitor their work from the backroom at Mission Control. The crew also trained to spend much more time than their predecessors taking photos of rocks they collected and even landscape panoramas covering 360 degrees. The high fidelity of these field trips helped the astronauts prepare, but MSC geologist Uel Clanton remembered that the process of debriefing crews on what they did well there and where they needed improvement proved the most helpful aspect. The "time consuming and painful process" for the geology instructors to develop the photos the astronauts took, paste them together, and then spend several hours with the astronauts allowed the moonwalkers to learn from their mistakes.[2]

The last few months before launch provided still more signs of the improvement made in training moonwalkers. Conrad and Bean took time in August to examine the rocks just returned from the Sea of Tranquility. An MSC geologist remembered this as helpful in allowing these astronauts to see and discuss textural features that they hoped to find at the Ocean of Storms. The astronauts then made their last field trip, to the volcanic fields of Hawaii that geologists considered analogous to the Ocean of Storms, and the geologists felt the two handled every problem that confronted them, took

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[2] Phinney, 103-107.

exemplary photos, and found the most useful rocks to return.[3] Their last few weeks before launch took the crew to the Cape. Conrad and Bean rehearsed the deployment of their ALSEP package, a much more advanced collection of experiments than the package their predecessors had deployed, in a sand pile modified to precisely simulate lunar surface properties. During their evenings at the Cape, the two men reviewed traverse maps until they became second nature while geology instructors briefed them extensively on their planned activities. This focus on lunar surface time dwarfed that of the *Apollo 11* crew.[4] Since that crew had succeeded in executing a lunar landing and return, training for all of the tasks associated with traveling there and back had become standardized. This allowed Conrad, Gordon, and Bean to focus on the part of their flight that was new: making a precise landing next to the *Surveyor*, then making two outings that would take them to the western side of the Moon and further from their lander than their predecessors.[5]

Traveling to another world still contained surprises, however, and the launch of *Apollo 12* provided some of the most compelling evidence yet in favor of the training that astronauts and flight controllers had received. When the *Saturn V* sent the crew into a rainy Florida sky on November 14, two streaks of lightning flashed toward the launch tower. The astronauts heard the master alarm sound in the cockpit and saw that the fuel cells had automatically disconnected. Flight controllers saw that they had lost reliable data from the spacecraft. The multibillion dollar trip to the Moon depended on solving

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[3] Compton, 175.

[4] Phinney, 103-107.

[5] Young with Hansen, 201.

this conundrum, and training allowed controller John Aaron to do just this. He recognized the random set of numbers he now saw on his console from a simulation about a year earlier and remembered the correct action to restore reliable data. The spacecraft had a component called Signal Conditioning Equipment (SCE) that was responsible for converting signals from the vehicle's sensors so that the information could be relayed to Mission Control. The SCE was not working due to the sudden change in voltage caused by the streaks of lightning. But he knew that if the crew switched to a backup (or auxiliary) power mode, the SCE would operate even with this change in voltage. Thus Aaron made his suggestion, which CapCom Jerry Carr relayed to the crew: "*Apollo 12*, Houston, try SCE to Auxiliary, over." Everyone associated with this mission was lucky that this one controller had the memory to know how to respond to a dangerous crisis.[6]

Yet one of the astronauts also needed to know how to respond. None of them flipped any switch immediately, because none knew what had happened or what to do. Conrad had his hand near the abort handle, however, and knew he might have to activate it within the next minute when he heard the call from Carr. Neither he nor Gordon knew where to find this switch. Only by chance did Bean remember from a simulation that it was located on the bottom right side of the instrument panel, in front of his seat. He flipped the switch, which restored data to Mission Control. Controllers could then tell him to reset the disconnected fuel cells, which restored power to the vehicle. The *Saturn*

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[6] Alex Pasternack, "How Curiosity, Luck, and the Flip of a Switch Saved the Moon Program," November 19, 2014, *Motherboard*, http://www.motherboard.vice.com/read/john-aaron-apollo-12-curiosity-luck-and-sce-to-aux (accessed September 21, 2016).

V safely reached space after all. Luck played in a role in both Aaron and Bean correctly responding to this situation, because other controllers and astronauts may not have participated in the same simulations that these two remembered. Yet their responses also vindicated the meticulous training sequence.[7]

Landing on the Ocean of Storms would have carried its own pitfalls if a trained operator had not been standing on the left side of the LM *Intrepid's* cockpit. Whereas Armstrong and Aldrin had landed four miles off target, Conrad needed to guide *Intrepid* to within walking distance of a spacecraft on the slopes of a crater. But he could see that his target to the right of the crater looked too rough to support a landing. Thus at a few hundred feet above the surface, he exercised his flexibility to slow the ship's forward speed, look for and find a safe spot between two craters, and adjust the landing point. He also encountered an obstacle in the last hundred feet, because the engine kicked up so much dust that his view of the surface blurred. This forced him to fly entirely by instruments, in the tradition of airplane pilots who have logged simulator time for just such a situation. Bean called out "Contact light" in response to the blue light on the instrument panel and Conrad shut down the engine. The vehicle touched down gently and later examination showed no translation and very low sink rates at the end of its flight. *Intrepid* had also landed just 535 feet from the *Surveyor*. Only a trained pilot could have accomplished this in the midst of the dust cloud that had obscured his vision.[8] Although geologists wanted one of their own to explore the Moon, Conrad

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[7] Ibid.

[8] Chaikin, 258-260 and *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 12* (Houston, TX: MSC-01855, 1970), 9-7.

made a telling statement during a post-mission press conference. He said that landing *Intrepid* required all of his piloting skill.[9]

Conrad and Bean demonstrated their flexibility during their two moonwalks as well, although their experience did call for improvements in training. The two men walked about 1,600 feet from *Intrepid*. Their training in following their traverse route, along with the photo maps they carried on their suits, paid off when they reached all of their scientific targets. Their physical training to strengthen their arms and hands paid off when they managed to carry their tool carrier without exhaustion, although they did deal with forearm ache and thirst by the time their second outing ended.[10] Their training in making observations paid off when they found unusual specimens to study, inspected the *Surveyor* spacecraft to determine the effects of over two years on the dusty and irradiated Moon, and especially in digging a trench at Head Crater. *Lunar Orbiter* photos had revealed a light colored streak on the Ocean of Storms that geologists suspected had originated at Copernicus Crater. The thinking went that a meteor had struck the Moon and formed this crater, while throwing up ejecta that was now on the Ocean of Storms. Bean noticed that when Conrad dug a trench, the color of the surface changed to a lighter gray and the geologists in Mission Control understood they had found that ejecta. This was the kind of on-the-spot observation that vindicated the decision to send trained humans to the Moon. Study of the material returned after the mission indicated that the Copernicus impact happened 810 million years ago, a crucial

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[9] Compton, 186.

[10] Chaikin, 260-280.

event in recent geologic history. Geologists also found that the Ocean of Storms rocks were 500 million years older than the Sea of Tranquility rocks, meaning the lunar maria were not formed by just one event. The information in general went well beyond what any robotic vehicle had returned.[11]

Apollo 12 called for improvement in training in two areas. Conrad and Bean found that this region of the lunar surface was rather unrevealing. Geologists on Earth typically saw features that gave them clues as to the relative position of rock layers. This allowed them to observe and learn about the history of the Earth. But Bean reported of the Moon, "That whole area has been acted on by these meteoroids or something else so that all these features that are normally neat clues to you on Earth are not available for observation." The two men also had shown a reluctance to make geologic commentary during their seven hours on the lunar surface. *Apollo 12* thus suggested the need for future astronauts to develop their skills in field observation and description by training on challenging landscapes more closely reflecting the Moon.[12]

The greatest breakthrough in this area took place in time for the *Apollo 13* crew. As the only professional geologist in the astronaut corps, Jack Schmitt understood that this crew needed a compelling teacher to instill these skills in them. He sought out Lee Silver, a professor at the California Institute of Technology, and arranged for him to meet with *Apollo 13* astronauts Jim Lovell and Fred Haise. When the astronauts traveled with him to California's Orocopia Mountains for eight days in September 1969, they

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[11] Don E. Wilhelms, *To a Rocky Moon: A Geologist's History of Lunar Exploration* (Tucson: University of Arizona Press, 1993), 217-229.

[12] Ibid, 223-225.

discovered the difference between Silver and their previous instructors: he challenged them to a greater extent than the others. He asked them to describe the layers of rocks they saw and constantly pushed for improvement from the time they went into the field after breakfast until supper time. The astronauts then talked about geology around a campfire until retreating into their tents for the night. Silver generally found that since these pilots already possessed years of experience flying airplanes, they had the skills of observation that could also advance lunar geology. The astronauts were also competitive people who wanted their missions to stand out, and Lovell and Haise agreed that understanding geology was a worthwhile pursuit that would make *Apollo 13* stand out.[13] The two thus made several more field trips with radios, the real equipment they would have with them on the lunar surface, and flight controllers there to watch them. They also rehearsed their exact traverses at the Cape's sand pile a few weeks before launch. They felt confident by this point that they could make a groundbreaking contribution to the Fra Mauro Formation, the first landing site in the lunar highlands (the lighter colored surface as seen from Earth).[14]

Training for this mission also marked a breakthrough for the CMPs who orbited the Moon while their crewmates landed on it. On the first two Moon landings, Mike Collins and Dick Gordon had very limited training time for orbital observation. Yet an Egyptian born geologist named Farouk El-Baz understood that with travel to and from the Moon already accomplished multiple times, *Apollo 13's* Ken Mattingly should make

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[13] Chaikin, 392-394.

[14] Phinney, 111.

a much more concerted effort. El-Baz had pored through every one of the thousands of photos already taken from orbit and listed every feature he could identify, from the tallest mountain to the smallest knob. When he met Mattingly, he covered the walls of a conference room with photos marked to show *Apollo 13's* orbital path and challenged his pupil to describe geological features from above with the kind of enthusiasm that Silver had for geology at ground level.[15] The enthusiasm rubbed off on Mattingly enough that the astronaut met regularly with his instructor and even described the geology of Texas while passing over in an airplane (a training technique that he began and which all future *Apollo* CMPs continued). Mattingly gradually bought into the importance of observation, as El-Baz attests: "He wanted to make absolutely certain that we get the absolute maximum return and he was very thoroughly convinced that that's why we're sending man to the Moon; or else we can send machines. So we'd better prove that man is better than a machine."[16]

Preparation for *Apollo 13* did include one first in the history of training astronauts. When backup crewmember Charlie Duke exposed his colleagues to the German measles a week before the April 11, 1970 launch, a doctor found that Mattingly had no immunity to this disease. This resulted in Mattingly's removal from the crew only two days prior to launch and the elevation of Jack Swigert from backup to prime CMP. Since *Mercury*, the point of having a backup crew had been for an astronaut to step in during a situation like this. But could Swigert do so in the record time of two

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[15] Chaikin, 394-396.

[16] Phinney, 144.

days? Lovell admitted years later to feeling concerned about the switch, because in the integrated simulations he had grown used to hearing Mattingly's voice during mission critical moments.[17] The Commander of the backup crew, John Young, argued against the switch. Yet Swigert was a highly experienced pilot who had also written the malfunction procedures for the Command Module.[18] He had logged time in the simulator in late March and early April, so he did have recent training experience. Riley McCafferty recalled that because of these factors, the simulator staff did not have to worry about teaching Swigert about the Command Module or the mission during those last two days. The two days of simulations were more about making sure he communicated and worked well with Lovell and Haise, and his two crewmates felt confident that he did.[19] When Ron Howard dramatized *Apollo 13* in his 1995 movie, he portrayed fellow astronauts and flight controllers as uncertain that Swigert could do his job. This portrayal gave a misleading impression of Swigert's abilities.[20]

On the evening of April 13, Lovell, Swigert, Haise were about 205,000 miles away from Earth when the most famous emergency in human spaceflight placed their training to the ultimate test. When Swigert stirred an oxygen tank in the CSM *Odyssey*, he did not know about an incident in a routine launch pad test a month earlier. A drain tube in this tank had been knocked out of alignment, so engineers decided to use heaters

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[17] James A. Lovell, Interviewed by Ron Stone, May 25, 1999, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/LovellJA/JAL_5-25-99.pdf (accessed September 23, 2016).

[18] Young with Hansen, 146.

[19] [*Apollo 13* Training Summary, Box 081-14, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 2-3 and Interview with McCafferty, 12-13.

[20] *Apollo 13*, directed by Ron Howard, Universal Studios, 1995.

to force out the oxygen after the test. Yet the heaters stayed on for about eight hours to do this, a thermostat switch mistakenly not equipped to handle the voltage welded shut, and the tank temperature climbed to 1,000 degrees. This melted the insulation that protected the tank's wiring. Thus when Swigert started a fan to stir the tank, this acted as a trigger for a spark to fly from a naked wire and ignite the tank.[21] The crew did not need much training to look at *Odyssey's* instrument panel and see that pressure in one oxygen tank was gone and falling fast in the other. Lovell looked out the window and saw oxygen venting into space, which confirmed the reality of the loss. The crew could have reasoned at this point that they were doomed, destined to become the first Americans to die in space. Yet these three had experience in responding to emergencies in aircraft flights and the simulators, which proved crucial in their attitudes during the first few hours. According to Lovell, "The thought crossed our minds that we were in deep trouble. But we never dwelled on it…We never admitted to ourselves that, 'Hey, we're not going to make it.'"[22]

But in order to make it back to Earth, the crew would have to implement a technique with which they had little familiarity from training: use the Lunar Module as a lifeboat. The assumption until *Apollo 13* was that a catastrophe severe enough to cripple the CSM would also kill the crew, meaning a simulation of the scenario would not have been useful. "I don't believe we ever got to the point where we simulated the configuration of the Lunar Module as a lifeboat," Dick Koos recalls. "I don't remember

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[21] Jim Lovell with Jeffrey Kluger, *Apollo 13* (Boston: Houghton Mifflin, 2000), 344-351.

[22] Interview with Lovell.

anything like that. We created situations where you had to abort…But we didn't simulate everything that really happened during *Apollo 13*. The lifeboat was considered, but never really followed through with in terms of the reconfiguration that they had to do on the real mission." Lovell's memory is similar to Koos's on this point. He remembered taking part in simulations where the CSM engine failed around the Moon and he had to use the LM engine instead. But those instances covered only a brief time span. His training had not taught him to operate the LM on a four day journey back to Earth, yet his life now depended on just that.[23]

The crew did reap the benefits of training on several elements of their return flight, however. About two hours after the loss of the oxygen tank, Lovell and Haise were already powering up systems in the LM *Aquarius*. The contractors from Grumman had participated in integrated simulations in case their experience from manufacturing the vehicle could help the flight controllers and astronauts, as Koos recalls.[24] This proved useful on April 13, because the crew did not have enough time to power up *Aquarius* by the standard checklist before *Odyssey* lost power completely. The LM experts pared down this checklist for Lovell and Haise, while Swigert scrambled to shut down *Odyssey*. Swigert's success in shutting down the vehicle and then joining his crewmates in *Aquarius* placed the crew out of immediate danger, but another hurdle lay about three hours ahead. They would have to fire the LM engine to return their course to a free return trajectory, which would then take them around the Moon and on a journey

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[23] Author Interview with Koos and Interview with Lovell.

[24] Author Interview with Koos.

back toward Earth. Without this burn, they would miss the Earth by 45,000 miles. Once again their training assisted them in preparing for this. Lovell had rehearsed the procedure for transferring the navigation platform from the CSM to the LM, a thorny task that required arithmetic, and this helped him to avoid any errors. He had also rehearsed taking the LM hand controller and stabilizing the vehicle while it was attached to the CSM. Though he called the experience "like learning to fly all over again," he kept the unwieldy combination aligned in time for the burn. The free return maneuver succeeded on the morning of April 14, which was partly a testament to the hardware but also to the efforts of a trained crew.[25]

The simulators designed to train crews became one of the most critical tools in saving the lives of Lovell, Swigert, and Haise. Riley McCafferty said it best when he declared, "I guess I will never be able to say enough to my people." He made this comment because he and several of his fellow simulator engineers rushed to the space center within two hours of the crisis to simulate the conditions in *Odyssey* and *Aquarius*. Before he even left his house, he had already received phone calls from employees asking him if there was anything they could do to help. He said yes, and these personnel spent about 20 hours operating the simulators during each of the four days that the *Apollo 13* crew remained in space. When they needed to sleep, they often used bunk beds in the space center. McCafferty also sent four of his employees to the backroom at Mission Control, as he did for every mission, so these personnel could remain in close

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[25] Chaikin, 297-303 and Young with Hansen, 146.

contact with the Flight Activities Officer in the control center.[26] About 17 astronauts participated in the simulations as well. Even as Ken Mattingly received all of the credit for this in Hollywood's version of the mission, Young remembered being "awake and either in meetings or in the Lunar Module Simulator for about 120" of the 145 hour flight.[27]

In his book, Lovell recounted the key moments when the simulators aided the effort to rescue the crew. John Young and Charlie Duke climbed into the LM simulator just a few hours into the crisis, as the crew abandoned *Odyssey* for *Aquarius*. The first major problem that these two tried to solve concerned navigation. Could a crew align the LM by the stars even when a debris cloud surrounded the ship, as it now did *Aquarius*? Although these two rehearsed maneuvers to take them away from a simulated debris cloud, Lovell found he could not align his ship with the stars and instead had to transfer the navigation platform from the CSM. Young and Duke did help confirm that the LM's digital autopilot could maintain a proper attitude during the free return burn.[28] A day later, these two were back in the simulator. The *Apollo 13* crew needed to make another burn after passing around the far side of the Moon to speed their ship's return home. Without this push, *Aquarius's* consumables might not last long enough. But how could the crew check that their navigation platform remained sound? Young and Duke rehearsed an idea to sight on the one star the crew could see to do that: the Sun. Sure enough, the idea worked on the simulator and aboard *Aquarius*. Lovell manually fired

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[26] Interview with McCafferty, 13-14.

[27] Interview with Faber and Young with Hansen, 150.

[28] Lovell with Kluger, 174-176.

the engine on the evening of April 14 and sent the vehicle on a speedier path home. Now the crew faced the challenge of surviving 62 more hours of cold and lack of sleep aboard *Aquarius*, before powering *Odyssey* back up for reentry into Earth's atmosphere.[29]

Because the crew needed *Odyssey* to return home, the Command Module Simulator also served as a tool in saving their lives. The flight controllers needed to send them a checklist to power the ship back up, which required testing all of the steps in the CMS. Normally this took three months, but now the controllers had less than two days. The flight controller who had been so instrumental in saving the last mission, John Aaron, teamed with Arnold Aldrich to devise the checklist and then called on a group of astronauts to implement each procedure in the simulator. "Just wring it out," Mattingly recalls the astronauts being told. "See if there's anything in the process that doesn't work." After this essential work, he read every step to the crew on the evening of April 16 and added, "We think we've got all the little surprises ironed out for you."[30] No SimSup had ever simulated powering up a Command Module after several days in cold soak, but Swigert did just this two and a half hours prior to reentry. All three astronauts climbed back into *Odyssey*, cast aside *Aquarius*, and splashed down safely in the Pacific Ocean.

What lessons about training can one infer from the "successful failure" of April

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[29] Ibid, 237-246.

[30] Chaikin, 315-325 and Thomas K. Mattingly, Interviewed by Rebecca Wright, November 6, 2001, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/MattinglyTK/MattinglyTK_11-6-01.htm (accessed September 24, 2016).

1970? One lesson concerns the progression of astronaut training as an institution. The simulation staff had grown from a few people at the Space Task Group in Virginia to a group that McCafferty described as containing 43 civil service employees and 250 contractor employees. Although many of these people were only a few years removed from their college bachelor's degrees, the group showed the tenacity to simulate the ad hoc procedures that Lovell, Swigert, and Haise needed to implement.[31] Another lesson concerns the value of the simulations this group conducted. Many historical tragedies, from the sinking of the *Titanic*, to the Pearl Harbor attack, to the 9/11 attacks, have been attributed to "failure of imagination." *Apollo 13* falls into this category as well, in that the *Apollo* team failed to foresee that an action taken during a launch pad test would cripple an oxygen tank. But since the tank catastrophe did not kill the crew immediately, astronauts and the simulator personnel had the gift of time to "imagine" and then test procedures. They did not have to leave these key milestones to chance. On top of this, they also had the reassurance that Lovell, Swigert, and Haise had already trained in simulators for many of the actions they had to take. Decades later, Mattingly pointed to "the extraordinary role of the simulation program that put all of those tools in people's toolboxes" as one of the elements that made *Apollo 13* successful.[32] The crew failed to land on the Moon, which meant much of their training had gone for naught. Yet the emergency had tested the ability of the astronaut corps and simulator personnel more than a successful mission probably would have.

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[31] Interview with McCafferty, 12.

[32] Interview with Mattingly.

The remainder of 1970 provided a pressing reminder that *Apollo's* days were numbered and the few crews left would need to make their missions the most productive yet. NASA Administrator Tom Paine announced that budget cuts had eliminated the last three moon missions, meaning the program would end with *Apollo 17*.[33] The onus of expanding lunar surface capabilities in the wake of the near disaster fell to *Apollo 14* astronauts Alan Shepard (surgery had cured his inner ear ailment and allowed him to make his second spaceflight nearly a decade after his suborbital *Mercury* voyage), Stu Roosa, and Ed Mitchell. Though Shepard and Mitchell planned to land in the same Fra Mauro Formation that their predecessors had failed to reach, training for this mission broke new ground in several areas. First, the two trained in the operation of ambitious new experiments. Mitchell rehearsed setting up a mortar in the proper location with the proper alignment and then firing explosive charges to study the Moon's seismic activity. Another experiment called for readings of a magnetometer designed to study the Moon's magnetic activity. Second, the two trained to conduct geology observations while carrying along a Modularized Equipment Transporter (MET) that would carry 360 pounds of equipment. This would ease their task of carrying core tubes, sample bags, cameras, maps, and hand tools while on a tiring trek to the rim of Cone Crater. Third, the two adjusted to a challenging new method of geology while on their field trips. The instructors taught them to collect several walnut-sized rocks from varied localities rather than a few large rocks from the same locality, a technique known as a "comprehensive sample." The need for multitalented astronauts who could make observations in a

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[33] Compton, 201-203.

spacecraft and on a new world was becoming clearer and clearer, because the expectations for each mission only went up.[34]

The simulations grew more creative as launch approached. Shepard and Mitchell planned to visit an excavation caused by a meteor impact on the Moon, so the geology instructors found numerous sites in the U.S. and overseas where meteors had blasted the Earth to send the astronauts. These included the Ries Crater in Germany, where two men received instruction from foreign professor Wolf von Engelhardt. This marked one of the early examples of American astronauts integrating foreign expertise into their training. The arrival of the "rock star" astronauts also created much publicity for geology research in Europe.[35] Shepard and Mitchell also visited the craters of the Nevada Test Site and a man-made Black Mesa Crater field near Cottonwood, Arizona. At the latter site, USGS personnel had used explosives to artificially create a pockmarked Earth. At these ingeniously selected training sites, the instructors asked the two men to plan their own traverses to give them experience in thinking for themselves. The suited walkthroughs in Houston also grew more creative, because the astronauts made traverses that included simulated malfunctions. On November 9, for instance, a fan in one astronaut's life sustaining PLSS backpack malfunctioned and he had to consult with Mission Control on the proper solution. This provided a reminder that simulations of moonwalks were continuing to mature, to the point that they more closely

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[34] Phinney, 111-114 and Compton, 206.

[35] Martina Kölbl-Ebert, *From Local Patriotism to a Planetary Perspective: Impact Crater Research in Germany, 1930s-1970s* (Surrey: Ashgate, 2015), 312-314.

resembled spacecraft simulations.[36]

Apollo 14 brought the program from the brink of disaster back to successful lunar exploration in February 1971, but not without the lessons learned that were natural in a program where each mission was more ambitious than the last. The crew proved themselves well prepared for the surprises that cropped up on every Moon voyage. When a problem with the docking mechanism prevented the CSM *Kitty Hawk* from docking with the LM *Antares*, Roosa aligned the probe of his ship with the drogue of his target and held them there with *Kitty Hawk's* thrusters. This contact finally triggered the docking latches. Landing *Antares* on Fra Mauro provided two more tense moments, but Shepard and Mitchell worked with controllers to bypass an abort signal in the ship's computer and gain radar data by cycling a circuit breaker. The astronauts remembered these problems as ordinary compared to the grim scenarios they had encountered in simulators, and they did not prevent Shepard from landing an unexpectedly close quarter of a mile from his target.[37] The major lessons learned concerned the task that no astronauts had done before: walk thousands of feet from their lander in search of a spectacular crater rim. Shepard and Mitchell knew that the closer they came to the rim of Cone Crater, the deeper the source of rocks they could uncover and the more knowledge they could glean from a critical point in the Moon's history. But the two had to stop climbing after coming within 65 feet of the rim, because they felt unsure about their location and time ran out. This suggested two lessons for training: the need to

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[36] Phinney, 111-114.

[37] Chaikin, 352-359 and Compton, 210.

identify landmarks across a rolling terrain and the need to avoid falling behind the scheduled timeline (the two usually found themselves well ahead of the timeline in training but slightly behind on the Moon, finding that their actions took 25 to 30 percent longer there than in one-G conditions on Earth).[38]

Another lesson, at least according to several of the instructors, concerned the attitude of the Commander. Shepard had worked hard to get himself back on flight status and up to speed on *Apollo* hardware, but numerous geologists who trained the crew argued that he lacked the interest in surface exploration that several of his colleagues had. They also believed that since he was the Commander, his attitude rubbed off on his crewmates. Given that he and Mitchell came up just short of the crater rim, the most telling comment came from Gordon Swann of the USGS. Swann had offered the two a briefing on how to spot landmarks a few weeks before launch, which would have helped them navigate to the rim, but he remembered the two as being unconcerned. The instructors could not deny that they had worked hard, as evidenced by Shepard's heart rate reaching 150 as he climbed by far the steepest lunar slope encountered to date, and also granted that the preflight photography the crew had studied during training did not adequately prepare them. Yet several instructors have implied in their comments that *Apollo 14* reinforced the need for a Commander who made maximizing science return a top priority.[39] In fairness, the crew still set a new standard for productivity of trained humans on the lunar surface. The men collected nearly 100

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[38] Phinney, 114.

[39] Chaikin, 372 and Phinney, 112.

pounds of rocks and soil, from football sized fragments to "comprehensive samples," and took enough photos so scientists could visually locate much of the material. Most importantly, Shepard and Mitchell had used a hammer to chip at large boulders close to the crater rim. This gave scientists ejecta kicked up by one of the largest meteor impacts in the history of the solar system: the one that had formed Mare Imbrium.[40]

But every crew needed to set a new standard for productivity, and the stakes grew much higher for *Apollo 15*. Thanks to upgrades in the *Saturn V* booster, the crew of Dave Scott, Al Worden, and Jim Irwin could take to the Moon a heavier LM than ever before that carried enough water, oxygen, and electrical power to support three days of surface exploration. This LM could also carry three times more scientific equipment than any of its predecessors, most remarkably the first car to be driven on another world. Contractors at Boeing had spent the last two years designing and manufacturing a Lunar Roving Vehicle (LRV, or "Rover") that could take almost 1,000 pounds of equipment on a drive of several miles. Instead of expending energy on a tiring uphill climb, astronauts could now sit back in the Rover and cruise at up to 11 miles per hour. The *Apollo 15* landing site also intrigued geologists more than any other place astronauts had visited: a plain next to a 1,300 foot deep channel called Hadley Rille and a series of mountains several thousand feet tall called the Apennines. The geologists' fondest hope was that Scott and Irwin would collect material there dating back to the Moon's creation 4.5 billion years ago. The expectations for Worden were also greater than any previous

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[40] *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 14* (Houston, TX: MSC-04112, 1971), 3-14 to 3-15.

CMP: operate a Scientific Instrument Module (SIM) on the exterior of his spacecraft containing cameras, spectrometers, and a laser altimeter, then deploy a satellite to measure the Moon's magnetic field.[41] All of this suggested the crew needed a stronger relationship with their geology instructors than any before, and two personalities meshed to produce just that.

Scott and Lee Silver came from different backgrounds, but shared the same goal and came to admire each other during a series of field trips lasting twenty months. Scott had come to the astronaut corps from the test pilot community, but had shown interest in archaeology dating back to his time in the Air Force. He already felt confident in his own ability to reach the Moon and return, based on his experience flying aboard *Apollo 9* and rehearsing lunar landings as backup Commander of *Apollo 12*. Thus he felt willing to accept Silver as his geology instructor and set a new record by spending one-third of his training time on lunar geology. Once again, the attitude of this Commander rubbed off on his crewmates.[42] Silver shared with him the goal oef achieving the maximum science return from *Apollo 15*, but he had to teach Scott to develop a geologist's mental tools. Scott praised Silver for his ability to do this, remarking in his memoir, "When asked to describe what I saw on one of the first trips to Orocopia, I got not much further than saying, 'Boy, there's a lot of stuff on the other side of the hill.' Lee Silver helped us tune in to the language of geology, and soon we were describing the composition of that 'stuff' as granite, basalt, sandstone, or conglomerate, and its shape as

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[41] Compton, 225-227 and Chaikin, 402-403.

[42] Chaikin, 399-400.

angular, sub-angular, or rounded." Silver instilled these lessons on field trips at least once a month in 1970 and 1971, so that the astronauts would not miss glimpsing a piece of the Moon's primordial crust and would know how to describe it in expert language. In turn, Silver praised Scott when he saw the Commander recognize geological problems and eventually try to solve them on his own initiative.[43]

Scott and Irwin began driving a training version of the Rover in November 1970. This training prepared them for the mechanical skills they would need on the Moon. First, they would have to operate a pair of lanyards that deployed the Rover from the side of the LM descent stage. When Scott climbed into the driver's seat, he would orient the Rover navigational gyroscope with the Sun and then drive by using a T-handle to control forward and reverse speed, braking, and steering. He would also have a panel containing power monitors and controls, a navigational readout, and a speedometer. Throughout the drives, he would have to know the Rover's ability to climb over rocks, climb and descend slopes, and park on slopes.[44] Instructors first tried to give astronauts driving experience by stringing the vehicle from the side of an MSC building, but this did not create the desired fidelity. Scott and Irwin drove a training version instead, structurally strengthened and featuring conventional tires rather than the real Rover's wire mesh tires, and Scott and Irwin found the vehicle fairly easy to drive.[45]

More personnel than ever took part in these field trips, which highlighted the increasing emphasis on science in preparing for a mission. *Apollo 15* marked the first

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[43] Phinney, 115-118.

[44] Compton, 227-230.

[45] Scott and Leonov with Toomey, 266.

mission in which Flight Directors traveled to the sites, so they could observe what the geology instructors wanted the astronauts to accomplish. One of the geologists explained the reasoning behind this: “The operations folks began to have a much better appreciation for what the science folks were trying to do and at the same time the science folks began to get a real appreciation for what the real constraints were: the safety things and the like.” *Apollo 15* also marked the first mission when a flight controller in Houston would be able to control a Rover mounted TV camera on the Moon, so camera operator Ed Fendell made the field trips as well. Yet another innovation for this mission concerning the flight controllers was the introduction of “math model” simulations of the moonwalks. In these simulations, a group of geology instructors stood in for the astronauts and introduced problems to challenge the controllers. Upon the loss of a film magazine or the failure of the Rover, the controllers would have to work with the scientists in the Mission Control backroom to find a solution without placing astronauts in harm’s way.[46]

The final field trip that Scott and Irwin took, to Arizona on June 25, 1971, encompassed more personnel and contained a greater degree of fidelity than ever before. The two astronauts carried their PLSS backpacks and radios while driving their Rover to replicate exploring the Moon. Nature had carved the Little Colorado River Gorge and Coconino Point into the landscape, so this site gave the men a sense of how to explore a fissure like Hadley Rille and mountains like the Apennines. Well over 50 people made the trip, from the CapComs, to the Flight Director, to Principal Investigators, to the

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[46] Ibid, 120-124.

scientists who sat in the Mission Control backroom sketching what the astronauts described, plotting the astronauts' position, and collating samples. The entire group stayed together for two days, so they could ask questions and make recommendations for the astronauts after each traverse just as they would when Scott and Irwin were on the Moon.[47] Though the crew still spent time in simulators as launch day approached, Scott made a comment during the post-mission debriefing that drove home just how much *Apollo* training had evolved over the last few years: "I think the system has matured enough so that the crews can now concentrate on accomplishing the mission objectives…rather than spend a great amount of time, like we have in the past, on malfunctions."[48] The maturation of the hardware helped him shift his attention to science, and he was about to reward geologists' faith in him.

Yet the Moon still had surprises in store for the fourth crew to land there and the simulator personnel who thought they had done an exemplary job preparing them. On July 30, Scott found a major surprise when the LM *Falcon* descended through the last 10,000 feet to the Hadley-Apennine site. He explained the problem in his memoir: "The plaster of Paris model of the Moon's surface we used during training was a relatively flat 15 feet by 15 feet. Mount Hadley Delta to our left loomed 11,000 feet high."[49] His time in the simulator thus did not prepare him very well for the experience of flying across tall mountains. That plaster of Paris model also replicated the landing site based on

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[47] Ibid, 124 and 150.

[48] "*Apollo 15* Technical Crew Debriefing," August 14, 1971, *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/ /alsj/a15/a15-techdebrief.pdf, 17-7 (accessed September 30, 2016).

[49] Scott and Leonov with Toomey, 291.

photos of relatively low resolution. When he was in the simulator looking out his window at this model, he could easily see the series of craters he expected to see along his descent path. But above the actual site, the fidelity of the model broke down as he saw many features he had not seen in training and initially felt disoriented. Yet he overcame the training flaws and again demonstrated the value of a trained human presence above the Moon. He set an *Apollo* record by redesignating the landing point eighteen times, stayed on a constant flight path all the way to the surface rather than leveling off high as previous crews had done, and descended the last fifty feet on instruments as dust obscured his view. Because he knew the engine bell at the bottom of the lander was longer than on previous missions, he made sure to stop the engine as soon as possible and the *Falcon* plopped the last few feet onto the plain at Hadley.[50]

Only two hours after the landing, Lee Silver watched from Mission Control as Scott placed the training he had given them to use. "One of the things that I had used in the training approach which the crews all seemed to appreciate was, first, stop and look," Silver explained.[51] Whether on Earth or the Moon, Silver wanted geologists to begin their work by making a general reconnaissance of their site. This would place their work of hunting for individual rocks in a broader context. Scott implemented this suggestion by climbing onto the ascent engine cover in *Falcon's* cabin, opening the top hatch, and sticking his head out. For half an hour, he aimed his telephoto lens at the features of his landing site and described for the scientists the extremely rounded mountains and

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[50] Mindell, 252-254.

[51] Phinney, 117.

hummocky terrain.[52]

Scott and Irwin called the Moon their home the next three days, during which the mental and physical flexibility they had obtained during the twenty months of training made them far superior explorers than any robotic vehicle. One example of their physical flexibility came when Scott drilled 10 feet into the soil, which allowed him to collect 42 layers of soil dating back millions of years. Although the drill initially did not budge when he and Irwin tried to lift it back up, the men demonstrated their value by hooking their arms under the handles and removing it.[53] The success in driving the Rover also attested to their physical flexibility, although this task proved to be more difficult on the Moon than on Earth. Scott had to constantly pay attention to the terrain to avoid obstacles, while braking required twice the distance on the Moon as in the training vehicle on Earth.[54] During their first two outings, they drove to the slopes of Mount Hadley Delta and placed their mental flexibility to work. Scott knew from his training that especially large boulders would give geologists rare insight into lunar history, because they had probably sat in their present location for a long period. Thus when he saw a knee-high boulder, he made sure to knock off a piece with his hammer, then roll it over and sample the soil underneath it. This soil allowed geologists to know how long the boulder had sat there. The following day, Irwin spotted a green coating on another rock. His vision had allowed him to make a finding which proved crucial,

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[52] Chaikin, 414-415 and Scott and Leonov, 295-296.

[53] Chaikin, 439-440.

[54] *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 15* (Houston, TX: MSC-05161, 1971), 9-8-3.

because geologists who studied this rock after its return to Earth found that it was made of tiny spheres of glass which implied volcanic activity.[55]

But amid the numerous examples of mental flexibility one can cite, the most striking came at Spur Crater on the second day. Irwin found a white rock that he encouraged Scott to lift with his tongs. When Scott wiped off the coating, he could see its white crystals glinting in the sunlight and exulted, "Guess what we just found? I think we found what we came for." While training in California's San Gabriel Mountains, Lee Silver had shown him a piece of anorthosite and emphasized the scientists' belief that this crystalline rock might represent part of the Moon's primordial crust.[56] Thus training had sent Scott and Irwin to the Moon with informed minds that encouraged them to pick up this sample and return it to Earth. Geologists on Earth, he reflected in his memoir, have the luxury of doing this work for weeks or months in one place. But on the Moon, "we would have to rely on instinct and training in picking a sample and would have only about five seconds to look at it, and maybe ten seconds to describe it, before bagging it and moving on." Given the time pressure, a less well trained astronaut might have missed this rock or its significance. But Scott returned this one to Earth so scientists could study the "Genesis Rock," as a reporter called it, in a laboratory environment and learn that it was almost as old as the entire solar system: 4.5 billion years.[57]

During the three days that Scott and Irwin spent at the Hadley-Apennine site,

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[55] Chaikin, 421 and 430.

[56] Ibid, 405 and 430-431.

[57] Scott and Leonov with Toomey, 273-274.

Worden kept himself busier than any of his predecessors thanks to the new SIM bay outside his ship *Endeavour*. He felt that his simulator training prepared him well for a challenging set of tasks: maintain the health of his spacecraft, deploy and monitor the science instruments as well as monitor glitches with their operation, and take photos. The demands on his time proved even greater than expected. The mass spectrometer boom did not fully retract and the mapping camera extended and retracted slower than expected, which required his attention. He also described the process of taking photos as "more detailed than anticipated," meaning he could not precisely follow the flight plan. But these issues did not derail him. Thanks to the combination of time in the simulator, flying over the mountains of the United States, and studying previous photos of the Moon, Worden went into lunar orbit proficient enough in target recognition that he did not require detailed flight plan times. While his two crewmates utilized training to expand knowledge of the Moon on a micro level, Worden did so on a macro level. His observations of Littrow Crater even paved the way for *Apollo 17* to land in that region.[58] During the return flight to Earth, Worden also performed an EVA to retrieve film magazines from the SIM Bay. He felt that his sessions in the KC-135 aircraft helped him to maneuver along handrails and bring himself down to a set of foot restraints next to the bay of science instruments. The CMPs for the next two missions repeated this task successfully.[59]

Next came *Apollo 16*, a mission designed to shed light on one of the Moon's

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[58] *Apollo 15* Mission Report, 9-9-2 and "*Apollo 15* Technical Crew Debriefing," 17-11.

[59] David Woods, "*Apollo 15* Flight Summary," *Apollo Flight Journal*, http://www.history.nasa.gov/ap15fj/a15summary.htm (accessed October 6, 2016) and "*Apollo 15* Technical Crew Debriefing," 17-15.

remaining mysteries: how volcanism had affected the highlands. Scientists knew from studying the basalts collected at the Sea of Tranquility and Ocean of Storms that the Moon's interior had once been molten. But these rocks all came from maria, which covered just 17 percent of a lunar surface about the size of Africa. If astronauts explored the highlands instead, they might add substantially to the body of knowledge about the Moon's volcanic history. Had the Moon been geologically alive as recently as one billion years ago? The *Apollo* Site Selection Board directed *Apollo 16*'s John Young and Charlie Duke to the Descartes Highlands near the equator to answer that question, while Ken Mattingly stayed behind in orbit.[60]

This decision affected their geology training. Young and Duke had already visited mountains and craters from Colorado, to New Mexico, to Arizona, to Nevada, to California, to Ontario, Canada. But the selection of the Descartes Highlands in June 1971 spurred the instructors to send them to sites featuring recent volcanism. A trip to the Long Valley Caldera in California allowed them to study a volcanic tableland that produced a flow of rhyolites into the ground, because some geologists believed they would find this rock. Rhyolite was an especially hard, granular material that could teach geologists about the Moon's history while also potentially serving as a building material for a lunar base. Since no astronaut had brought home any rhyolite yet, the instructors and astronauts valued this trip to an analog site on Earth. The instructors also adjusted the schedule of field trips to account for the prevalence of anorthosite that previous astronauts had found on the Moon. As on *Apollo 15*, the discovery of anorthosite could

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[60] Chaikin, 452-456.

teach scientists about the earliest part of the Moon's history. Realizing that Young and Duke needed experience in prospecting for this type of rock, the instructors sent them to the San Gabriel Mountains and the Duluth Complex in northern Minnesota.[61]

Training to work on the lunar surface continued to evolve even as the fifth lunar landing approached. One of the MSC geology instructors, Fred Hörz, convened a meeting at which his colleagues decided that astronauts should train for several new sampling techniques. Young and Duke learned about the new procedures and equipment to collect the uppermost film of lunar soil, split rocks, fillets, permanently shadowed soil, and radial samples. They also learned about the ALSEP they would deploy, which contained two new experiments. One would make them the first lunar astronomers. The astronauts planned to place an ultraviolet telescope in the shadow of their LM, point it at different portions of the sky, and remove the film for return to Earth. The other new experiment required them to slide open a plate containing sheets of mica, foil, and glass and hang it onto the LM to determine the effect of cosmic rays on these materials. Young and Duke felt prepared for all of these tasks, because of the time they spent in their suits. Young recalled that he spent 350 hours training in his suit for this mission, because he had to know how to operate through thick gloves and a stiff torso that did not bend easily. Sessions of several hours each at the rock pile allowed them to rehearse deploying the ALSEP 13 times.[62]

Geology instructor Bill Phinney kept a log of the astronauts' training that

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[61] Young with Hansen, 156-157.

[62] Phinney, 128-129.

underscored how thoroughly Young and Duke could prepare given how experienced they already were in operating spacecraft. They had each been backups on *Apollo 13,* while also participating in early reviews of the upgraded LM and Rover that gave them understanding of the new hardware they would have to operate on *Apollo 16*. This allowed them to spend 40 percent of their training time preparing to solve the scientific mysteries of the Moon.[63] Geology lectures took up 124 hours of their time. Hörz directed a series of sessions to study Moon rocks returned by the four previous landing crews, which took up another 50 hours. Suited sessions at the rock pile lasted about four hours each for a total of 142 hours. Field trips took up another 36 days, with flight controllers preparing themselves during 12 additional days of "math model" simulations. Ken Mattingly had a less grueling schedule for his orbital duties, but did listen to 36 hours of lectures by Farouk El-Baz and spent 18 days honing his observational skills by flying over the United States.[64] Young summarized the experience by explaining, "It's easy to look back and say you didn't need this or you didn't need that but I think the purpose of most training is to help you take what you learned and go on from there…It's not the amount of training you do. It's just how it prepares you. I think we were all well prepared."[65] Stated another way, he understood that his goal was not to memorize every detail from those hours but to develop a new way of thinking: that natural features could tell a story about geologic history.

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[63] *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 16* (Houston, TX: MSC-07230, 1972), 9-1.

[64] Phinney, 264-267.

[65] Ibid, 127.

Young, Mattingly, and Duke first needed to reach the Moon, however, and the journey there provided a striking case study in the need for a trained crew that could overcome glitches with finicky equipment. "I think we calculated once that we worked on about 99 things during the mission that we either solved in real time or that the ground had to solve," Young explained afterwards. "It was the most of anybody, I think. But we had been trained to do that. That's what our line of work is." The men had barely grown accustomed to zero gravity after their launch on April 16, 1972 when flight controllers noticed a possible leak in the primary coolant loop for the CSM *Casper*. Yet the crew checked the ship's settings and resolved the problem. The controllers also found a helium leak in the *Saturn* rocket stage that would propel the astronauts beyond earth orbit. Yet the crew had *Casper's* thrusters ready to maintain a proper attitude if required.[66] The greatest scares came on landing day, April 20. When Young and Duke climbed into the LM *Orion* and prepared its systems for the undocking from *Casper*, they found they could not move the antenna used to communicate with Earth in the yaw axis. This meant that flight controllers could not directly uplink the numbers that *Orion's* computer needed to navigate the ship to the landing site. Duke had no choice but to copy and insert a series of five-digit numbers into the computer, which he did with no mistakes. Young then found that the RCS in the descent stage had overpressurized. Yet he vented pressure from this system into the propulsion system in *Orion's* ascent stage, which would not affect the landing. The need to diagnose these issues and take

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[66] Tim Brandt, "*Apollo 16* Flight Summary," *Apollo Flight Journal*, http://www.history.nasa.gov/ap16fj/a16summary.htm (accessed October 5, 2016).

corrective actions under time pressure helped to vindicate those many hours of simulator time.[67]

The most serious issue that day almost prevented Young and Duke from landing, but instead vindicated the value of integrated simulations. After the two men overcame their problems and undocked in their ship *Orion*, Mattingly discovered an inexplicable shaking in his ship *Casper* when he used a set of thumbwheels to control the SPS engine's gimbal motors. Upon hearing his words, "I be a sorry bird," the dejected Young and Duke assumed they would have to abort the landing.[68] Yet they underestimated the network of Command Module experts across the United States, who had the experience of problem solving during integrated simulations for several lunar flights. The simulator personnel fed the strip charts of telemetry from *Casper* into the computers that operated the Command Module simulator, where Gene Cernan tried to halt the unwanted shaking of the vehicle. He could not do so, but the question remained: were the oscillations serious enough to abort the mission? Engineers at North American Rockwell studied the same telemetry data and did not believe there was structural damage to the engine. These engineers believed *Casper* could maintain its proper heading during all future burns. Finally, former astronaut Jim McDivitt weighed in as manager of the *Apollo* Spacecraft Program Office. He remembered the shaking of a firing SPS engine on his *Apollo 9* flight and recommended that the mission could still continue to new MSC Director Chris Kraft. Four hours after Mattingly's troubling

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[67] Young with Hansen, 166-167.
[68] Ibid, 167-169.

words, the CapCom gave Young and Duke the news that they could land after all. This provided one of the best examples in the entire *Apollo* program of why astronauts trained in conjunction with engineers at NASA and contractor companies whose knowledge could save missions.[69]

The landing provided still another reminder of an *Apollo 16* theme: that adversity could easily thwart the efforts of a crew that did not have the training to overcome it. Young relied on his experience in the Lunar Module Simulator and LLTV to make several landing point redesignations in a terrain far more heavily cratered than most of his predecessors had confronted. A later discovery confirmed the danger of this task. If he had landed about 80 feet in any direction from where he did, *Orion* would have touched down on a slope of six to ten degrees and thus placed their liftoff a few days later in serious jeopardy. Yet he had the presence of mind and the luck, as he admitted in his memoir, to land in a clear and flat region. He also landed more upright than any *Apollo* Commanders except Neil Armstrong and Pete Conrad, and those two did not have to deal with such a heavily cratered landing site.[70] Young's experience was a dramatic testament to one of the main themes of *Apollo*: that a trained aviator deserved a place on a lunar mission. No robotic lander could have surveyed a landscape and made adjustments in real time to avoid an unfavorable site.

The first outing onto the Descartes Highlands provided still more adversity, as Young and Duke set up their ALSEP package. Their experience doing this illustrated

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[69] Richard Witkin, "Exhaustive Ground Tests Find Trouble Not Critical," *New York Times*, April 21, 1972.

[70] Young with Hansen, 171.

why they had rehearsed so thoroughly for such a seemingly routine task. As Duke carried a package containing the Radioisotope Thermoelectric Generator (RTG) intended to power the experiments, the RTG inadvertently fell onto the surface. This incident did not cause any damage, but Young made a mistake that curtailed the Heat Flow Experiment. He tripped on a cable to the experiment and severed it, as he remembered doing a few times in training. "It became clear to me once again that when you fail in simulations, you either need to fix the simulation or correct the situation, because if you can't do it right in training, you won't get it done correctly in the real world, especially not on the Moon," he lamented. This was one of the few examples in *Apollo* when nobody learned a lesson from the training experience and modified equipment or procedures for the real mission.[71] Still, Young and Duke could have corrected the mistake with more time. A team of engineers met over the night and devised a method by which to reattach the experiment cable into the Central Station connector. The method entailed the astronauts stripping away the cable's insulation and exposing its wires, using lunar rock as an abrasive, and then reconnecting the experiment into the Central Station. This would have been one of the clearest indications yet of the value of sending trained humans to the Moon rather than robots only, and backup Commander Fred Haise demonstrated that it could work, but *Apollo* Program Director Rocco Petrone vetoed the idea as too time consuming.[72]

The other major lesson of *Apollo 16* concerned that new way of thinking that

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[71] Ibid, 177-178.

[72] Chaikin, 477-478.

geology training had instilled in Young and Duke. If these astronauts had tried to simply memorize what geology instructors had told them, they would have been led astray because they did not find what the geologists had expected them to find at Descartes. The point of picking this landing site had been to find volcanic rocks, yet Young and Duke sampled only breccias (a mixture of rock fragments welded together by a meteorite impact). They needed the intuition to recognize what they actually found and adapt to this knowledge, and training had given them this ability. During their field trips and studies of previously returned Moon rocks, they had come to quickly recognize breccias and basalts and knew they were not finding any of the latter. Despite knowing that the two men were pilots and not professional scientists, the field trips had given the geologists in the Mission Control backroom confidence in their ability to observe and sample.[73]

As it turned out, Young and Duke proved they could add usefully to knowledge of the Moon even if the prediction of what they would find had proven incorrect. The idea of ancient meteorite impacts shaping the highlands also intrigued scientists, and the two men provided evidence for this by traveling to the highest vantage point ever reached on the Moon on the second day and to the rim of the deepest excavation ever explored on the third day. The drive 500 feet up the slopes of Stone Mountain revealed rocks rounded by the cosmic bombardment of ancient meteorites. The drive to the rim of 650 foot North Ray Crater revealed bedrock that had been ejected from the crater floor. Duke convinced Young to walk to one rock that was forty-five feet high and chip

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[73] Ibid, 474.

off samples with a hammer, which Duke described as "like trying to dismantle the Empire State Building with a crowbar." Here again, the men realized they were seeing material fused together by ancient impacts and not volcanism.[74] Besides giving them the flexibility to interpret and describe their findings, training helped them overcome several glitches. From the loss of the Rover's pitch indicator, to the loss of the Rover's right rear fender, to the loss of power to the Rover's rear wheels, to the failure of the sample collection bags to stay tight, Young remembered "about thirty-five things that would have been anomalies while we were on the Moon." Yet he quickly added, "We were able to fix all of them in real time without bothering Mission Control." When Young and Duke lifted off from Descartes on April 24 and splashed down with Mattingly three days later, they could say that they had overcome more problems than almost any of their predecessors while suggesting a new hypothesis about the history of the Moon.[75]

Only one chance now remained for astronauts to explore the Moon, and the crew of *Apollo 17* marked a major departure from all previous crews that had traveled into space. For the first time, a professional scientist would voyage into space. The normal selection pattern would have resulted in the *Apollo 14* backup crew of Gene Cernan, Ron Evans, and Joe Engle flying the last mission. But the *Apollo 15* backup crew contained Harrison "Jack" Schmitt as LMP, which raised a crucial question. Given that training now focused heavily on developing geological skills, why should geologists train a pilot like Engle when a Ph.D. geologist could voyage to the Moon instead? Deke Slayton was

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[74] Chaikin, 478-490 and Charlie and Dotty Duke, *Moonwalker* (Nashville: Oliver-Nelson, 1990), 203-204.

[75] Young with Hansen, 189-190 and Eric Jones, "Descartes Surprise," *Apollo Lunar Surface Journal*, http://www.hq.nasa.gov/alsj/a16/a16.htm (accessed October 6, 2016).

well aware of this argument, but considered Engle "a terrific stick and rudder guy" who was still the most qualified choice for LMP on *Apollo 17*. He understood that Schmitt had become a jet pilot himself and had worked hard to understand *Apollo* hardware over his seven years in the astronaut corps, but submitted a crew of Cernan, Evans, and Engle to Washington, D.C. The NASA Headquarters personnel promptly rejected Slayton's choice. The Director of Flight Crew Operations had no choice but to abide by their wish for a scientific presence on the last *Apollo* crew and submit a crew of Cernan, Evans, and Schmitt instead.[76] This in turn raised a crucial question the crew would have to answer in training: how could Cernan and Schmitt overcome their differences in background and become an effective team on the lunar surface?

Schmitt answered the question by demonstrating his skill in the cockpits of aircraft and spacecraft simulators. He needed to prove that a Ph.D. geologist would not be a liability while in flight and the evidence indicates that he did this. Even Slayton and Cernan, who had indicated their dismay with the idea of sending scientists into space earlier in their memoirs, each had positive assessments of Schmitt's performance on *Apollo 17*.[77] Schmitt himself remembered that his time flying helicopters helped him improve his hand/eye coordination and build his confidence in the maneuvers he would experience in a spacecraft. But the real test of his ability as a crewmember came in the Lunar Module Simulator. Only Cernan piloted the vehicle, so his job was not about the stick and rudder skills Slayton had mentioned anyway. He only needed to become

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[76] Slayton with Cassutt, 271.

[77] Ibid, 280 and Cernan with Davis, 334.

proficient in operating the ship's computer, responding to any glitches that he saw on the instrument panel, and communicating effectively with Cernan during the landing and subsequent liftoff from the lunar surface. He also needed to become knowledgeable in CSM systems on the right side of the vehicle, where he would fly for the remainder of the mission. He argued, "I could fly, and I could do the simulations as well as, maybe, anybody," and no fellow astronaut has disputed this. He also impressed his colleagues with his work ethic in logging simulator hours. At least in Schmitt's case, cross training a geologist to operate a spacecraft did not pose any serious problems either in training or flight.[78]

Cernan needed to prove the opposite: that cross training a pilot to become a geologist would work and (the difference between *Apollo 17* and previous flights) that he could interface well with a Ph.D. geologist. He explained the difference in backgrounds between himself and Schmitt in blunt terms, saying that Schmitt was a scientific *investigator* who "could jump in with his colleagues back here on Earth and tear those rocks apart from now until hell freezes over," whereas he was only a scientific *observer* who was content to describe his general geological surroundings.[79] But the 14 field trips that the two men took together from October 1971 to November 1972 helped build Cernan's confidence to the point that he felt comfortable making detailed descriptions and interpretations of the geology he saw without deferring to his more

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[78] Harrison H. "Jack" Schmitt, Interviewed by Carol Butler, July 14, 1999, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/SchmittHH/SchmittHH_7-14-99.htm (accessed October 6, 2016) and Chaikin, 396-397 and 400-401.

[79] [Interview with Eugene A. Cernan, Houston, Texas, April 6, 1984, Box APO-074-42, *Apollo* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 1-2.

experienced crewmate. The geology instructors showed no bias toward Schmitt in giving the astronauts lectures and speaking to them during the field trips, instead giving Cernan equal treatment. At the end of this process, none of them complained about Cernan's ability or his working relationship with Schmitt. "He is one of the most articulate astronauts, and he possesses an exceptional ability to describe what he is observing," argued USGS instructor Don Wilhelms.[80] Cernan remembered himself as a useful complement to Schmitt. Despite lacking the knowledge of his crewmate, he did not feel intimidated by Schmitt because he felt he could make geological interpretations just as effectively. Schmitt's advantage in knowledge may have been more pronounced if the crew planned to stay several months on the Moon, but the two men only planned to explore for about 21 hours.[81]

The selection of the Valley of Taurus-Littrow as the last *Apollo* landing site especially affected the training of Cernan and Schmitt. The two would visit a region that appeared in Al Worden's *Apollo 15* photos to contain volcanic cinder cones, some of the darkest and youngest lunar material on the valley floor, and some of the oldest lunar material in two mountains called the North and South Massifs.[82] The detail in these photos meant instructors knew what analog sites Cernan and Schmitt should visit on Earth. Thus the two made an August 1972 trip to the 430 foot Lunar Crater in Nevada, which contained cones formed around a volcanic vent. In October, the astronauts, geology instructors, and scientists who would populate the backroom at Mission Control

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[80] Phinney, 129-130 and Wilhelms, 316.

[81] Interview with Cernan, 5.

[82] Chaikin, 506-507.

visited the Blackhawk landslide in southern California. The instructors knew that large boulders had fallen down the Moon's North and South Massifs in landslides, so they directed the astronauts to investigate this 5 mile long landslide while driving the Rover and performing all the tasks of a 7 hour lunar exploration. The last field trip ever made by *Apollo* astronauts took Cernan and Schmitt to Sunset Crater near Flagstaff, Arizona. On November 2 and 3, USGS instructor Hank Moore evaluated the astronauts and the backroom personnel in their joint efforts to investigate this site. Even at this point, he managed to make criticisms that proved the value of training. The backroom personnel directed the astronauts to follow a route that proved impassible, for instance, which forced them to re-plan the traverse and waste valuable time. Yet Moore made a highly positive assessment of the astronauts' performance in his memo. The time had come to take one last crack at deciphering the Moon's secrets.[83]

When Cernan, Evans, and Schmitt launched on December 7, they embarked on a mission that bore all the marks of an experienced team strengthened by training. None of the lunar landings had fewer hardware glitches than the last, which according to the mission report "represents the culmination of continual advances in training." None returned more material from the lunar surface than Cernan and Schmitt did, at 243 pounds. These men proved that trained humans could not only return hundreds of times more material than any robotic vehicle, but had the flexibility to return large rocks, permanently shadowed soil, and core tube soil samples up to about 10 feet deep.[84]

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[83] Wilhelms, 316-317 and Phinney, 130-131

[84] *Apollo* Mission Evaluation Team, *Apollo* Program Mission Report, *Apollo 17* (Houston, TX: MSC-07904, 1973), 16-1 and 10-20.

Schmitt also proved that the descriptive ability of a geologist went beyond that of the pilots who had explored the Moon thus far. He argued himself, “We got excellent sampling, we got excellent photography…but until *Apollo 17* we did not get very much good, solid descriptive work.”[85] The *Apollo 17* air to ground transmissions show the difference that his presence made on the last mission. When he told the CapCom, “Bob (Parker), I’m at the east-southeast rim of a thirty-meter crater, in the light mantle, up on the scarp and maybe two hundred meters from the rim of Lara,” he gave the backroom scientists a better idea of the setting and allowed them to more effectively plan traverses. Yet at the same time, the scientists acknowledged that Cernan made useful observations and proved, on the strength of his training, that he could be more than Schmitt’s caddy.[86]

But most compellingly, the men proved that trained humans had the power of recognition that robots did not have. During their second outing, Cernan decided to stop the Rover on the way to Shorty Crater even though the backroom personnel had advised against this. This allowed Schmitt to reach down with a scoop and collect a light-colored soil he had spotted. Scientists later recognized this as ejecta from the crater Tycho that had sat in the valley for 109 million years. Thus the two astronauts’ acuity of vision and thought allowed scientists to learn when one of the Moon’s most famous craters had formed. About an hour later, Schmitt was walking near the rim of Shorty when he exclaimed, “There is orange soil!” Again his acuity of vision had allowed him to make an unexpected finding, and immediately his thoughts turned to the volcanic sites

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[85] Compton, 267.

[86] Chaikin, 524-525.

he had visited while training. At these sites, he had seen chunks of lava that had been colored after being exposed to an eruption of hot gases. He and Cernan collected a 3 foot core sample of the material, allowing scientists to study it back on Earth and make a crucial discovery: an eruption of gases called a fire fountain had propelled these tiny beads of glass into the sky 3.5 billion years ago. Some of the beads were orange because they were high in titanium content, while some were especially dark and explained the appearance of the valley floor in Worden's photos. More importantly, the scientists' knowledge of the gases in the fire fountain caused them to rethink how the Moon had evolved.[87] Both of these findings were classic examples of trained humans exercising their ability to make unexpected findings, a key advantage that humans have over robots in exploring space.

No human has set foot on the Moon since Cernan made his last footprint in the Valley of Taurus-Littrow on December 13, 1972. President John F. Kennedy had made the decision to send astronauts there in the first place on the basis of the Cold War competition with the Soviet Union, and with that competition won Richard Nixon's administration shut down any hope of a permanent lunar base that would build on the achievements of *Apollo*. But the meticulous training of the *Apollo* crews left no doubt that astronauts could contribute to the scientific understanding of the Moon. Anybody could have filled a container with rocks, but training had given them the ability to instantly recognize where they should focus their attention and to communicate their knowledge to scientists listening on Earth. Those who claim that all of this could have

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[87] Ibid, 525-530.

been done by robotic vehicles are wrong. The Soviet Union did launch three *Luna* probes that deployed rovers which returned lunar material to Earth in the 1970s, but hundreds of times less than that returned by the astronauts and collected indiscriminately. These rovers did not have anything nearly as sophisticated as a human brain that people could train, and consequently scientists understand the geologic structure of the six *Apollo* landing sites much better than the *Luna* sites. Another way to look at this issue is to consider how geologists attain knowledge on Earth. Geologists do not send small rovers into field sites and hope for the best. Geologists visit sites repeatedly and use their intelligence to make a determination about what is worthy of their attention and what is not. Some sites still provide knowledge after being studied for more than 100 years.[88] The *Apollo* astronauts trained to maximize their intelligence and as a result easily surpassed what robots could have done.

Because the astronauts had taken such informed minds to the Moon, scientists have been able to make informed studies of the 842 pounds of lunar material they returned. For more than forty years, scientists have studied these rocks more thoroughly than almost any other collection of material in the history of science. These studies have given scientists a clearer view of the history of a 4.5 billion year old object, which contains no erosion to wipe away that history as Earth does.[89] Major findings continued even into the 1980s. Scientists announced then what is still the leading theory for how

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[88] Francis Slakey and Paul D. Spudis, “Robots vs. Humans: Who Should Explore Space?” February 1, 2008, *Scientific American*, https://www.scientificamerican.com/article/robots-vs-humans-who-should-explore (accessed October 9, 2016).

[89] Paul D. Spudis, *The Value of the Moon: How to Explore, Live, and Prosper in Space Using the Moon’s Resources* (Washington, D.C.: Smithsonian Books, 2016), 28-29.

the Moon formed: shortly after the formation of Earth, an asteroid the size of Mars struck it and ejected part of Earth's mantle into space, the remnants of which fused together to form the Moon. Scientists also found a gas called helium-3 in lunar material, which could provide a clean energy source if future generations choose to mine it (the gas is highly rare on Earth).[90]

The scientific rewards of the astronauts' work run even deeper than this. The knowledge of the Moon that they returned still guides scientists' interpretations of the entire solar system. Specifically, the timescale of lunar history that scientists now have has informed their estimates of the timescales of planets such as Mercury and Mars. The knowledge gained from lunar samples has also shaped scientists' understanding of impacts throughout the solar system. Scientists now know the telltale signs of materials that have made hypervelocity impacts into planets, such as excess amounts of the element iridium. Several years after *Apollo* ended, geologist Walter Alvarez found an excess amount of iridium in the clay layer that marks the end of the Cretaceous Era on Earth. This provided crucial evidence for the idea that a meteorite had slammed into Earth 65 million years ago and accounted for the extinction of the dinosaurs. "It was thought that we got some rocks and some ages for a few ancient events in the history of the Moon—but so what? That 'so what' is now recognized as a revolutionary paradigm shift in our understanding of the significance of impact in Earth history," explains Paul Spudis. "We now view the process of the evolution of life on Earth from a new and

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[90] Chaikin, 574-576.

unexpected perspective."[91] The evidence is clear that though *Apollo* began for political reasons, the program produced an exceptional scientific legacy. This is the best barometer of *Apollo* astronaut training.

Training the next humans to set foot on the Moon will probably differ significantly from *Apollo*. Whether the effort originates from NASA, a U.S. private company, or the Chinese National Space Agency, future crews will travel to the Moon aboard a vehicle with far fewer switches than the *Apollo* CSM and a computer with far more than *Apollo's* 64 kilobytes of memory. Simulator training will thus have to reflect 21st century hardware and software. These crews will likely spend much more than three days on the lunar surface and stay together for their entire journey, meaning the *Apollo* practice of keeping one astronaut in orbit will probably remain relegated to the past. Instructors will thus have to place a greater emphasis on evaluating these crews for compatibility over a long duration. These crews will likely need to have a much more diverse skill set than their *Apollo* predecessors, to ensure that they can produce their own food, construct habitats, operate robotic equipment, and perform large-scale mining of resources such as helium-3.[92] Training for many of these skills will more closely approximate the ISS era than *Apollo*, because the ISS supports crews for long duration missions, using present technology, with the intention of preparing for flights beyond Earth orbit. Training technology itself will also reflect the improvements made since the

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[91] Spudis, *The Value of the Moon*, 30-31.

[92] See Young with Hansen, 371-374 and Harrison H. Schmitt, *Return to the Moon: Exploration, Enterprise, and Energy in the Human Settlement of Space* (New York: Copernicus Books in association with Springer-Praxis Publishing, 2006), 131-133.

Apollo era, as seen in the virtual reality devices that college students now use to build their geology skills.[93]

Yet future instructors will have to bear in mind some of the lessons of *Apollo* training. Bill Phinney has already cited several lessons in his history of the subject. Instructors should continue to prepare astronauts for lunar exploration by sending them to analog field sites on Earth, because this remains the best method to teach geological skills. Classroom instruction should continue as well, but only on an introductory level before instructors move on to hands-on work in the field. Phinney suggests a training site in Antarctica may be useful to acclimate crews to living for long periods in hostile conditions. The other lessons he cites are similar to training for spacecraft operation. Mission Control personnel should closely monitor the field work, as they did during training for the last *Apollo* missions. Simulations in the field should include contingencies designed to test the resolve of astronauts and controllers working together. At the end of the sessions, all personnel should take part in debriefings with the instructors.[94] In addition to Phinney's points, the *Apollo* experience makes clear that future lunar explorers should train to deal with the fine grained dust that clung to the astronauts' suits and even hampered their driving. Training to land a spacecraft in one-sixth gravity should also remain a priority. The challenge here will be to develop a vehicle that allows astronauts to rehearse controlling lateral motion and rate of descent in low gravity, but without the safety hazards of the LLTV.

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[93] Jamie K. Pringle, "Virtual Geology Special Issue: Developing Training, Teaching and Research Skillsets for Geoscientists," *Geology Today* Vol. 31, Issue 6 (November/December 2015): 213.

[94] Phinney, 176-178.

Almost a half century after the last human set foot on Earth's neighbor in space, the words of one of the twelve men who walked there still have the ring of authenticity. After the splashdown of *Apollo 15*, the crew held a press conference at which Dave Scott said, "We went to the Moon as trained observers in order to gather data, not only with our instruments on board, but also with our minds. Plutarch, a wise man who lived a long time ago, expressed the feelings of the crew of *Apollo 15* when he wrote, 'The mind is not a vessel to be filled, but a fire to be lighted.'" This man whose life work revolved around airplanes and engineering had nonetheless helped to transform scientific knowledge of the Moon through a training process that had fired his curiosity. The descent stage of his Lunar Module still sits next to the mountains he explored for three days in 1971, waiting to light a fire in the next wave of explorers.[95]

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[95] Scott and Leonov with Toomey, 320.

CHAPTER IX

SKYLAB: "NO WEAKNESS WAS OVERLOOKED"

Edward Everett Hale authored the first known proposal of the idea. In 1869, the Massachusetts writer published a short story in the *Atlantic Monthly* describing how thirty-seven people lived in a "brick moon" launched into Earth orbit. The inhabitants of this space station enjoyed a high quality of life as they planted their own food and served as a navigational reference for sailing vessels on the Earth below them. From this humble beginning, the futurists of the early twentieth century made the first technical designs for a space station. Virtually all serious space enthusiasts proposed space stations as orbital "base camps" to more distant destinations, in the tradition of mountain climbing. The idea of building a large structure that rotated to produce artificial gravity flowed from the writings of Russian Konstantin Tsiolkovsky and Germans Hermann Oberth and Wernher von Braun, to a major element in a NASA long-range plan prepared in 1959. President John F. Kennedy's declaration prompted the decision to send men to the Moon directly, without stopping at any "base camp." But space station advocates within NASA continued to study the concept, knowing the urgency of reaching the Moon would eventually fade and that an orbital outpost would mark one of the next steps in spaceflight.[1]

Advanced studies at the LRC and MSC helped to develop a strong rationale for

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[1] Roger D. Launius, *Space Stations: Base Camps to the Stars* (Washington, D.C.: Smithsonian Institution, 2003), 1-50.

this by 1963. The first visits of astronauts to a space station would determine whether they could function for several weeks in zero gravity or upon their sudden return to normal gravity. The astronauts could perform biomedical experiments for this purpose, as well as investigations in astronomy and physics. These first flights would verify the engineering and operational details of a more ambitious station, from where astronauts might embark to the Moon or Mars. But the first station would derive from *Apollo* hardware, as a *Saturn V* rocket would launch it and astronauts would travel to it aboard a CSM launched by a *Saturn IB* rocket. In 1965, George Mueller announced the formation of an *Apollo Applications* office designed to plan for future uses of this hardware.[2] Though plans to continue using the hardware for a lunar base fell by the wayside in the wake of NASA budget cuts during the last years of Lyndon Johnson's presidency and first years of Richard Nixon's, Mueller's advocacy managed to keep the space station idea alive. The years of program definition finally ended in 1970, when a design review established the final form of a space station now named *Skylab*: an orbital workshop with room for three astronauts to eat, sleep, and perform research, surrounded by a solar observatory called the *Apollo* Telescope Mount (ATM), solar arrays, a micrometeoroid shield, and an adapter with which an *Apollo* CSM could dock.[3] If the *Apollo* astronauts had been explorers analogous to Christopher Columbus and his crew in 1492, the *Skylab* astronauts would be settlers analogous to those at Jamestown, Virginia in 1607. They would have to master living in this new environment over the

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[2] W. David Compton and Charles D. Benson, *Living and Working in Space: A History of Skylab* (Washington, D.C.: NASA-SP-4208, 1983), 9-21.

[3] Ibid, 111-113.

long haul.

The astronauts who would carry out this feat learned of their assignment to America's first space station in 1970. Deke Slayton announced at a Monday morning pilots' meeting early that year that he had assigned *Gemini* and *Apollo* veteran Pete Conrad to the program and trusted him to supervise the tasks crews would perform in training. Most of the others who had already flown in space decided to move on after the end of *Apollo*, but Alan Bean, Rusty Schweickart, and Walt Cunningham also joined the program. A group of pilots from the 1966 class including Vance Brand, Jerry Carr, Don Lind, Jack Lousma, Bruce McCandless, Bill Pogue, and Paul Weitz joined in hopes of gaining their first spaceflights. A group of scientists from the 1965 and 1967 classes including Owen Garriott, Ed Gibson, Karl Henize, Don Holmquest, Joe Kerwin, Bill Lenoir, Story Musgrave, Bob Parker, and Bill Thornton joined in hopes of contributing their research skills. Finally, the program gained a few of the pilots who had worked on the Air Force's canceled Manned Orbiting Laboratory before transferring to NASA in 1969. This group included Karol Bobko, Bob Crippen, Hank Hartsfield, and Dick Truly.[4] All participated in the development of the program and support of the three flights, but the announcement of the three crews who would fly aboard *Skylab* came on January 18, 1972. Conrad, Kerwin, and Weitz would fly for 28 days on the first mission (doubling the previous duration record for an American human spaceflight). Bean, Garriott, and Lousma would fly for 56 days on the second mission. Carr, Gibson, and

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[4] Slayton with Cassutt, 271-272 and Brooks, Grimwood, and Swenson, 373-380.

Pogue also would fly for 56 days on the third mission.[5]

The three crews would need to follow an even more daunting training regimen than their *Apollo* predecessors. Conrad had sent a memo to his colleagues in April 1971 explaining that each crew would consist of three members: the Commander, Science Pilot, and Pilot. The Commanders (Conrad, Bean, and Carr) would have responsibility for the success of the mission, the safety of the crew, the *Apollo* CSM systems, and any EVAs while at the orbital workshop. Conrad expected this crewmember to train for 1,411 hours. The Science Pilots (Kerwin, Garriott, and Gibson) would have responsibility for most experiments, which would push this crewmember's training load to 1,500 hours. Thus for the first time in American spaceflight, one of the crew positions called for a background in science rather than piloting. The Pilots (Weitz, Lousma, and Pogue) would specialize in the station's hardware, including the airlock, docking adapter, and workshop systems, as well as Earth resources experiments. Conrad expected 1,420 hours from this person. The hours for all three crewmembers surpassed that of *Apollo* crews, because although *Skylab* crews did not have to confront the dynamic tasks of landing a spacecraft on another world or exploring it, they would have to develop their knowledge for a more complex spacecraft and a far greater number of scientific investigations.[6] A NASA publication stressed that training time for *Skylab* astronauts would equal the classroom hours for a four-year college degree. Add this to the time the men spent studying documents, exercising, and flying T-38 airplanes, and

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[5] David Hitt, Owen Garriott, and Joe Kerwin, *Homesteading Space: The Skylab Story* (Lincoln: University of Nebraska Press, 2008), 67.

[6] Hitt, Garriott, and Kerwin, 68.

Skylab crews found every day full except Sundays.[7]

The regimen began with lectures designed to give the astronauts basic familiarity in their hardware and tasks, following the tradition established during *Mercury*, *Gemini*, and *Apollo*. This began in 1970, when an investigator for the ATM called for the astronauts to receive lectures on solar physics. Richard Tousey, an astronomer who had been a pioneer in observing the Sun from unmanned space vehicles, knew that crews would benefit from an understanding of solar physics as they operated the telescope mount. An informed crew would collect data more intelligently just as the *Apollo* moonwalkers had. He sent a letter to *Skylab* Program Manager Robert Thompson in February complaining "that little has been done as yet to arrange for scientific training of the crew." This was largely because the aforementioned astronauts were still participating in design reviews, but a group of MSC managers decided at Tousey's prodding that they should begin a 10-week, 60-hour course in October. This took place under the direction of Dr. Frank Orrall, a University of Hawaii physicist. Though several of the astronauts found the content unfamiliar and difficult to follow, the evidence indicates that the knowledge they accumulated made them more skilled and enthusiastic about studying the Sun from orbit. The nine men who flew aboard *Skylab* operated the telescope mount past scheduled times and even into their sleep periods, because the knowledge attained during training sparked their curiosity.[8]

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[7] Leland F. Belew and Ernst Stuhlinger, *Skylab: A Guidebook* (Washington, D.C.: NASA EP-107, 1973), 37 and Hitt, Garriott, and Kerwin, 69.

[8] Compton and Benson, 221-226 and John A. Eddy, *A New Sun: The Solar Results From Skylab* (Washington, D.C.: NASA SP-402, 1979), 57.

Lectures continued into 1971, following a syllabus created by the MSC's Robert Kohler. Principal Investigators from various universities lectured the astronauts on the theories behind what became 82 experiments covering space science, Earth resources, life science, space technology, and student projects. Two Principal Investigators, Henize and Thornton, even came from the astronaut corps. Then came lectures from Martin Marietta instructors explaining the equipment and operational procedures behind each experiment. As one example, the astronauts learned that the Human Vestibular Function experiment would be crucial to understanding their physiological response to long-term stays in zero gravity, because it would test for changes to the sensitivity of their semicircular canals. Then they learned about the rotating chair they would have to sit in, which contained a motor that could whirl them around at speeds from 1 to 30 rpm to collect data. Instructors from Martin Marietta and McDonnell Douglas, the contractor chosen to manufacture the orbital workshop, lectured the astronauts on *Skylab* systems. Finally, North American Rockwell instructors visited Houston to give the astronauts 130 hours of lectures on *Apollo* CSM systems. Though crews would only spend a handful of hours in these ships, most of the astronauts had not flown in one before and an error could have proven fatal. In evaluating the lectures as a whole, MSC training chief John Von Bockel praised the astronauts as eager to learn but believed instructors had too much difficulty in finding material. He argued that future instructors should prepare training materials further in advance.[9]

The tradition of astronaut participation in hardware checkout continued through

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[9] Compton and Benson, 226-230.

the three years prior to *Skylab's* 1973 launch. Leland Belew, a *Skylab* manager at the Marshall Spaceflight Center (MSFC) in Huntsville, Alabama decided to call upon astronauts and groups of engineers to take part in monthly crew station reviews. These required them to travel to the McDonnell Douglas plant in St. Louis, walk through mockups of the 48 by 21 foot orbital workshop (about the size of a small three bedroom home) this company had manufactured and verify that the vehicle met operational requirements. The astronauts could then send their input to a configuration control board, which made judgments on the benefits of proposed changes and effects on cost and schedule. Since *Skylab* crews would have to live in this workshop rather than make the camping style trip of the *Apollo* era, their recommendations on crew comfort especially carried weight.[10] The men who would fly on the station eventually spent about 200 hours observing tests of its hardware. Joe Kerwin remembered traveling to St. Louis for a 1972 test and finding, "The spacecraft was clean, beautiful, and completely functional. We felt that industry had finally learned how to build them and test them, and we partied that night at the motel with our contractor teammates."[11] When asked about the value of this experience today, he remarks, "The critical factor in our knowledge of the workshop was that we participated in design and testing, not just training. We had several years of that and got really good at it."[12]

Like their predecessors, *Skylab* astronauts had multiple simulators in which to train prior to their flights. The first step would be the launch, rendezvous, and docking

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[10] Ibid, 124-125.

[11] Ibid, 227 and Hitt, Garriott, and Kerwin, 69-70.

[12] Kerwin, E-Mail Correspondence with Author.

with the space station aboard an *Apollo* CSM. *Skylab* crews thus continued to use the Dynamic Crew Procedures Simulator to become familiar with launch procedures. The Command Module Simulator then prepared them to voyage to the station. Most of these astronauts had not flown in space before, but they could still make use of the experience in piloting procedures from *Gemini* and *Apollo*. They and the simulator instructors could draw on a vast knowledge base concerning the act of slowing to a fraction of a foot per second relative to a target and then using probe and drogue hardware to slip into a docking port. This knowledge base contributed to a rendezvous procedure book which guided them in responding to computer, optics, and radar failures in the CSM, as well as failures in the *Skylab* tracking lights. Some changes from *Gemini* and *Apollo* also helped these astronauts. The spacecraft could now determine its range rate from a target using VHF tracking and display this data to a crew. The introduction of the Minimum Keystroke program reduced crew workload in operating the computer. *Skylab* also contained two docking ports, so a crew had two options in linking to the station.[13] The innovations and the experience of simulator instructors allowed the last *Skylab* crew to write in their mission report, "Rendezvous techniques and the rendezvous phase have matured to the point that…rendezvous can best be described as being rather routine…the inflight stationkeeping and flyaround inspections were much easier to perform than was expected from training."[14]

When asked today, Joe Kerwin praises the Command Module Simulator and

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[13] John L. Goodman, *History of Space Shuttle Rendezvous* (Houston: JSC-63400, 2011), 54.

[14] *Skylab* Mission Evaluation Team, *Skylab Program Mission Report, Third Visit* (Houston, TX: JSC-08963, 1974), 9-1.

notes that sessions there were essential in mastering the challenging learning curve for astronauts such as himself training to make their first flights. "By the time our crew got there, the simulators had been honed and were excellent for learning and executing procedures," he reflects. "The apex was using them to conduct simulations with the entire flight control team, with malfunctions thrown in. They could be tough. Launch aborts were probably the hardest. One of the *Apollo* Flight Directors, Phil Shaffer, tells a funny story about that. He was in the MOCR preparing for a sim when a guy from NASA Headquarters came in and said, approximately, 'Hello, I'm from Headquarters and I'll be here to approve your decisions as Flight Director.' Phil thought for a minute, then said, 'you can sit over there.' Then he went to his SimSup and said, 'Put in the *Apollo* tape' (a launch sim with all the worst failures). They ran that sim. Engines failed, computers went nuts, a cabin leak developed, and at the peak of confusion Phil walked over to the guy from HQ and said, 'What shall I do now?' HQ pulled the plug on his headset and left the room, never to reappear.'"[15] The thorniest simulations had not lost their ability to awe those who were not familiar with the stress inherent in them.

The astronauts would also have to perform EVAs outside *Skylab*, which took them to the Neutral Buoyancy Simulator in Huntsville, Alabama. Personnel at MSC and MSFC had each developed pools for EVA training in the aftermath of the *Gemini* program, but since MSFC featured a far more advanced pool, *Skylab* crews used the facility in Huntsville. At the suggestion of Jim Splawn, the manager of space simulation at the Process Engineering Laboratory, a group began experimenting with incrementally

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[15] Kerwin, E-Mail Correspondence with Author.

more ambitious pools in the mid-1960s. The first pool was just six feet in diameter and the second was 25 feet in diameter, based around an interstage for a *Saturn* rocket. Alan Bean became the first astronaut to use this one, prior to his first spaceflight on *Apollo 12*. This experience prepared the team for the 1968 move to a pool that was 75 feet in diameter, 40 feet deep, and containing 1.3 million gallons of water (by comparison, the Water Immersion Facility at MSC was only 25 feet in diameter and 16 feet deep). The depth and width allowed personnel to submerge a mockup of *Skylab* which crews could maneuver across to rehearse EVA tasks, while the underwater lighting and audio system made the simulations feasible. The facility also featured a decompression chamber, which an astronaut could use if he surfaced too quickly and needed to purge his body of the nitrogen that had developed in his bloodstream (what divers call the "bends").[16] Another critical feature was a test control trailer, where personnel monitored and controlled the video, communication, and instrumentation systems for the pool.[17]

At a time when only a few Americans had ever performed an EVA in flight, the facility contributed several lessons learned for the benefit of the more than 100 who have now done so. It set an impressive new standard for safety, given the master alarm, emergency power generator, fire extinguishing system, and several divers carrying air hoses who surrounded the astronauts on each run. The use of color television with which the trailer personnel could monitor each run was a first and proved much more helpful than the black and white television of *Gemini* and *Apollo* training. Daily

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[16] Hitt, Garriott, and Kerwin, 73-82.

[17] *MSFC Neutral Buoyancy Simulator* (Huntsville, AL: NASA TM X-64844, 1974), 1-10.

Operational Readiness Inspections worked well in eliminating technical issues and ensuring that astronauts could train in a timely manner. The experience in training for *Skylab* missions did suggest room for improvement, however. The Marshall personnel called for a clear set of rules concerning how long astronauts could stay underwater, a larger work space near the top deck from which to maintain underwater hardware, and a more powerful pneumatic hoist with which to raise or lower objects. Though the long-term future of EVA training was at Houston, upon the opening of a new neutral buoyancy facility in 1980, prior experience with the facility in Huntsville benefited those future astronauts and all who supported them.[18]

All of the fifteen astronauts who composed the *Skylab* prime and backup crews trained in this facility for a total of 543 hours. The standard procedure was for two to go into the pool at a time, surrounded by at least nine divers, four personnel on the top deck qualified in operating the decompression chamber and working with pressure suits, and a control room containing a few people who communicated with the astronauts and monitored data. This amounted to a total of 21 people supporting the astronauts for each run. The standard *Skylab* EVA called for two men to maneuver to the ATM and install a new film canister, so EVA training began with this task. The two donned their suits, went down the steps into the pool, received lead weights from divers which made them neutrally buoyant when placed in their suits, and went to the airlock of the *Skylab* mockup. From there, the first astronaut stowed the film equipment at his workstation and sent it to the second astronaut by transfer boom for installation. Though these were

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[18] Ibid, 1-30 to 1-32.

rather simple tasks, the success of the astronauts' underwater preparation convinced instructors that they could handle unexpected and much more difficult workshop repairs. As it turned out, *Skylab* would need just that.[19] After a two or three hour session, the astronauts resurfaced for a debriefing. The pattern of flying their T-38 jets from Houston to Huntsville for three days at a time of these sessions tested the astronauts' stamina, but the men gained enough efficiency to reduce underwater time by as much as 50 percent. Joe Kerwin described the value of the training best when he said, "By the time we launched, each of us could don and zip his own suit unassisted and move around in it with the same familiarity as a football player in his helmet and pads."[20]

The other new element in *Skylab* training was the workshop simulator, where astronauts began working in February 1972. When astronauts did not need to use complex display systems, they could train in a one-G mockup of *Skylab* located nearby.[21] But it was the workshop simulator that built on the progress of electronic flight simulation. This device, manufactured and delivered by McDonnell Douglas contractors to MSC Building 5 in October 1971, differed from *Mercury*, *Gemini*, and *Apollo* spacecraft simulators by training crews for more diverse tasks. *Skylab* crews still needed to train in spacecraft operation, as the workshop contained displays concerning the health of the vehicle and multiple instrument panels that the astronauts could control. The hardware in the simulator still closely matched the actual vehicle, a lesson from previous programs. SimSups still inserted malfunctions into this simulator. But these

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[19] Ibid, 5-1 to 5-14.

[20] Ibid and Hitt, Garriott, and Kerwin, 74.

[21] Compton and Benson, 228.

crews also needed to live for an extended period aboard the workshop, which contained a wardroom for eating, a private sleeping area the size of a walk-in closet, a shower, and a toilet. Thus the simulator prepared crews for the challenges of habitability. Astronauts would need to know how to respond if the shower or toilet malfunctioned, if the temperature climbed or dropped, or if a crewmember became sick. Their training in this device thus marked a departure from the brief, dynamic tasks of *Apollo* to more open-ended tasks.[22]

Training for these open-ended tasks proved successful in developing the astronauts' ability to maintain their vehicle over the long haul. Some of them were routine chores, such as vacuum cleaning inlet screens or replacing filters for the shower (scheduled for once every seven days), fecal collector, and urine separator (scheduled for once every 28 days). But some of them were unscheduled tasks that tested the astronauts' knowledge of tools and procedures. For instance, a malfunction in the electrical system required them to replace a window heater control unit and cable, replace general illumination flood lights, and potentially install *Skylab* to a contingency power cable in the CSM docked to it. The astronauts also participated in fire drills, which gave them crucial knowledge of the caution and warning system, fire sensors, fire extinguishers, and the flammability of materials.[23] The experience solving these problems in the workshop simulator proved prescient, because the three crews that traveled to *Skylab* performed about 30 contingency maintenance tasks. Especially given

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[22] Interview with Faber.

[23] [Kenneth S. Kleinknecht to NASA Headquarters, April 3, 1972, Box 521, *Skylab* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas.

the hardware glitches astronauts could expect, their job required them to become plumbers, electricians, and more.[24]

This also included the job of doctor. Given the sicknesses that *Mercury*, *Gemini*, and *Apollo* crews had experienced, the fact that *Skylab* crews would shatter the American spaceflight duration record, and the medical experiments they would have to perform, the astronauts needed to hone their medical skills. Thus the men traveled to the U.S. Air Force Dental Clinic at Brooks Air Force Base to gain experience in extracting teeth and the Ben Taub Hospital in Houston to observe and ask questions of emergency teams dealing with life-threatening trauma. Back at MSC, consultants from the Houston medical community lectured the astronauts and produced a manual that explained for them the equipment they would have onboard (diagnostic equipment, minor surgical instruments, a laryngoscope and tracheostomy kit, intravenous fluids, and medications) and operating procedures. Although most of the astronauts had backgrounds only as pilots, the combination of these training resources and the presence of experts with whom they would be in voice contact should any emergency arise in flight left them confident about their medical skills. Their time in the workshop simulator allowed them to place their knowledge to the test by responding to mock emergencies while following a timeline. The astronauts also built their confidence by rehearsing medical experiments, including the first blood draw of American space travelers.[25]

They still needed to train for dynamic tasks such as observation of the Sun and

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[24] Robert E. Pace, Jr., *Repair of Major System Elements on Skylab* (Huntsville, AL: NASA TM X-64928, 1974), 2-4.

[25] Hitt, Garriott, and Kerwin, 82-88.

the Earth, however, which required simulator computers capable of supporting them. Stanley Faber, still the head of the MSC Simulation Branch, remembered that the workshop simulator benefited from a more advanced computer type than the DDP-224s that had controlled the *Apollo* simulators. The Air Force had a surplus IBM 360/65 from a military space project that had been cancelled and when a Pentagon official offered it to Faber over the phone, he accepted. A team of engineers at MSC and IBM then worked together to write the software for this computer and the others that would control the workshop simulator. The computers allowed for an unprecedented quality of simulations. When an astronaut flipped a switch, he received a more immediate response than in previous spacecraft simulators. The computers also controlled readings on six instrument panels, more than any previous simulator, so SimSups could introduce malfunctions. The computer simulation of images also made a crucial advance because *Skylab* astronauts needed to observe the Sun and the Earth. Simulating a high-fidelity view of the Sun had been unthinkable during the *Mercury* era, but computer technology had progressed to the point that an IBM 360/65 could now simulate a view of this massive object as it appeared from 93 million miles away.[26]

Observation of the Sun was not only the most technically demanding task to simulate, but also the most intricate from the crew's perspective. The instrument panel for the ATM featured three times as many controls as the *Apollo* CSM. Astronauts would operate these controls in response to displays revealing the health of the telescope mount, two that displayed an image of the Sun as seen through the H-alpha telescopes,

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[26] Interview with Faber.

one that displayed the solar corona as seen through the coronagraph, and one that displayed an X-ray monitor. A crewmember would need the hand-eye coordination to aim one of these instruments at a feature of scientific interest using a hand controller. He would also need the scientific knowledge to find and observe those features, from the Sun's outer atmosphere (the corona and chromosphere), to the areas of reduced surface temperature (sunspots), to the brief eruptions of high energy radiation from the Sun (solar flares), to the times when the Sun was obscured by the Moon (solar eclipses). Astronauts thus spent 200 hours studying solar activity as generated on the workshop simulator video screens and manipulating the controls to make the desired observation.[27] Carr explained why this was such an intricate task: "I always thought of it (the ATM) being like a big Gatling gun or a gun turret, because it turned. What you did is you would turn the drum inside there and you'd position one of the experiments to take solar data, and then when you finished with that, you would position another one and take data…The spacecraft had to be in exactly the right attitude, and then the drum had to be pointed…to within a tenth of a degree of accuracy, which is incredible accuracy."[28]

Observation of the Earth was another intricate task that required precision by the astronauts over a short time span. The Principal Investigators who had lectured them counted on them to take photos and make observations of Earth resources. Environmental awareness in the U.S. had risen dramatically since World War II as activists published books about the dangers of air and water pollution. If astronauts

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[27] Compton and Benson, 174-175 and 228.

[28] Gerald P. Carr, Interviewed by Kevin M. Rusnak, October 25, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/CarrGP/CarrGP_10-25-00.htm (accessed October 21, 2016).

could monitor resources such as crops, minerals, and water supplies from orbit, and especially if they could identify shortages that could cripple future generations, they would contribute valuable knowledge to this cause. Members of Congress and their constituents understood and supported this idea more easily than any other *Skylab* objective.[29] The astronauts thus spent time in the workshop simulator preparing to maneuver the cameras and other instruments to a desired site, center the site in the cross hairs, and track it while the instruments obtained data. Only an astronaut who had gone through the lectures would have been able to develop the knowledge to make intelligent observations of the Earth, and only one who had gone through the simulator sessions would have been able to make time sensitive observations and respond to any malfunctions.[30]

After individual astronauts had developed their expertise in tasks such as these, the first crew of Pete Conrad, Joe Kerwin, and Paul Weitz had made enough progress by September 1972 to begin integrated simulations. This crew entered the workshop simulator at 6 a.m. and left at 10 p.m. during integrated simulation days.[31] The astronauts learned that their relationship with Mission Control differed significantly from previous programs. The Principal Investigators for experiments could speak to the astronauts directly and provide any assistance necessary, although only when the simulated flights brought the workshop over a ground station. The relationship also

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[29] Compton and Benson, 183-184.

[30] Paul J. Weitz, Interviewed by Carol Butler, November 8, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/WeitzPJ/WeitzPJ_11-8-00.htm (accessed October 21, 2016).

[31] Compton and Benson, 228-230.

differed in that controllers sent the astronauts their daily activities via teleprinter, rather than preparing a completed plan ahead of time as on previous American spaceflights. The simulations thus allowed the controllers to rehearse coordinating tasks, from vehicle maintenance to experiments to any unexpected situations that SimSups introduced. Flight Director Shaffer remembered that during one real mission, he had to decide between having an astronaut eat a meal and having him operate Earth resources sensors while *Skylab* was above an erupting volcano. The simulations prepared him for conflicts such as this one, when he overruled the man at the surgeon console and sent the astronaut to observe the volcano. The controllers involved with the experiments also benefited from simulations reflecting the unprecedented complexity of their jobs. For instance, the controller in charge of the Earth resources equipment coordinated with pilots flying aircraft over selected sites and weather experts to ensure that the crew could garner useful data.[32]

Given that NASA envisioned a much more ambitious space station following *Skylab*, what lessons learned did the workshop simulator offer? Astronauts identified a few shortcomings of the device for the benefit of future space station crews. Compared to the Command Module Simulator, this simulator lacked the displays to provide SimSups with rapid indications of the operations that astronauts performed inside. The simulator training underestimated the amount of time required to activate the workshop, which resulted in crews falling behind schedule and struggling to keep up the pace at the

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[32] Hitt, Garriott, and Kerwin, 88-94.

beginning of their missions.[33] According to Stanley Faber, the astronauts also complained that the images of the Sun did not closely match what they had seen in the workshop simulator.[34] Training personnel in Houston also identified a few shortcomings in a 1974 document called *Lessons Learned on the Skylab Program*. For instance, the intracommunication system in the simulator did not duplicate the system in the actual vehicle closely enough and drove home the need for high fidelity.[35]

Yet positive lessons abounded and outweighed the negatives. As with *Apollo*, one of the main strengths of *Skylab* training was that the instructors evaluated the astronauts in terms of competence and not just how many hours they had filled. A Commander could decide that the number of hours allocated to a task was not sufficient, as Conrad did when he had his crew spend 125 hours training to activate *Skylab* rather than the 20 hours initially allocated. This resulted in a remarkably thorough experience, as the second *Skylab* crew recalled: "The best training protocol was a mixture of what the crew thought was needed and what the training coordinators and training instructors believed the crew needed. Overtraining in some areas resulted from satisfying both groups, but no weakness was overlooked." None of the three members of this crew could remember any scheduled task for which he had not trained in the workshop simulator, which matched the vehicle well despite the rare exceptions noted above.[36] The document about lessons learned suggests that integrated simulations also proved

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[33] *Skylab* Mission Evaluation Team, *Skylab Program Mission Report, Second Visit* (Houston, TX: JSC-08662, 1974), 10-74 and *Skylab Program Mission Report, Third Visit*, 9-5.

[34] Interview with Faber.

[35] *Lessons Learned on the Skylab Program* (Houston: JSC-09096, 1974), 12 and 92.

[36] Compton and Benson, 229 and *Skylab Program Mission Report, Second Visit*, 10-70.

useful, in that they allowed the astronauts to rehearse communicating with Principal Investigators and allowed flight controllers to get a feel for the complexity of their jobs before a mission lifted off.[37]

While the astronauts trained in this simulator, *Skylab* managers considered how to prepare for the psychological challenge of long-term habitation in space. The closest analog for this on Earth appeared to be the work of Navy personnel on submarines, which prompted NASA to study a submarine mission in 1969. An engineer from MSFC climbed aboard a six-person submarine called the *Ben Franklin* and voyaged from Florida to Nova Scotia on an oceanographic mission lasting 31 days.[38] This experience mimicked a *Skylab* mission in subjecting the crew to psychological factors such as confinement, social isolation, deprivation, close quarters, a hostile environment, operational stress, a meaningful mission requiring the collection of scientific data, and data transmission difficulties. Based on data obtained prior to the mission to establish a personality profile of the crewmembers, a daily questionnaire and log during the mission, and a series of questionnaires after the mission, NASA personnel drew the conclusion that the men showed an increased desire for withdrawal and privacy as the mission continued, with depression being the greatest at the midway point. Yet none of them suffered significant deterioration in performance or physical deconditioning. The crew also accomplished 96 percent of their unscheduled maintenance tasks. The *Ben Franklin* mission indicated that long-term space missions were feasible from a

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[37] *Lessons Learned on the Skylab Program*, 90 and 93.

[38] Compton and Benson, 139-140.

standpoint of psychology and habitability, but the data did suggest recommendations for *Skylab*.[39]

A 1970 conference presentation explained the applicability of the submarine mission to *Skylab*. The presenter argued that the *Skylab* design should mitigate the issues that caused frustration for the *Ben Franklin* crew by providing for private areas, adequate lighting and comfortable chairs, sleeping quarters isolated from the sound of the work areas, and simple food preparation devices and techniques. One of the other major takeaways from the *Ben Franklin* mission was the need for highly skilled crewmembers who had been trained in maintaining the ship and could therefore ensure mission success. This crew commented that their preparation in reviewing maintenance procedures, troubleshooting information, checklists, and equipment built their confidence and was instrumental in their impressive maintenance record. The presenter ended by arguing, "Space stations will require many more highly complex subsystems, and mission duration will be measured in months and years rather than days. Hence, it appears that sophisticated analysis, training, and automatic failure detection methods will be required."[40] Thus NASA's study of the closest analog to space station flight reinforced the importance of the simulations astronauts were performing at the time.

But the most ambitious and innovative training for long-term habitation in space was the Skylab Medical Experiments Altitude Test (SMEAT). Astronauts Bob Crippen, Karol Bobko, and Bill Thornton lived for 56 days, from July 26-September 19, 1972, in

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[39] Matthew J. Ferguson, "Use of the *Ben Franklin* Submersible as a Space Station Simulator" (Presentation, ASTM/IES/AIAA Space Simulation Conference, September 14-16, 1970), 604-606, 612 and 614.

[40] Ibid, 608-613.

a vacuum chamber at MSC Building 7. Engineers configured this chamber to simulate the orbital workshop, from the 380 square feet of floor area, to the toilet that *Skylab* crews planned to use, to the food they planned to eat, to the bunks on which they planned to sleep. The use of the vacuum chamber allowed engineers to make the most critical configuration: lowering the atmospheric pressure to just one-third as high as Earth's, mimicking the *Skylab* atmosphere. From a medical point of view, weightlessness was the only major element of life on the space station that the chamber could not mimic.[41] Placing a crew in this analog environment fulfilled six major objectives: to obtain and evaluate baseline medical data for the crew, evaluate *Skylab* hardware, evaluate data handling procedures, evaluate medical operations and equipment, and train the *Skylab* medical operations team for the flights.[42]

The results of the test built confidence in all of these areas. The chamber contained the equipment for the medical experiments that *Skylab* crews would perform, and when the crew performed the experiments they returned data providing a comprehensive view of their day to day health. Data on variables such as mineral balance and metabolism indicated no significant changes. At the end of the 56 days, despite noticing issues such as increased flatulence and lower transmission of sound in the lower atmospheric pressure, Crippen, Bobko, and Thornton remained in strong health with no degradation in their performance. Thus scientists concluded that although long stays in weightlessness would affect the health of *Skylab* crews, the atmosphere,

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[41] Richard S. Johnston, *Skylab Medical Experiments Altitude Test* (Houston: NASA TMX-58115, 1973), 3-1 to 3-29.

[42] Ibid, 1-2 to 1-3.

work, and social conditions would not create any bias in their medical data. The test built confidence for scientists trusted to handle *Skylab* data as well. Though the computer processing of data lagged during the initial days, by the end of the test data flowed smoothly. This allowed scientists to form a trend chart displaying the health of the astronauts on a daily basis, a new technique in American human spaceflight that proved effective. As for the last objective, the MSC Director of Life Sciences argued that the test built the confidence of the entire medical operations team. “A number of new management concepts were used in SMEAT under which a diversified life sciences group, consisting of engineers, physicians, physiologists, biologists, psychologists, and others, became a cohesive program team,” he wrote.[43]

Though Crippen, Bobko, and Thornton did not fly aboard *Skylab* and had to wait until the Space Shuttle era to reach orbit themselves, they did *Skylab* crews a major service by evaluating hardware and making suggestions for improvement. Crippen felt that these crews especially benefited from the use of medical experiment equipment over 56 days. “If we’d flown those without running them in some sort of operational situation, I think there would have been a problem,” he said. The crew did identify several problems so that they could be solved before *Skylab* launched. The urine collection system burst, because the astronauts exceeded the 2,000 milliliters per day allocated for it, which forced engineers to redesign the system. The bearings on the bicycle ergometer failed, which forced engineers to install a new shaft and bearings and restrict its power to 250 watts. Thornton revealed another critical problem: the daily

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[43] Ibid, 22-1 to 22-3 and Hitt, Garriott, and Kerwin, 113-114.

caloric intake for the crew was too low to maintain his body mass, and this resulted in the decision to send extra food to *Skylab*. Engineers also heeded the suggestions of the crew by redesigning the lower body negative pressure device, recalibrating the equipment used for measuring blood pressure, redesigning the metabolic analyzer unit, preventing the electrode cement used for a heart test from causing skin irritation, adding anticoagulants to prevent blood samples from changing to a solid state, and redesigning the centrifuge used for blood separation.[44] When the astronauts stepped out of the chamber, three of their colleagues were just eight months away from placing their training to the ultimate test.

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[44] Hitt, Garriott, and Kerwin, 111-117.

CHAPTER X

SKYLAB: "FATE HAD US RIGHT WHERE SHE WANTED US"

Attention now turned to the first astronauts who would live aboard an American space station. When May 1973 arrived, Pete Conrad, Joe Kerwin, and Paul Weitz had obliterated the amount of training time that Conrad had suggested in his memo two years earlier. As the Commander, he tallied 2,151 hours and would have logged even more if not for his experience in training for three previous spaceflights. The rookies Kerwin and Weitz surpassed him with 2,437 and 2,506 hours, respectively.[1] As demanding a pace as the lunar landing crews had set, the first *Skylab* crew surpassed all of them in training time. The task of learning all of the experiments, space station systems, CSM systems, emergency medical procedures, and EVA procedures would not have been possible without a division of labor that allowed astronauts to focus on their assigned fields. Conrad specialized in the Command Module Simulator, logging 400 hours there (55 more than either of his crewmates) because the Commander had the responsibility of delivering the crew to and from the station. Weitz spent far more time training for Earth resources experiments than either of his crewmates, while Kerwin far surpassed his crewmates by spending 181 hours training for medical experiments. On April 26, eighteen days before launch, the crew entered quarantine at the Cape and began eating specially prepared flight diets. *Skylab* sat inside a modified *Saturn V* booster at Pad 39A, while their CSM sat atop a *Saturn IB* booster at Pad 39B. Given how well trained

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[1] Ibid, 69.

and confident the astronauts felt, Kerwin reflected, "You could say Fate had us right where she wanted us.[2]

The crew was one day from launch on May 14, when they watched the last *Saturn V* soar into space on the *Skylab 1* mission. Little did the astronauts know that this launch and its aftermath would prove the value of human intervention in space science better than arguably any previous event. Flight controllers at the Johnson Space Center (the new name for the MSC adopted after the 1973 death of President Lyndon Johnson) received data about a minute into the launch indicating that *Skylab's* micrometeoroid shield had deployed early. This shield was supposed to provide thermal protection for the orbital workshop as well as shielding it from micrometeorite strikes. When the workshop temperature climbed and did not fall to acceptable levels, controllers realized that the shield was gone, jarred loose during the period of maximum dynamic pressure on the *Saturn V*. This event also caused the loss of one of two solar panels that provided *Skylab's* electrical power. The other generated just a trickle of current, indicating it was stuck shut.[3] The launch could have been one of the greatest embarrassments in NASA history, given the more than $2 billion spent on this space station. If *Skylab* had been designed as an unmanned scientific instrument with no human access, it would not have returned the data it did. Only the flexibility of human operators trained to solve problems could save the outpost.

But in order to train Conrad, Kerwin, and Weitz to save *Skylab*, engineers first

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[2] Compton and Benson, 228-229 and Hitt, Garriott, and Kerwin, 135-136.

[3] Hitt, Garriott, and Kerwin, 136-140.

needed to decide how to save it. With their launch delayed from May 15 to 25, engineers in Houston and Huntsville worked 16 to 18 hour days trying to solve the problem of the lost shield. Some other method would have to shield *Skylab* from the Sun's rays and reduce the temperature of the workshop from over 100 degrees to 70. From Houston came a solution that would win the head of the JSC Technical Services Division, Dr. Jack Kinzler, the NASA Distinguished Service Medal: a large square of cloth called a parasol that the crew could deploy over the Scientific Airlock. From Huntsville came a solution called the "Marshall Sail," which was an aluminized mylar film that a pair of astronauts would have to deploy on an EVA. Both sides had rationales as to why the competing solution was not ideal. JSC engineers knew that the proposed EVA was more complex than any ever done before and argued for the deployment of a parasol that did not require going outside. MSFC engineers argued against placing a parasol on the airlock, because they feared debris might block the airlock. But engineers had a tool that could help them solve this argument: the neutral buoyancy facility in Huntsville. Simulating EVAs at this facility would show engineers what astronauts could accomplish outside a spacecraft.[4]

Just two days after the accident, Kerwin and Rusty Schweickart (a member of the backup crew for the first mission) were in Huntsville to work underwater with the "Marshall Sail." The astronauts assembled a mounting bracket to the *Skylab* mockup, installed two 55 foot poles (consisting of eleven interlocking segments) in the bracket, and attached the forward edge of the sail to the clothesline hooks on each pole. Only

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[4] Ibid, 144 and Compton and Benson, 256-261.

seven years and a handful of EVAs in the past, Gene Cernan could not even manage to maneuver his body to the back of a small *Gemini* spacecraft. The difference now was that *Skylab* astronauts could draw upon not only the experience of past spacewalkers, but also a training environment realistic enough to provide them with neutral buoyancy and large enough to house a mockup of the hardware they would have to handle. Engineers even modified hardware based on the astronauts' inputs after trips to the pool, from tighter restraint around the top of the sail stowage bag, to the addition of tether devices to the mounting bracket, to teflon inserts that reduced friction on the poles. 75 engineers attended the first debriefing session when Kerwin and Schweickart made their recommendations, highlighting the importance placed on neutral buoyancy simulations. By May 22, after several astronauts had tried their hand at deploying the sail, Conrad and Kerwin finally made a nearly flawless simulation and did not have to make any recommendations. With the top ranking *Skylab* managers in Huntsville to see the success for themselves, MSFC personnel packed the sail for shipment to the Cape that evening.[5]

One more *Skylab* repair task required simulation: freeing the stuck solar panel. If the crew could not find a way to use this one remaining panel, they would have only the power generated by the ATM and the ambitious science program for them and the next two crews would have been conceived in vain. Freeing the stuck panel required a standup EVA, where Weitz would stick his body outside the CSM hatch and remove debris via tools such as sheet metal cutters, cable cutters, a mushroom head, and

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[5] Compton and Benson, 261 and *MSFC Neutral Buoyancy Simulator*, 5-20 to 5-32.

shepherd's hook. To simulate this, MSFC personnel built a support structure that could lift a 2,000 pound Command Module into the pool. On May 22, Weitz stood up outside the submerged hatch and went to work on a *Skylab* mockup in the condition the real vehicle appeared to be in after the launch mishap, with loose wires, twisted bolts, and fragments of the lost micrometeoroid shield. He had difficulty aligning his tools with the solar panel and surrounding debris, but with the launch three days away he had to return to the Cape. With the results in from the neutral buoyancy sessions, top *Skylab* managers decided that the proposed EVA tasks were not impossible after all. They met at a design certification review in Huntsville on May 23 and decided that the first crew would take both the parasol and the "Marshall Sail" to combat *Skylab's* rising temperatures. Weitz would also make his standup EVA, though with an MSFC engineer ready to go into the pool to simulate any unexpected problems that arose while he was in space.[6]

Conrad, Kerwin, and Weitz placed their troubleshooting training to the test on May 25, when a *Saturn IB* sent them into orbit. The *Skylab 2* crew found their station as crippled as expected from the CSM windows, but Conrad voiced his optimism that Weitz could free the panel. The standup EVA began that evening, with Weitz holding his tools while standing out the open hatch, Kerwin holding his crewmate's legs in place, and Conrad maneuvering the spacecraft. Weitz found that the panel was stuck shut because a metal strap inadvertently wrapped itself across the panel beam after the launch mishap, but he could not free it. The astronauts had to dock with *Skylab* without solving

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[6] *MSFC Neutral Buoyancy Simulator*, 5-27 to 5-35 and Compton and Benson, 267-269.

the problem.[7]

As if they did not already have enough to deal with, the astronauts ran into yet another snag when Conrad tried to dock. The CSM probe did not engage the workshop drogue. Kerwin recalls how training helped them utilize a backup procedure that solved this problem. Prior to launch, "One afternoon, the three of us were in the room with the mockups and we'd finished that day's activities when our instructor said, 'Guys, we missed one earlier that I'd like to run through with you just so you'll know where the equipment is. It's the third backup for a docking system failure; you have to don suits, depressurize the Command Module, crawl up in the tunnel and cut some wires. Won't take long.' He showed us the switches to be configured and the wires to be cut, and we went home, never again to think of that procedure. Until day one in flight, when after a long, difficult day, the docking latches failed to latch…If we couldn't dock, we'd have to come home, with nothing accomplished. So we wearily put on our helmets and gloves, dumped the air out of the Command Module, and I went up and cut those wires. Back out of the tunnel, Command Module pressurized, Pete was ready to try it, and the main latches loudly latched, all twelve of them, a really wonderful sound. That illustrates the value of training, and also the value of having procedures based on a very deep knowledge of the systems. Kudos to the flight control team, which wrote them."[8]

Thus the crew surmounted this obstacle to reach the interior of the space station. They also did not have to give up on freeing the solar panel. Weitz sent the information

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[7] Compton and Benson, 269-271.

[8] Kerwin, E-Mail Correspondence with Author.

he had gleaned from his EVA to the Huntsville personnel who could run more neutral buoyancy simulations to better understand how to do this. The standup EVA had not worked, but a much more complex outing might pay off. MSFC engineers had modified the *Skylab* mockup to match the real vehicle by May 27, so that astronauts could test a new procedure: exit the station airlock, move across the airlock trusses to a long antenna boom, use a pole as a handrail to reach the solar panel, remove the metal strap debris, and use a tether to break a frozen hydraulic damper on the panel. The lack of footholds at this portion of the station hampered Rusty Schweickart and Ed Gibson as they rehearsed this, but the two men had developed enough skill underwater to accomplish the job on June 2 and 3. Schweickart then briefed the *Skylab 2* crew on the hardware he worked with and maneuvering methods he used in the pool.[9]

On June 7, Conrad and Kerwin performed the job for real and proved a critical point about the maturation of spaceflight operations. The two men quickly found out that EVA still presented a formidable environment, especially in attempting to maneuver their bodies to the panel when every one of their actions produced an equal and opposite reaction. Kerwin’s heart rate soared to 150. Yet the two men managed to reach a position where Kerwin cut the metal strap debris with cable cutters and Conrad “heaved with all my might” along with him to break the frozen damper. By the next day, the panel was extended and producing nearly 7 kilowatts of power. This experience proved the point that if expensive hardware malfunctioned, and even if a first repair attempt failed, high fidelity training equipment could assist a crew in making the adjustments to

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[9] *MSFC Neutral Buoyancy Simulator*, 5-35 to 5-55 and Compton and Benson, 272-273.

solve the problem. Flights such as *Apollo 13* had proved this point in the past, but now astronauts were making a transition toward living in space as they would have to do for a flight to another planet someday. Developing the troubleshooting ability of a crew prior to their departure, and then having other astronauts on standby for real-time simulation during the flight if necessary, was a critical step along the path toward the continuous occupation of space aboard the ISS and the currently planned voyage to Mars. The pool in Huntsville was not a perfect analog for space, but astronauts could feel comfortable that if one could simulate a task in a pool, one could usually do the same in space. Thus astronauts and all who supported them had a vital tool that meant they did not have to leave a difficult chore to chance; they could simulate it and iron out difficulties ahead of time.[10] Kerwin summarizes the point today by declaring, “We could not have erected the stuck solar panel without all that training.”[11]

The 28 days this crew spent in the workshop proved another point: that trained humans could benefit spaceflight operations of this unprecedented length. No robot could have performed that delicate June 7 repair that restored power. The same was true of the parasol deployment on the second day of the mission, which the crew needed to accomplish to cool the station to a livable temperature (flight controllers left the EVA to deploy the “Marshall Sail” to the second mission). Conrad and Weitz inserted the parasol container into the Scientific Airlock, cranked open the outer door to expose the parasol to space, and inserted seven metal rods one at a time to carry the device into

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[10] Compton and Benson, 273-276.

[11] Kerwin, E-Mail Correspondence with Author.

place. The operation was so intricate it took about two hours, but the temperature fell to under 80 degrees as a result.[12] By solving the problems of thermal control and power, the astronauts saved *Skylab*. But the question remained: could this crew collect scientific data on a day to day basis that proved the value of human flight as well?

The three men made a compelling demonstration of their flexibility here as well. Several experiments focused on their physiological response to the longest ever American spaceflight. Not only did the crew prove their value by donating their bodies as test subjects for these experiments, which would hopefully pave the way toward extended flights to the Moon and Mars, but also by making needed adjustments to equipment or procedures. For instance, the astronauts found the lap and shoulder harness on the bicycle ergometer restricted their movement. Weitz found he was not using his leg muscles enough. Thus the crew discarded the harness and stabilized themselves by locking triangular cleats into the pedals instead. Based on medical data received, flight controllers decided to increase the number of runs for each astronaut on the ergometer as well. The Velcro seatbelt on the rotating chair for the Human Vestibular Function experiment did not latch securely, but the crew made a modification and collected data. The crew spent an unusual amount of time calibrating the Specimen and Body Mass Measurement experiment to ensure it would obtain accurate data.[13] In each case, training helped the crew to surmount all difficulties and add to the database on the human body's response to extended weightlessness. One might criticize these

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[12] Hitt, Garriott, and Kerwin, 175-178.

[13] *Skylab* Mission Evaluation Team, *Skylab Program Mission Report, First Visit* (Houston, TX: JSC-08414, 1973), 4-2.

experiments as simply space research for the sake of more space research, but medical research on space stations has also benefited life on Earth through terrestrial applications of the technology used onboard.[14]

The crew also demonstrated their value in making solar observations, though with more difficulty. On the fifth day of the mission, Kerwin became the first astronaut to observe the Sun through the four displays that the ATM provided. He admitted to making several mistakes in operating the ATM, due to the many switches and monitors for the device and the precise timing needed to make observations. When *Skylab* had been in the planning stages, some astronomers had doubted the value of a human operated solar observation facility. But as Mission Control received the first results from the ATM observations, the Principal Investigators each agreed that a trained human operator could make a difference in solar science. When Weitz observed a solar flare on June 15, for instance, he monitored the displays to confirm the eruption, initiated a computer program, and pinpointed the flare with the ATM instruments within a few seconds. Thanks to the skill that training had given him, he tracked the flare through two minutes of its rise and fall and allowed scientists to collect data.[15] Training gave crews the flexibility to not only immediately respond to events of scientific interest such as this, but also to make repairs. By the end of the *Skylab* program, astronauts had replaced and modified ATM equipment inside the vehicle while also making EVAs to replace film, open experiment doors, replace a jammed camera, and remove debris from

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[14] See Julie Robinson, ed., *International Space Station Benefits for Humanity* (Houston: NASA NP-2015-01-001-JSC, 2015).

[15] Compton and Benson, 290-291.

the ATM. The fact that trained astronauts could operate and take care of the device helped make possible the hundreds of articles that scientists wrote about the results of the solar observations.[16]

The crew began Earth resources studies on the sixth day of the mission, demonstrating that trained operators could benefit the study of humanity's home as well. Unmanned spacecraft had already taken many useful photos of specific sites on Earth, but *Skylab* crews could observe the Earth in ways not possible aboard automated vehicles. Trained humans could quickly discriminate between the features they deemed important and those they deemed not important and respond to unexpected events. For instance, an astronaut could follow and describe ocean currents for over 2,000 miles, recognize eddies of cold water, discover the same phenomenon in an unexpected location, and then wait for the best moment to take a photo of the phenomenon. No robot could have duplicated this ability.[17] While the astronauts utilized their observational skills based on the instruction they had received during briefings, they relied on remote sensing equipment to supplement their abilities. This equipment recorded over 8 miles of magnetic tape of Earth observations, many of it in wavelengths beyond visible light. The results made for a good start to the *Skylab* program, but the unexpected repairs to the station reduced the amount of time this crew could spend observing the Earth. The crew could only perform 60 percent of the work they had expected in this area. Thus the 28 days Conrad, Kerwin, and Weitz spent in orbit only

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[16] Eddy, 57-58.

[17] Compton and Benson, 347.

whetted the appetites of scientists.[18]

The crew made a point of praising the time they had spent in the workshop simulator prior to the mission, even if it had not been a perfect analog. When the astronauts activated the workshop at the beginning of the mission, they had to deal with chores such as handling small items and locating equipment that were more difficult in zero gravity than they had been in the simulator. This contributed to their falling behind schedule. But after they had become acclimated to life aboard the station, and after the excitement of saving it over the first two weeks had faded, they often found themselves ahead of schedule. The simulation of their tasks ahead of time, especially when integrated with flight controllers who sent the astronauts a list of their daily activities, made this possible. Conrad said near the end of the stay, "The things that are easy to do in the trainer are easy to do here, ninety-eight percent of the time. And vice versa."[19] As the flight neared its end, the crew and the flight controllers did worry about the time lag between their training for reentry and splashdown and their actual performance of these tasks. "But 28 days wasn't long enough to make us rusty," Kerwin explains. "We scheduled a couple of entry run-throughs while on orbit, which were useful especially for the time everything took." He and his crewmates finally climbed into their CSM on June 22 and undocked. After Conrad flew the CSM around the station for an inspection and photos, two deorbit burns sent the crew to a splashdown near the *USS Ticonderoga*.[20]

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[18] Ibid, 289 and *Skylab Program Mission Report, First Visit*, 4-3.

[19] Compton and Benson, 287-288 and Hitt, Garriott, and Kerwin, 226-229.

[20] Kerwin, E-Mail Correspondence with Author.

The *Skylab 3* crew set a new standard for amount of training and amount of data returned from orbit, but not without some disturbing drama concerning their ride to *Skylab*. Alan Bean, Owen Garriott, and Jack Lousma each averaged about 2,800 hours of training and were emphatic in their mission report that the exhausting schedule paid off.[21] But none could have guessed that the oldest hardware in the program would place their training to the test. During launch on July 28, Lousma noticed what appeared to be a CSM thruster floating by the window. The crew then realized that what they had seen was not an actual thruster, but leaking propellant from a thruster that froze into ice and floated by Lousma's window. Bean noticed a master alarm indicating that a thruster was at low temperature, supporting this idea. After checking with Mission Control, he made a decision that was unprecedented in all the years of CSM flights: he turned off one of the four quads of thrusters that provided directional control to the spacecraft. This posed a problem, because making a rendezvous and docking with *Skylab* required a series of thruster firings to match the CSM's speed with *Skylab*. What was Bean to do?[22]

He needed to isolate the thruster quad and adjust his spacecraft's approach to *Skylab* accordingly. "Back in the simulator, Owen, Jack, and I were really good at rendezvous," Bean explained. "We never missed a rendezvous in all our training time. They gave us failures by the zillions; we didn't blink—we'd rendezvous." But in all of that time, he never had to isolate a thruster quad and not use it again. Thus his real flight presented him with a new situation, in which the vehicle produced an asymmetric thrust

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[21] *Skylab Program Mission Report, Second Visit*, 10-70.

[22] Hitt, Garriott, and Kerwin, 239-240.

and did not brake as easily as it would have with all four quads available. The crew still proved that well trained operators could handle the problem, however. Garriott and Lousma estimated their vehicle's range to *Skylab* as Bean focused on braking just enough to match the target's speed. If he closed too quickly, he might collide with *Skylab*; if too slow, he would have to use excess fuel and throw off the timing of the docking. Garriott proved the value of having multiple astronauts onboard when he urgently told Bean that he was closing too quickly and needed to brake more. Bean docked safely and credited his crewmate with providing that critical advice. "Our best efforts and skills were tested," he recalled, providing another timely reminder of why astronauts logged those long hours in simulators. He said that his heart rate during the incident was even higher than when he had gone to the Moon aboard *Apollo 12*.[23]

The condition of the CSM worsened after the docking, which brought a new training issue into the realm of possibility. The crew confirmed that another quad thruster had sprung a leak on August 2. This raised three questions: whether the crew could maneuver their ship to a safe return with only two of four quads, whether another failure might further cripple the vehicle, and whether a rescue mission would be necessary. JSC engineers answered those questions by sending astronauts Vance Brand and Don Lind to the Command Module simulator, who concluded that the vehicle could return safely with two quads or even one. These engineers also concluded that the failures of the two quads were not related, which eased the crew's worries. Bean, Garriott, and Lousma did not need rescue, but their colleagues Brand and Lind did train

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[23] Ibid, 241-244.

for this possibility and prove yet another point about the maturation of spaceflight operations by 1973.[24]

The rescue plans went into effect within hours of the troubling news on August 2. If the mission had been deemed necessary, engineers at the Cape could have mated another CSM to a *Saturn IB* within a week and made room for two additional couches on this vehicle. By foregoing standard tests, Brand and Lind could have launched by early September. They could have docked their ship with a spare port and returned to Earth with the *Skylab 3* crew by making use of those two new couches behind the three standard couches. Brand and Lind proved they could train for this emergency with just a month's notice by spending long hours simulating this mission and providing crew inputs to engineers. "We were involved in not only training but the planning, certification and verification, and stowage and that the couch (redesign) would work," Brand remembered. "We were just involved in a lot of the general planning on how you would do this, which made it especially interesting."[25] The ability to train astronauts and launch them to rescue another crew before that crew's supplies ran out marked a critical step forward in spaceflight operations.

The rest of the mission provided further vindication to the training this crew had performed, especially when Garriott and Lousma performed their EVA to deploy the "Marshall Sail" on August 6. The two men stayed outside for 6.5 hours, by far the longest EVA in history and a harbinger of the Space Shuttle and ISS eras. Fatigue was

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[24] Compton and Benson, 298-299.

[25] Ibid, 299 and Hitt, Garriott, and Kerwin, 247-259.

and still is one of the greatest problems on an EVA of this length, but Garriott and Lousma had logged more than 100 hours at the pool in Huntsville and knew how to maneuver their bodies to minimize the fatigue. The two men had also worked underwater with the cumbersome hardware they would have to deploy to control *Skylab's* temperature. Garriott thus managed to connect the eleven segments of the two 55 foot poles, before Lousma attached them to a base plate so that they formed a V. Lousma then fastened the sail to rope that ran the length of the poles and hoisted a sunshade. This took three hours, then the men spent an additional three and a half hours replacing ATM film and pinpointing a *Skylab* coolant leak. The deployment of the "Marshall Sail" marked another first in spaceflight, because two astronauts worked together on the most ambitious EVA yet and accomplished a task that they had not foreseen until the launch mishap in May. Despite being rookie spacewalkers, Garriott and Lousma trained for and carried out a solution to *Skylab's* thermal problem due to their preparation on short notice.[26]

Training benefited the *Skylab 3* crew for another task related to EVA: a test of a maneuvering unit inside the cabin. This required the crew to don a backpack that contained nitrogen gas to propel them, a precursor to a more advanced backpack planned for use outside the Space Shuttle. The *Skylab 3* crew used an air bearing trainer, as the *Gemini* spacewalkers had, which gave the astronauts an understanding of the procedures required to operate the backpack but provided limited degrees of freedom. "The maneuvering skills were much better learned on the 6-degree-of-freedom simulator," the

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[26] Compton and Benson, 300-301 and Hitt, Garriott, and Kerwin, 272-275.

crew concluded.[27] Training helped them discover that over 75 hours of operation in flight, "The automatically stabilized maneuvering unit modes were operated in great precision. Specific tasks included inspection, cargo transfer, rescue, retrieval, tracking, tumble recovery, rendezvous stationkeeping, and docking." The testing of the backpack aboard *Skylab* in turn benefited wearers of the Manned Maneuvering Unit (MMU) a decade later.[28]

Bean, Garriott, and Lousma emphatically proved that well trained astronauts could steadily increase productivity aboard *Skylab* from flight to flight, though they did bring back suggestions for improvement in their mission report. Despite being hampered by motion sickness at the beginning of their stay, the *Skylab 3* crew increased their efficiency by taking steps such as eating meals separately (so that two of them were always working while one was eating) and moving items to and from storage during the day to reduce the amount of time they had to spend on housekeeping. Bean remembered becoming so efficient that the crew had to convince flight controllers to give them more work.[29] The crew not only increased productivity on maintaining the station, but also on obtaining scientific data. *Skylab* program manager Ken Kleinknecht said that the crew achieved more than 150 percent of their scientific goals. The number of man hours spent on solar activity increased from the first mission, which allowed the astronauts to view the first coronal mass ejection from space and the largest solar prominence ever viewed from space. Scientists following from the ground felt thrilled by the realization

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[27] *Skylab Program Mission Report, Second Visit*, 10-75.

[28] Ibid, 5-2.

[29] Hitt, Garriott, and Kerwin, 282.

that this bright wisp of gas was nearly three quarters the size of the entire Sun. The crew also gathered three times the amount of Earth resources data as their predecessors. Sensors recorded over 90,000 feet of magnetic tape data, which benefited the taxpayers who had invested in *Skylab* by adding knowledge of such subjects as Oklahoma's soil moisture, Utah's mineral formations, and Houston's urban growth.[30]

By early September, the astronauts began to think about the ride back home aboard a CSM in less than top condition. Bean received several changes to the reentry checklist that Vance Brand and Don Lind had perfected in the Command Module Simulator, due to the two failed thruster quads, and studied them thoroughly so he would feel ready to return home on September 25. He had an unusual amount of difficulty holding the desired attitude with only two quads that day, but his study of the new checklist had taught him how to null unwanted attitudes with the hand controller. Once again, the work done in the Command Module Simulator had benefited a crew confronted with a threatening situation. Despite the unprecedented 56 days in weightlessness, the crew did not feel close to graying out and remained mentally alert as the Command Module splashed down next to the *USS New Orleans*.[31]

What complaints could such a productive crew have? Bean, Garriott, and Lousma believed that they could have received more thorough training for their Earth resources studies, a statement that was consistent with that of the first *Skylab* crew. "Essentially all of the limited preflight training in this area was initiated by the crew, yet

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[30] Ibid, 329-330 and Compton and Benson, 302-304.

[31] Hitt, Garriott, and Kerwin, 314-315 and *Skylab Program Mission Report, Second Visit*, 10-65.

numerous tasks were assigned in flight that required identification and photography of special areas of interest," the astronauts explained. "Additional training time should have been spent in understanding the objectives relating to geology, geography, meteorology, hydrology, fishing, etc." The crew felt that handheld photography training inside the simulator was similarly lacking. Bean, Garriott, and Lousma also raised a point that was new to astronauts due to the transition toward living in space: inflight training. Astronauts could not expect to take to space all the skills they would need during a mission as long as 56 days. Thus this crew recommended setting aside time every week or two to study the changes to hardware operations. The crew performed drills for a fire and a rapid loss of pressure during the first few days of the mission and took time to rehearse the revised reentry procedures, so this lengthy mission did accelerate a trend toward inflight training.[32] But in the end, the complaints and suggestions were rather minor compared to the astronauts' skill in maximizing output from such an expensive mission. Over three decades later, Bean still proudly carried an article in his briefcase calling *Skylab 3* a "supercrew."[33]

The success of the "supercrew" encouraged flight planners to form and Kleinknecht to approve a schedule for the last *Skylab* mission that was arguably too ambitious. Though *Skylab 4* astronauts Jerry Carr, Ed Gibson, and Bill Pogue had originally planned to spend another 56 days on the station, the new plan called for 84 days. The crew would surpass their predecessors by working on experiments for 28

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[32] *Skylab Program Mission Report, Second Visit*, 10-70 to 10-76.

[33] Hitt, Garriott, and Kerwin, 329-330.

hours per day, which would test the astronauts' stamina and ability to adjust to weightlessness. Carr, Gibson, and Pogue had been last on the priority list to use the *Skylab* simulators and had only begun receiving uninterrupted use of the simulators after the previous crew launched in July. Then the approval of a more ambitious flight schedule made training even more intensive, especially given that none of the three had flown in space before. But these astronauts could still benefit from the experience of their predecessors. This crew felt better prepared for their flight thanks to the knowledge that they should exercise more per day than previous crews to counteract the effects of weightlessness, for instance. On November 16, a *Saturn IB* sent the astronauts to the last mission at *Skylab*.[34]

One mistake made the mission more frustrating than necessary and provided another lesson learned. During training, the crew and flight controllers had not interacted as closely as on previous missions. "Usually integrated training is done as much to train Mission Control as the crew, but they'd been through it all with the first two missions and weren't eager to revisit that 'demanding boredom' more than absolutely necessary," Carr explained. Yet if the two groups had developed a closer rapport during the last few months before launch, both would have understood the need to limit the unrealistic workload planned for *Skylab 4*. From the day they docked and activated the workshop, Carr, Gibson, and Pogue found themselves behind schedule and unable to meet the ambitious goal of 28 hours per day. As with all crews, they only gradually made an adjustment to working in weightlessness. Yet the schedule did not

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[34] Compton and Benson, 312-313 and Hitt, Garriott, and Kerwin, 338-340.

allow them time to make the adjustment. The men rushed around to complete experiments, which made them prone to making mistakes, and flight controllers tried to compensate for the mistakes by tightening the schedule even more. This vicious cycle contributed to frustration on both ends. It is not true, despite what authors have written in a few books, that the crew went on strike. It is true that the crew complained about one month into the mission, with Carr calling the mission a “33-day fire drill.” Flight controllers decided to cut back on the crew’s workload by about 15 percent, which improved crew morale dramatically.[35]

The incident contained a couple of major lessons from a training perspective. First, the incident highlighted the value of integrated simulations, particularly for a crew that had never flown before but planned to take part in a mission nearly three months long in which they would have to develop a working relationship with flight controllers. Second, the incident emphasized that no matter how many hundreds or even thousands of hours a crew trained, astronauts and flight controllers needed to respect the fact that living in weightlessness required an adjustment period. The only way to train for this on Earth was to experience it for a handful of seconds at a time aboard an aircraft, not for the nearly three months that Carr, Gibson, and Pogue needed to work in it. Thus no matter how many sessions a crew had performed in a simulator, the crew still needed to avoid overconfidence while working in this condition that could not be part of the simulations. The astronauts argued in their mission report that future crews should receive a 50 percent time cushion for the first inflight performance of tasks, even for

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[35] Hitt, Garriott, and Kerwin, 351-359 and Compton and Benson, 323-324.

which they had received training. In an interview decades later, Flight Director Neil Hutchinson admitted that the controllers in Houston were partly to blame for enforcing the overly heavy workload and said that they were careful not to repeat the mistake when the Space Shuttle era began in the 1980s. "There was just no point in pushing them early on, because they weren't going to get the job done," he explained. "We don't do that these days on the Shuttle. We let them get really organized first."[36]

ATM observations reached an especially exciting conclusion on this last *Skylab* mission, because the crew became the first to observe a comet in space. Comet Kohoutek made a close approach to the Sun in 1973, not to return again for the next 75,000 years. The astronauts aimed the ATM instruments at what media outlets had dubbed "The Comet of the Century." These instruments measured the intrinsic brightness of this icy body as it heated up during its approach to the Sun, collected data on the composition of its coma and tail, and measured the radiation it emitted. The crew also made their own visual observations of the size, orientation, and color of the tail and made sketches based on them. During an EVA in December, Carr and Gibson even observed the comet from outside *Skylab*.[37] The mission report that this crew wrote explains why astronauts needed extensive training in tasks such as these. The astronauts could not see the comet at the time they pointed the ATM instruments toward it, so they pointed about 18 milliradians away from it, calculated the maneuver they needed to make to center the instruments, and centered them. These steps had the potential to

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[36] Hitt, Garriott, and Kerwin, 356-357 and *Skylab Program Mission Report, Third Visit*, 9-6.

[37] Compton and Benson, 324-326.

introduce errors for an inadequately trained crew, given the low margin for error. While examining the various features of the comet, the astronauts then had to adjust the instruments every one or two minutes to account for its drift. The three men found that they were better at doing this on the 80th day of the mission than the 30th day, because of the "growth factor" in improving their mechanical and interpretive skills.[38]

What difference did it make to have trained crewmembers onboard *Skylab* observing Comet Kohoutek? Carr, Gibson, and Pogue admitted that the comet was less brilliant than expected, but ensured through their flexibility that they could return useful data for scientists. Despite the intricacy of pointing the ATM instruments in the correct direction, the astronauts had trained in this task and scientists could feel assured they could accomplish this task. The astronauts also had the chance to exercise human judgment in collecting more or different data than planned, which would not have been possible aboard a completely automated facility. In making their sketches of the comet, the crew demonstrated another capability that a robot could not match, as Gibson explained: "In addition to what we could capture on film, we recorded on paper what our most sensitive and versatile optical instruments onboard could detect—the human eye."[39] Even if Comet Kohoutek failed to live up to the hype of the American media, the accomplishments of the astronauts in observing it and the Sun from the ATM console helped to illustrate what trained astronauts could contribute to astronomy.

The training and execution of Earth observations made a major leap from the first

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[38] *Skylab Program Mission Report, Third Visit*, 9-9 to 9-11.

[39] Ibid, 9-9 and Hitt, Garriott, and Kerwin, 434.

two *Skylab* missions to the last. The *Skylab 4* crew reported that they spent about 30 hours in preparation for this activity. After the last crew had complained about the limited training time available to them, for this mission a team of 19 scientists developed a more thorough plan for Earth observations and briefed the astronauts on areas of interests ranging from ocean currents, to geology, to African drought regions. The scientists even prepared a book detailing what the crew should look for and should expect to see.[40] Thanks to this effort, Carr, Gibson, and Pogue arrived at *Skylab* prepared to observe 165 features and phenomena. The three men did not let the scientists down, as they returned about 2,000 photos and what no robot could have made: 850 verbal descriptions. The photos also contained a higher resolution than previous photos taken on *Landsat* satellites.[41]

Results from the mission filled an entire book called *Skylab Explores the Earth*, which described how the astronauts' contributions to science went well beyond that of the first two crews. Thanks to *Skylab 4*, scientists had a better understanding of how deserts formed around the world, major fault zones in California and Mexico, the harvesting and subsequent replanting of crops, dust storms, flood conditions, sea-ice formation, and pollution. The most exciting observation came when a Japanese volcano erupted and the crew managed to obtain photos of the entire sequence. Carr and JSC scientist Verl Wilmarth admitted that the training for these tasks was still too limited, even if it had been increased from the first two missions. The astronauts would have

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[40] *Skylab Program Mission Report, Third Visit*, 9-14 and Compton and Benson, 347.

[41] *Skylab Explores the Earth* (Houston: NASA SP-380, 1977), 1.

benefited from much more than the 30 hours they received in rapid site recognition. But scientists could feel assured that *Skylab 4* was not their last chance to obtain data. Given the success of crews in returning data thus far and the quickly evolving conditions on Earth, Carr explained, "Looking forward to the Space Shuttle, which will have better equipment and more sophisticated training, space observers can capitalize on this multimission Earth-orbiting platform to seek answers to many problems about the Earth and its processes."[42]

The crew trained for and conducted student experiments as well. As a way to spark the interest of young people in science and engineering, a few officials from NASA Headquarters, JSC, and MSFC formed a nationwide contest in which seventh through twelfth grade students submitted experiment requests. Out of 3,409 proposals, *Skylab* astronauts managed to perform 22. The lack of adequate training for some of these experiments, due to their late entry into the program, frustrated the three crews. Carr, Gibson, and Pogue argued that student experiments should continue, but that the experiments should do more to take advantage of crew initiative and judgment and that astronauts should devote more time to train on their operation. Although some of the experiments failed, those that succeeded fired the imaginations of the students. Among the 22 Principal Investigators who were in junior high or high school during the early 1970s, six of them went on to become science teachers, seven became engineers and/or scientists, and three became medical doctors. To this day, astronauts aboard the ISS

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[42] Ibid, 1-3 and vii.

seek to inspire students by conducting their experiments.[43]

As the mission neared its end, the crew felt satisfied with their abilities but experienced one more incident that was instructive for training purposes. In addition to logging more training hours than any previous crew, Carr, Gibson, and Pogue benefited from more time to develop their skillset in space than any of their predecessors. Their increased proficiency in operating equipment and exercising scientific judgment combined with the resolution of their arguments with Mission Control meant all three men enjoyed high morale as February 1974 began.[44] On the morning of February 8, the crew climbed into their CSM, undocked from *Skylab*, and fired their SPS engine to return home. Nine minutes later, Carr tried to maneuver the vehicle with his hand controller but found it did not respond to yaw and pitch commands. He switched to a backup system and regained control. The crew found out later that they had mistakenly opened four circuit breakers and disabled the yaw and pitch thrusters. This incident suggested that during a long duration mission of several months, astronauts needed to maintain proficiency in spacecraft operations. The skills needed to perform research on space stations differed dramatically from the skills needed to operate a spacecraft through the dynamic phases of reentry and splashdown, but astronauts needed to make sure the latter skills did not deteriorate after nearly three months of concentrating on the former. Fortunately, the mistake did not affect the return of the *Skylab 4* crew and Carr, Gibson, and Pogue splashed down safely.[45]

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[43] Hitt, Garriott, and Kerwin, 440-442 and *Skylab Program Mission Report, Third Visit*, 9-21 to 9-22.

[44] Hitt, Garriott, and Kerwin, 385.

[45] Compton and Benson, 336.

These men were the last to visit *Skylab*, because NASA squandered the opportunity to save it. The plan in 1974 was that the *Skylab 4* crew would be the last to visit the station using an *Apollo* spacecraft, but that a Space Shuttle crew could visit in the future (President Richard Nixon had approved this vehicle two years earlier). Just before that last undocking, Carr fired the CSM thrusters to nudge *Skylab* into a higher orbit of 269 by 282 miles. Calculations based on expected solar activity and atmospheric density showed that from this orbit, *Skylab* would fall into Earth's atmosphere in 1983. NASA envisioned a shuttle crew attaching a propulsion module to the station that would boost it to a higher orbit in the late 1970s, but this did not happen for two reasons. Delays in shuttle development meant the vehicle did not reach space until 1981. The predictions of *Skylab's* orbital decay also proved inaccurate, because increased solar activity heated the Earth's upper atmosphere and dragged the station down faster than expected. On July 11, 1979, *Skylab* reentered and splattered a sparsely settled region of Australia with debris. Especially in retrospect, the failure to save *Skylab* appears to be a mistake. No American flew on a space station again until 1995, meaning NASA lost many personnel who had developed expertise in training for and executing long duration missions. The Soviet Union instead took the lead in long duration flight with their series of *Salyut* space stations that hosted crews beginning in 1971 and *Mir* beginning in 1986.[46]

The training of *Skylab* astronauts carried a positive legacy by proving astronauts could utilize their trained judgment to make scientific and operational contributions

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[46] Ibid, 361-372.

impossible aboard a fully automated vehicle. All previous astronauts who had flown in space had focused on achieving the goal of a Moon landing. During *Mercury, Gemini,* and *Apollo,* Earth orbit was only a steppingstone toward the lunar goal. But through briefings by highly qualified instructors and an unprecedented amount of simulator time, *Skylab* astronauts prepared themselves to prove the intrinsic scientific value of having humans in Earth orbit. Thus the three crews succeeded in advancing knowledge about the medical effects of weightlessness, materials processing, the Sun, and the Earth. In the category of operations, the astronauts succeeded in performing the most complex EVA tasks yet on the strength of the new pool in Huntsville. They also proved that given adequate training in hardware, they could make repairs to keep a space station in operation. "The Russians were over here about that time, and they were impressed at how we could do on-orbit repairs, some of these kinds of things," Bob Crippen said. After over two thousand hours of training time each, astronauts also proved they could adapt to the psychological challenge of spending up to 84 days in a tightly confined space with two colleagues. Pilots and scientists worked together effectively.[47]

The success of the three *Skylab* crews in these respects shaped the future of human spaceflight. If these astronauts had proven unable to function after several weeks or months of weightlessness, or if PIs had not expressed intrigue with the experiments they conducted and the questions they raised, this would have placed a damper on the recently approved Space Shuttle program. But in the wake of the promising results from *Skylab,* shuttle astronauts expanded on the scientific research, complex EVA tasks, and

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[47] Hitt, Garriott, and Kerwin, 461-466.

equipment repair pioneered aboard *Skylab*. Pilots and scientists formed a close working relationship on every flight. The proficiency of *Skylab* crews also meant that NASA Administrator Jim Beggs could point to a track record of success when he proposed a new space station as the "next logical step" for human spaceflight in the early 1980s. Unfortunately, 21 years passed from the splashdown of the *Skylab 4* crew until Norm Thagard became the next American to live on a space station and 26 years until an American lived on the ISS. Crippen remembered his disappointment about this gap, stating, "I thought we learned a lot of lessons, and it wasn't obvious when you get that big of a gap that you can transfer a lot of knowledge. That's the only disappointment I felt." Still, ISS astronauts have carried on the *Skylab* legacy by receiving detailed briefings on scientific experiments, rehearsing experiment operations in simulators, rehearsing EVA tasks in a neutral buoyancy pool, and utilizing their trained judgment in performing experiments once in space.[48]

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[48] Ibid and Launius, 114.

CHAPTER XI

APOLLO-SOYUZ: "SOYUZ, EHTO APOLLON"

The first meeting happened in spring 1962. The original American astronauts and Soviet cosmonauts had heard about each other from afar over the last two years, but on this occasion the second and third humans to orbit Earth met. John Glenn hosted Gherman Titov on a tour of Washington, D.C., including a meeting with President John F. Kennedy at the White House. Titov felt convinced of the superiority of his *Vostok* spacecraft over the American *Mercury* spacecraft, Soviet Communism over American democracy, and even Soviet buildings over the landmarks he saw in Washington, D.C., but still found common ground in speaking with Glenn on subjects like training and the feeling of weightlessness.[1] In the years to come, space travelers on both sides of the Cold War followed each other's flights and a few shook hands with each other. They knew that they shared similar lives by immersing themselves in the technical challenges of flight, but primarily isolated themselves from any matter outside their own jobs. "I never cared much about keeping up with news about the Russians," remembered John Young. "I don't think any of the astronauts did."[2] The astronauts considered traveling overseas to train for a joint mission and orbiting Earth alongside Russians as anathema throughout the 1960s.

Politics ensured that astronauts and cosmonauts would have to accept what they

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[1] Colin Burgess and Francis French, *Into that Silent Sea: Trailblazers of the Space Era, 1961-1965* (Lincoln: University of Nebraska Press, 2007), 118-120.

[2] Young with Hansen, 75.

once considered anathema. President Kennedy had briefly considered cooperating with the Soviets on a project to send men to the Moon before his assassination, but not until *Apollo* achieved that goal did cooperation become a serious possibility. President Richard Nixon had appointed Tom Paine as NASA Administrator in 1969, and Paine believed the space agency should "stop waving the Russian flag and begin to justify our programs on a more fundamental basis than competition with the Soviets." On an *Air Force One* flight to greet the *Apollo 11* crew after their Pacific Ocean splashdown, he told Nixon that he considered international cooperation an excellent way to do this and began corresponding with Mstislav Keldysh, the President of the Soviet Academy of Sciences. Paine and Keldysh agreed that the U.S. and Soviets would benefit from developing a common docking mechanism that could facilitate the docking of an *Apollo* and *Soyuz* spacecraft, because this would advance technological progress in both nations and even allow either spacecraft to rescue another. More broadly, cooperation between the two nations would foster the kind of Cold War détente for which the Nixon administration became famous. Keldysh invited NASA personnel to visit the cosmonaut training center in Star City (just northeast of Moscow) for a technical discussion of the new idea.[3]

This visit in October 1970 provided five Americans with their first close up view of how space travelers from another nation trained. MSC Director Bob Gilruth headed the delegation and traveled with MSC engineer Caldwell Johnson, MSC Flight Director

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[3] Edward Clinton Ezell and Linda Neuman Ezell, *The Partnership: A History of the Apollo-Soyuz Test Project* (Washington, D.C.: NASA SP-4209, 1978), 1-14.

Glynn Lunney, MSFC engineer George Hardy, and a director of international programs at NASA headquarters named Arnold Frutkin. The Americans found the *Soyuz* simulators arranged like those in Houston and saw the training specialists sitting outside to monitor spacecraft data just as in Houston. The difference going back to Yuri Gagarin's *Vostok* spacecraft still applied, in that Soviet vehicles contained remarkably fewer controls and instruments. When the Americans climbed inside and received briefings from cosmonauts Georgy Beregovoy and Vladimir Shatalov, Lunney remembered, "the very strong impression was one of simplicity—no circuit breaker panels, no large number of switches, not many displays." But cosmonauts could still exercise manual control of the *Soyuz* via a hand controller, particularly when making a docking as in this proposed joint mission. Lunney remarked on the way out that the vehicle appeared intuitive and comfortable, and that he had seen no obstacles to a joint docking mechanism. Representatives of both nations signed an agreement to work together on this device.[4]

The project received official approval at a U.S./Soviet summit in May 1972. Nixon furthered his legacy as a president who wanted to pursue a thaw in the Cold War by meeting with Premier Alexei Kosygin and jointly agreeing to arms limitations, protection of the environment, and the expansion of trade. Nixon and Kosygin also agreed that a three man *Apollo* crew would dock with a two man *Soyuz* crew in 1975. The development of the new docking mechanism had already advanced each nation technologically. On all space missions to this point, each spacecraft docking ring had a

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[4] Ibid, 97-123 and Lunney, 222-225.

unique design ("male" or "female") and had a specific role to play in the docking process (one had to be active and one had to be passive). But the new device was androgynous, meaning any spacecraft docking ring containing the device could dock with any other spacecraft. Thus two vehicles could reverse their roles as active or passive targets, which allowed for a more flexible mission design. The Nixon/Kosygin agreement paved the way for an American crew to not only test this device in docking an *Apollo* to a *Soyuz*, but also to visit the *Soyuz* and perform joint experiments in orbit. Just making the fifteenth piloted flight of an *Apollo* spacecraft, the most complex machine ever built, would have called for an intense training regimen for the three crewmembers. But now Nixon and Kosygin had added the complexity of training in another nation, using a *Soyuz* simulator, and working alongside aviators on the other side of the Cold War divide who spoke another language. The two sides accepted a list of 17 points of agreement in 1972, which stipulated that each nation would train with the other country's vehicle "for safety of flight assurance" and learn the other country's language "well enough to understand it."[5]

Who would comprise the first American crew to train in the Soviet Union? Several astronauts had taken lessons in the Russian language after the 1972 summit with an eye toward earning the assignment, including Director of Flight Crew Operations Deke Slayton. Slayton had made a trip to the Mayo Clinic in Minnesota, where a doctor had found no recurrence of the heart fibrillation that had grounded him back in the *Mercury* era. NASA doctor Chuck Berry announced that he was cleared for flight status

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[5] Ezell and Ezell, 161-193.

in March 1972. Slayton thus handed the crew selection for *Apollo-Soyuz* to center director Chris Kraft, who had to choose among dozens of candidates for America's last piloted spaceflight until the Space Shuttle era. Tom Stafford had flown three times during *Gemini* and *Apollo* and had met several cosmonauts while serving as pallbearer for a *Soyuz* crew that had been killed during a 1971 mission. He had the experience both to fulfill the technical and diplomatic tasks of the mission, so Kraft chose him as Commander. Vance Brand had impressed during his time as a backup for *Apollo 15*, so he earned the job of Command Module Pilot. Slayton rounded out the crew as Docking Module Pilot, meaning he would reach space sixteen years after becoming one of America's original seven astronauts. At the Paris Air Show in May 1973, the three met the two cosmonauts they would meet in orbit aboard the *Soyuz*: Alexei Leonov and Valery Kubasov.[6]

Stafford, Brand, and Slayton needed to concentrate first on Russian language proficiency, because the mission protocol called for the American crew to speak Russian and the Soviet crew to speak English. In case a crew from one nation needed to rescue the crew of another nation someday, both parties would benefit from prompt and accurate communication with each other. According to a Foreign Service Institute chart, Russian is one of the most difficult languages for English speakers to learn. On a scale from I to V, it is in Category IV and only a notch below Arabic, Chinese, Japanese, and Korean.[7] To mount this daunting obstacle, American and Russian officials met in the

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[6] Slayton with Cassutt, 274-281 and Ezell and Ezell, 249-250.

[7] "Language Difficulty Ranking," *Effective Language Learning*, http://www.effectivelanguagelearning.com/language-guide/language-difficulty (accessed November 20, 2016).

fall of 1972 to consider three options: enroll the astronauts in a formal class, contract with a university for their instruction, or bring instructors to Houston to work with them. The last option worked best, because it cost the least amount of time and money. NASA thus hired Nicholas Timacheff to fill the new civil service position of Russian Language Officer and Timacheff selected four teachers to come to Houston on the basis of their knowledge in contemporary vernacular Russian. Nina Horner taught the astronauts the Russian aerospace jargon they would need to know using a textbook from the Defense Language Institute in Monterey, California. Anatole Forostenko, Vasil Kiostun, and James Flannery accompanied the astronauts on their trips to Russia to help them instill knowledge of everyday Russian and even accompanied them to the gym to help attune their minds to the language.[8]

The *Apollo-Soyuz* experience taught all NASA personnel that language training needed to be a time consuming and intensive part of mission preparation. Stafford, Brand, and Slayton received close to 1,000 hours of instruction from early 1973 through the summer of 1975, which marked one-third of their training time. This ranked just below the 1,100 hours that the Foreign Service Institute recommends to reach general professional proficiency in speaking and reading, an impressive figure given the demanding schedule all astronauts confronted. As with geology training a decade earlier, these astronauts had to master a task in which they had taken no classes as college students and did not envision themselves doing even a few years earlier. This,

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[8] Ezell and Ezell, 255-260 and *Apollo* Mission Evaluation Team, *Apollo* Program Mission Evaluation Report, *Apollo-Soyuz* (Houston, TX: JSC-10607, 1975), 10-6 to 10-7.

combined with the immense cultural and linguistic differences between English and Russian, resulted in the crew arguing in their mission report that they “needed every hour of Russian training that was received—and would not have wanted less.” Stafford, Brand, and Slayton recommended based on their ordeal that future crews should begin language training at least two years before launch. They did compliment the in-house instructors and Defense Language Institute textbooks as worthwhile solutions to the problem.[9]

The astronauts had to take a break from their roughly fifteen hours per week of language training to meet Leonov and Kubasov on their trips to the United States and travel themselves to the Soviet Union. The first trip came in July 1973, when Leonov and Kubasov traveled to Houston for a taste of American spaceflight operations. Leonov had never visited the U.S. before and felt overwhelmed by the American skyscrapers, luxury cars, and museums. He also remembered a cultural shock from his first visit to JSC: the lack of supervision astronauts received compared to cosmonauts. Soviet instructors had closely supervised his physical exercise and diet, “but the American astronauts seemed to do what they wanted, with nobody paying attention to what they ate or what physical shape they were in.”[10] Another cultural shock came when he and Kubasov entered the Command Module Simulator and witnessed the array of switches and displays that Americans needed to learn prior to a flight. The number of systems an *Apollo* crewmember needed to learn dwarfed the number a *Soyuz*

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[9] *Apollo-Soyuz* Mission Evaluation Report, 10-6 to 10-7.

[10] Scott and Leonov with Toomey, 344-345.

crewmember needed to learn, meaning more briefings, more simulator sessions on each flight phase, and in general more knowledge to keep accessible in one's mind. But after all the hours of studying came a greater reward for an *Apollo* astronaut than a *Soyuz* cosmonaut: the ability to exert more control over a flight, which all self-respecting pilots wanted.[11]

The men who agreed to the training regimen, cosmonaut Vladimir Shatalov and astronaut Bob Overmyer, believed crews of both nations would benefit from learning each other's hardware. One day, a stranded crew might depend on the crew of another nation understanding their hardware well enough to perform a rescue. So Leonov and Kubasov watched videotaped presentations on the CSM and new Docking Module (DM) that a Russian speaking engineer from the North American Rockwell company narrated. They listened to tape recordings of air to ground transmissions from previous missions so they could understand how astronauts worked with flight controllers to execute procedures. The two also flew to the North American Rockwell plant in Downey, California, so they could participate in an American tradition dating back to *Mercury*: observe the work engineers were performing on the spacecraft to which they would entrust their lives in space. Lunney recalled that this marked another of the key differences in training between the two nations. Instructors encouraged the cosmonauts to ask questions at any time to make sure they absorbed a far more complex vehicle than any they had studied before. The instructors felt confident in Leonov and Kubasov by

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[11] Ezell and Ezell, 253.

the time the two returned to their homeland.[12]

The American and Russian crews also put to rest any worries that aviators from opposing sides of the Cold War could not get along. Leonov was a Soviet Air Force veteran who had flown MiG aircraft, the kind that American pilots had shot down in Korea and Vietnam. All three Americans had also flown military aircraft, with Stafford and Slayton being stationed in West Germany, across a wall from where pilots like Leonov flew. When Leonov made his first trip to the U.S. and visited astronaut Dave Scott's home, he was shocked to find a book with a Nazi swastika on the cover that would have been banned in his home country. When he had his first conversation with Scott, he expressed his dismay that the U.S. had sent troops to wage war in Vietnam. Scott countered that the Soviets had also sent troops to Vietnam. But despite the occasional uncomfortable conversation such as this one, both understood that they had flown similar planes and confronted similar challenges in their professional careers, meaning they were promising candidates to unite around a common mission. The amount of time that training required crews to spend together had long united *Apollo* crews. At the end of *Apollo-Soyuz* training, Leonov and Kubasov had grown so close to their American colleagues that they formed affectionate nicknames for Stafford and Brand: "Granddad" and "Vanya." Slayton described the two Soviets as "basically a lot like us" and Leonov particularly as "jolly and friendly."[13]

The American crew visited Star City for the first time in November 1973.

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[12] Ibid and Lunney, 270.

[13] Scott and Leonov with Toomey, 336-353 and Slayton with Cassutt, 286.

Stafford, Brand, Slayton, and the Americans who accompanied them received their own cultural shocks, partly from the massive amounts of vodka the Soviets consumed but especially from the heavy surveillance of their activities. During one conference, Bob Overmyer (a member of the support crew) moved his chair and saw a hidden microphone come loose. Incidents such as these fostered a sense of paranoia for Americans aimed at the KGB.[14] But the astronauts did relish the grand respect shown them in Star City. After leaving the plane that took them there, they went to the VIP lounge for drinks of vodka with the airport staff. Then they stayed at the prestigious Intourist Hotel, located right next to the Kremlin, and rode to Star City via a large bus with two police escorts who waved admiring peasants off the road. Training gave them a sense of the "rock star" status that transcended borders.[15] The crew also benefited from watching nine videotaped lectures on the *Soyuz* controls and displays for the flight control, environmental, and communications systems. They listened to tapes of air to ground transmissions from an earlier *Soyuz* mission just as the Soviets had for an earlier *Apollo* mission. The three men placed their knowledge to the test by climbing aboard the *Soyuz* general purpose and docking simulators. They also learned that the Soviets placed a greater emphasis on physical training than the Americans, meaning long hours of jogging, swimming and even a snowball fight before relaxing together in a steam bath, a Russian tradition.[16]

By the spring of 1974, the development of flight procedures allowed Stafford,

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[14] Young with Hansen, 217.

[15] Interview with Stafford.

[16] Ezell and Ezell, 256-257.

Brand, and Slayton to rehearse the specific actions they would have to take on the mission. The three men needed to climb into the simulator and learn the array of switches and displays that all *Apollo* astronauts had needed to know, over 400 hours per man, but instructors placed the main emphasis on teaching the astronauts about the element that would fly for the first time: the DM. This cylindrical pressure vessel, about 10 feet in length, connected to the nose of the CSM and enabled the ship to link up with the *Soyuz* while also serving as an airlock between the different atmospheres of the two ships. Stafford used the simulator to place his flying skills to the test, first in linking the CSM to the DM as it was stored in the *Saturn IB* rocket after launch and then in maneuvering the linked combination to a precise docking with the *Soyuz*. Then the astronauts trained for their transfer through the DM and into the *Soyuz*. This required working through hundreds of instructions, from establishing the integrity of seals and latches to equalizing the tunnel pressure so the crew could make their way to the *Soyuz*. "The second day we tried it, we did it in about one-third the time that we did the first day," Stafford told the media.[17] The simulator served an excellent purpose in alerting the crew to how they should handle the "what if" questions about this piece of hardware, from fire, to rapid pressure loss, to abnormal vehicle dynamics (as in *Gemini 8*), to the failure of an RCS thruster (as in *Skylab 3*). As the database of knowledge from past missions grew greater and greater, the instructors and astronauts could feel more comfortable that simulations could prepare them for emergencies.[18]

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[17] Ibid, 261-262 and 313.

[18] *Apollo-Soyuz Test Project* Operations Handbook Command/Service/Docking Modules (Houston, TX: JSC-09092, 1975), 20-1 to 21-9.

One training issue did become a source of controversy, however. The Soviets worried that as the CSM approached the *Soyuz* for docking, the plume generated by the RCS thrusters might hit the *Soyuz* and burn its thermal insulating blanket. The onus fell upon the astronauts to shut off the thrusters at just the right moment and the Soviets preferred to have the engines controlled by an automated system instead. The astronauts expressed their dismay that the Soviets would question their abilities and the simulator proved to be a valuable tool in proving they could dock without impinging on the *Soyuz*. When the DM captured *Soyuz*, an indicator light appeared in the CSM cockpit. Brand called out “contact” to Stafford, who reached up and turned off the four RCS switches that controlled the forward firing thrusters. Two skeptics from the Soviet side, engineer Boris Petrov and Flight Director Alexei Yeliseyev, climbed into the simulator and saw the procedure for themselves, upon which the controversy flagged. The episode illustrated the differences between the two nations. Americans believed in a pilot controlled approach to flight to a greater extent than the Soviets, which meant more simulator time and produced the flexibility of a trained human operator. In case a controversy emerged over a procedure, the beauty of the simulator was also that astronauts could place it to the test there and not leave the procedure to chance in flight.[19]

The flight controllers for the two nations also took part in simulations during 1974. Soviet controllers traveled to Houston to gain a taste of American Mission Control operations and American controllers traveled to Kaliningrad to gain their first

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[19] Ezell and Ezell, 274-278.

taste of Soviet Mission Control operations. The Americans felt impressed with the Soviet facility, especially because the Soviets had replaced the old center and spent several million dollars in building this new one over the past few years. This facility featured 24 consoles, clocks, a world map, a television picture of the spacecraft, and a typewriter keyboard, meaning the Americans immediately felt reminded of Houston.[20] American flight directors Pete Frank and Neil Hutchinson both recalled that the Soviets' computer hardware was archaic compared to the Americans'. Yet Frank did feel struck by the Soviets' talent in science, physics, and mathematics, including the fundamentals of orbital mechanics. The talent of the people gave him confidence in the mission.[21] The flight controllers benefited from visiting this center because control of the mission would be integrated between both participating nations, not just one. The Flight Directors in each center would converse with each other through Joint Flight Directors and their interpreters. Each side also appointed a group of visiting specialists who would travel to the other side's center and resolve any technical issues during the flight. American controllers thus familiarized themselves with the Russian center over ten day sessions and took part in simulations where controllers of both sides received malfunctions to solve.[22]

With the specific flight procedures in place and the flight controllers selected and trained for the mission, the astronauts and cosmonauts could now work together more

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[20] Ibid, 233-234 and Lunney, 311-312.

[21] M.P. "Pete Frank II, Interviewed by Doyle McDonald, August 19, 1997, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/FrankMP/FrankMP_8-19-97.htm (accessed November 23, 2016) and Neil Hutchinson, Interviewed by Kevin M. Rusnak, July 28, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/HutchinsonNB/HutchinsonNB_7-28-00.htm (accessed November 23, 2016).

[22] Ezell and Ezell, 290-291.

productively on their overseas trips. Leonov and Kubasov made their last visit in February 1975. After receiving a briefing on launch operations at KSC, the cosmonauts flew to Houston to rehearse their joint activities. This training now included a script prepared by the two crews and their language instructors. For instance, Stafford called out, "*Soyuz,* ehto *Apollon*. Stuikovka na pyat minut…" and Leonov replied, "*Apollo*, this is *Soyuz*. I understand; docking is in five minutes."[23] The crews could also now rehearse their joint activities. When the astronauts and cosmonauts climbed into one another's spacecraft, they would speak with heads of state, exchange gifts, and perform experiments on biological interaction, microbial exchange, use of a multi-purpose furnace, creation of an artificial solar eclipse, and ultraviolet absorption. Given the number of people who would watch the first handshake between astronauts and cosmonauts in space, both crews needed to feel comfortable with this phase of the flight and agreed that simulations helped them to "know what to expect from each other and work together in a relaxed manner." The crews needed to feel comfortable performing the experiments also, because $16 million went into them. Simulations taught them the teamwork required to collect data. For instance, the *Apollo* crew planned to undock their vehicle from the *Soyuz* and direct the nozzle of their SPS engine toward the Sun so as to create an artificial solar eclipse. The *Soyuz* crew would then use highly sensitive film to observe the solar corona.[24]

Stafford, Brand, and Slayton reciprocated by making a 16 day trip to the Soviet

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[23] Ibid, 262.

[24] Ibid, 278-279, Lunney, 305-306, and *Apollo-Soyuz* Mission Evaluation Report, 10-3.

Union in April. This allowed them to rehearse the joint phase of the flight aboard a mockup of the *Soyuz* spacecraft and solve contingencies aboard a *Soyuz* simulator. The astronauts especially benefited from seeing the Mission Control Center in Kaliningrad and the Baikonur Cosmodrome launch facility for the first time. The objective of the mission was to demonstrate that two superpowers could cooperate and seeing Soviet space operations in action built confidence for the *Apollo* crew. They knew that the Soviets prepared for missions differently than the Americans, as in the horizontal assembly of rockets and fewer rocket tests at the launch pad. They knew that cosmonaut Vladimir Komarov had perished due to a parachute failure on the *Soyuz 1* mission in 1967, that the *Soyuz 11* crew had perished in a reentry failure in 1971, and that the *Soyuz 18* crew had just undergone 21 Gs in a launch abort earlier that month. They also knew that U.S. Senator William Proxmire was making headlines with his criticism of the *Soyuz* program, arguing that a joint mission would be dangerous and even calling for a CIA investigation. Yet after seeing Soviet training and flight hardware up close, Stafford and Brand each told reporters that they felt satisfied with the reliability of the *Soyuz*. The cultural training these men received was an element that differed from all previous American space crews.[25]

By May, the Americans and Russians had reached the home stretch of the training sequence. This meant it was time for the crews to begin integrated simulations involving crews and flight controllers from both nations, each more ambitious than the last. On May 13, Leonov and Kubasov began a 25 hour session in the *Soyuz* simulator,

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[25] Ezell and Ezell, 280-282.

in which they simulated launch and the maneuvers that would take them toward *Apollo*. Stafford, Brand, and Slayton spent this time in the *Apollo* simulator, while interpreters sent messages back and forth between the two control centers. On May 15, the two sides performed a 56 hour simulation that allowed the crews to simulate rendezvous, docking, joint activities, and undocking. A May 20 session allowed them to prepare for this phase as well, but this time with emergencies instituted by SimSups. The grand finale of integrated simulations came from June 29-July 1.[26] By the time Stafford, Brand, and Slayton flew their T-38 jets to Florida on July 13, their training had surpassed that of any previous crew thanks largely to the language requirement. This was easily the most time consuming task, followed by rehearsals for joint crew activities, Command Module Simulator sessions, briefings and rehearsals for the scientific experiments, inspections of their actual spacecraft, and briefings for the mission techniques and rules. Slayton made up for his long absence from flight status by becoming the first astronaut to rack up more than 3,000 training hours for a flight. Stafford and Brand each finished with over 2,600.[27] The time had come for two nations to join forces beyond planet Earth.

The first day of the flight provided convincing evidence of the value of the most grueling training regimen yet. Leonov and Kubasov launched aboard their *Soyuz* on July 15. About seven hours later, the *Saturn IB* soared into space one last time with the words from an “Original Seven” astronaut: “Man, I tell you, this is worth waiting 16 years for.” The responsibility then fell to Stafford to separate the CSM from the upper

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[26] Ibid, 283.

[27] Ibid, 313.

stage of the booster, move around to face the DM stored inside, and dock with it. He peered through the alignment sight, only to see the glare from the sunlit Earth. Yet he improvised by moving about 30 feet away from the booster and stationkeeping with it until his target appeared to move toward Earth's horizon. He lined up the reticle on the alignment sight with the DM so accurately that the spacecraft were aligned to within a hundredth of degree when he achieved docking. On the last *Apollo* flight, he had set the record for most accurate *Apollo* docking.[28]

The docking on July 17 placed the communication and teamwork of the two crews to the test. Over the years, communication problems have caused several accidents in which two aircraft were in close proximity. Yet when the *Apollo* crew saw the *Soyuz*, first as a green speck against the velvet black sky and then as it grew larger and larger, the astronauts and cosmonauts clearly communicated in each other's language on the strength of their training. Most critically, Stafford gave Leonov the prompt to perform a 60 degree roll maneuver that gave *Soyuz* the proper attitude relative to *Apollo*. Leonov did so, before adding a lighthearted message in reference to the controversy during their training: "Tom, please don't forget about your engine." But he did not have to worry, because Stafford knew just what to expect from the simulations. Stafford began the final closing maneuver by precisely aligning the alignment sight with the cross on the *Soyuz* docking ring, slowing his velocity relative to the *Soyuz* to just over 0.3 feet per second, and making a graceful docking without impinging on his target. Then he retracted the guide ring, actuated the structural latches, and compressed the

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[28] Ibid, 320.

seals. The point here was that Stafford demonstrated the success of manual spacecraft control, which the Americans had always valued more heavily than the Soviets, and which depended on instilling the right habits in crewmembers through training. "We have capture," Leonov declared.[29]

Amid the hoopla of the next two days, including conversations with President Gerald Ford and General Secretary Leonid Brezhnev, the five men together in orbit performed experiments that placed their training to the test. This allowed the astronauts and cosmonauts to demonstrate the value of having trained experiment operators in space and that *Apollo-Soyuz* was more than a political mission. Stafford, Brand, and Slayton conducted an electrophoresis experiment, meaning the separation of human cells with electric current so as to examine them at a genetic level. The crew improved the techniques used to accomplish the insertion of the cell samples based on the experience of past *Apollo* crews and their knowledge helped to produce exciting data on kidney cells. The astronauts also exercised their knowledge in the use of a multi-purpose electric furnace. Thanks to their training in the operation of the furnace, they had the flexibility to manipulate the processing of materials in this device such as alloys or crystals. Two other experiments placed their flight training to the test. The astronauts undocked their CSM from the *Soyuz* on July 19 to direct the nozzle of their engine toward the Sun and create an eclipse. This required them to exercise the precise control honed in the simulator. The crew fired thrusters at just the right time for just the right number of seconds and maintained attitude hold long enough for Leonov and Kubasov to

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[29] Ibid, 328 and *Apollo-Soyuz* Mission Evaluation Report, 10-2.

obtain 125 photo frames of the eclipse. Stafford, Brand, and Slayton also flew away from the *Soyuz* for an ultraviolet absorption experiment. Once again following the reticle on the alignment sight, the crew projected beams of light onto a set of retroreflectors on the *Soyuz*, which reflected them back so a spectrometer on the CSM could yield data on the amount of atomic oxygen and atomic nitrogen in orbit. All three astronauts were busy, as Slayton operated the hand controller, Brand operated the computer, and Stafford went the lower equipment bay to turn on sensors.[30]

Despite the hundreds of hours in the simulator, the crew made one of their two notable mistakes at this point. Slayton flew the vehicle to dock with the *Soyuz* again, but he fired thrusters to roll the CSM for about three seconds after contact. This produced a sideways force that caused *Soyuz* to oscillate and made flight controllers in Houston and Kaliningrad nervous. Yet the *Soyuz* quickly aligned the two vehicles and neither was damaged. The brief scare proved that even highly trained astronauts were not immune to mistakes, but also the reliability of the new docking system. Slayton did not dwell on the incident in his memoir, arguing instead, “I think the exercise taught us something about possible future space rescue.” The astronauts undocked from the *Soyuz* again late on the evening of July 19. Leonov and Kubasov landed two days later, but the *Apollo* crew had five more days to spend in orbit: the last chance to obtain scientific data from astronauts until the Space Shuttle era.[31]

Most relevant from a training perspective was the collection of Earth observation

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[30] R. Thomas Giuli, *Apollo-Soyuz* Preliminary Science Report (Houston, TX: JSC-10632, 1976), 20-1 to 20-23, 22-1 to 22-9, 6-1 to 6-5, and 8-1 to 8-22 and Ezell and Ezell, 342.

[31] Ezell and Ezell, 341 and Slayton with Cassutt, 303.

data, following up on the exciting results from *Skylab*. Many of the scientists who had trained astronauts during the moon missions, such as Lee Silver, Farouk El-Baz, and Bill Muehlberger, trained this last *Apollo* crew to make the most of their observational skills. These men gave them 60 hours of classroom instruction on the phenomena they would see across 1974 and 1975, while the crew made flyovers of geologic features from California to Florida. This crew thus trained in a similar way as the lunar crews had, only in this case to observe a much more varied celestial body in which billions of humans lived. The fact that scientists doubled the amount of time devoted to training astronauts in Earth observations from *Skylab 4* to *Apollo-Soyuz* (30 hours to 60) suggested the intrigue of the results. Sure enough, Stafford, Brand, and Slayton made several significant findings in fields ranging from geology, to oceanography, to deserts, to hydrology, to meteorology, to the environment. The preliminary science report for the mission attested to the value of having people making these findings rather than robots. The case for humans in space remained strong because trained astronauts could study features of only transient visibility and unknown features much more effectively than automated machines.[32]

The crew's other notable mistake came during the reentry on July 24. Stafford called off the steps on the checklist to Brand so the latter could throw the correct switches. One of the steps called for arming two Earth Landing System switches at an altitude of 30,000 feet, which would shut off the vehicle's thrusters. But Brand did not hear Stafford make this call, probably because of the noise in the cockpit due to thrusters

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[32] Giuli, 10-1 to 10-64.

and the flight of the vehicle through the atmosphere. He did not arm the switches until 30 seconds after he was supposed to, meaning propellant from the thrusters had 30 seconds to flood the cabin through a pressure relief valve that had just opened. All three astronauts noticed they were now breathing toxic chemicals from that propellant and started coughing. Brand worked through the rest of the checklist, including the manual deployment of the main parachutes, until the ship splashed down in the Pacific Ocean. But the three now needed to place their emergency training to the test. Though they were hanging upside down in a vehicle that had just flipped over, Stafford still managed to crawl to the oxygen masks while grunting to keep just enough pressure in his lungs. He and Slayton donned masks and held one over the face of an unconscious Brand. Brand rallied and threw a switch to bring the vehicle upright, then Stafford opened a vent valve and fresh sea air poured into the ship. The crew had just inhaled nitrogen tetroxide at three hundred parts per million, dangerously close to a lethal four hundred parts per million, but managed to recover after two weeks in a hospital in Honolulu. Without training in the splashdown sequence, Stafford, Brand, and Slayton would have been less likely to save their lives in time.[33]

The *Apollo-Soyuz* mission marked the end of one era and the dawn of another. For the last time, an American crew rode an expendable vehicle into space atop a *Saturn* rocket and returned to a splashdown. But for the first time, an American crew had undergone training in another nation for a space mission. They had traveled overseas not only to understand a foreign spacecraft, but also to immerse themselves culturally

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[33] Ezell and Ezell, 347-349 and Slayton with Cassutt, 305.

and linguistically in a foreign nation. The question remained as to whether the two space superpowers would again unite in human spaceflight. Glynn Lunney remembered that the Soviets expressed interest in another *Apollo-Soyuz* flight during 1974 and 1975, and even in 1977 he traveled to Moscow with several NASA personnel to discuss a Space Shuttle flight that would dock with a *Salyut* space station. "But, there was no tentative proposal that looked like it would attract much or any support from NASA Headquarters," he concluded. Especially after a series of events soured American interest in Cold War détente, such as the Soviet military interventions in Angola in 1975 and Afghanistan in 1980, interest in another joint flight fell by the wayside.[34]

But after the Soviet Union dissolved, the time had finally come for American astronauts to travel to Russia again and tap into the expertise in long duration flight that carried over from the Soviet era. "We were a little of a spark or a foot in the door that started better communications," Brand reflected in 2000.[35] By that time, astronauts had followed in his footsteps by devoting hundreds of hours to learning the Russian language and immersing themselves in Russian culture, only this time by spending years in Star City prior to visiting *Mir* or the ISS. Flight controllers had followed in the footsteps of their *Apollo-Soyuz* predecessors by working together in joint simulations. The personnel involved in the Shuttle-*Mir* and ISS programs, from managers to flight controllers to astronauts, also had a trusting relationship that had been strengthened by the *Apollo-*

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[34] Lunney, 327-329 and Ezell and Ezell, 355-356.

[35] Vance D. Brand, Interviewed by Rebecca Wright, July 25, 2000, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/BrandVD/BrandVD_7-25-00.htm (accessed November 25, 2016).

Soyuz experience.[36] One of the Shuttle-*Mir* program managers, Frank Culbertson, remembered that his predecessor Tommy Holloway established a framework of working groups (another similarity between this program and *Apollo*-*Soyuz*) which resolved any issues in cooperating on the project. He remarked that Holloway could do this partly because of "the *Apollo*-*Soyuz* experience which some of the people had been a part of, particularly on the Russian side."[37] Although the Soviet empire did not survive until the end of the 20th century, the methods of preparing for and conducting a joint flight did not die with it.

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[36] Clay Morgan, *Shuttle-Mir: The United States and Russia Share History's Highest Stage* (Washington, D.C.: NASA SP-2001-4225, 2001), 158.

[37] Frank Culbertson, Interviewed by Mark Davison, March 24, 1998, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/Shuttle-Mir/CulbertsonFL/CulbertsonFL_3-24-98.htm (accessed November 25, 2016).

CHAPTER XII

STS: "PEOPLE WERE REALLY AFRAID OF THE DOGGONE THING"

John Young stood on the surface of the Moon, peering through a gold plated visor at the American flag and a desolate landscape, when he heard the voice of *Apollo 16* CapCom Tony England. "The House passed the space budget yesterday, 277 to 60, which includes the vote for the shuttle," England told him. Young had immersed himself in *Gemini* and *Apollo* for the past decade. But during that moment on an alien world, at the height of American success in human spaceflight, he declared, "The country needs that shuttle mighty bad. You'll see."[1] He knew that the best way for the United States to establish a lasting foothold in space was not to launch a vehicle there and then discard it after one use. Commercial airline companies did not throw away 747 jets after one flight, so why should NASA throw away spacecraft? The space agency could instead take a step toward making spaceflight more like air travel by launching a vehicle that would land on a runway at the end of its mission, then undergo refurbishing by a team of KSC engineers before launching again. Engineers would not have to worry about constructing a new vehicle for each mission, only a few which would fly frequently and expose high numbers of astronauts, payloads, and scientific experiments to low Earth orbit. "It will take the astronomical costs out of astronautics," President Richard Nixon said on January 5, 1972 in announcing his decision to approve the Space

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[1] Young with Hansen, 177.

Transportation System (STS), or Space Shuttle.[2] This potential was the vehicle's main political appeal, but the vehicle appealed to astronauts because new types of people could ride aboard it and contribute to a flight. This called for new training procedures that Young could not have foreseen during his *Gemini* and *Apollo* days.

The first step in forming new training procedures was to determine what types of crewmembers would fly aboard the Space Shuttle. Since advanced studies on the vehicle had begun in 1968, most NASA managers and engineers wanted an entirely reusable two stage design. Two pilots would ride in the first stage as it provided the initial thrust of launch, then detach and return to a runway landing. Two pilots would also ride along with up to a dozen crewmembers in the second stage, which would then provide the thrust to reach orbit. But this design would cost over $10 billion to develop and the Nixon administration did not want to make this investment. The president approved instead a partly reusable vehicle, featuring a pair of twin Solid Rocket Boosters (SRBs) that would provide the initial thrust of launch before being jettisoned, an External Tank (ET) that would provide fuel to three main engines before being jettisoned to burn up in the atmosphere, and a winged orbiter in which up to a dozen crewmembers would ride (as it turned out, the largest shuttle crew consisted of eight people). This design cut the development cost in half.[3] This design also marked a major evolution in the history of the American astronaut, because all previous vehicles had

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[2] Richard Nixon, "Statement Announcing Decision to Proceed With Development of the Space Shuttle," January 5, 1972, *The American Presidency Project*, http://www.presidency.ucsb.edu (accessed November 26, 2016).

[3] Wayne Hale, et al., eds., *Wings in Orbit: Scientific and Engineering Legacies of the Space Shuttle, 1971-2010* (Washington, D.C.: NASA SP-2010-3409, 2011), 13 and Young with Hansen, 213-214.

carried no more than three crewmembers. All of them spent the dynamic phases of flight, such as launch, docking, or reentry, sitting in front of the displays and controls on an instrument panel. But aboard the shuttle, only two members of a larger crew would sit in front of an instrument panel. The rest would sit behind them in the flight deck or below in the middeck, meaning their contribution to a flight would come in an area other than piloting.[4]

When NASA Administrator Jim Fletcher flew to Los Angeles, California to meet with Nixon concerning the president's announcement in January 1972, he took with him a "fact sheet" suggesting how astronaut selection and training would change. The sheet read, "No special flight training would be required for passengers, making it possible to send scientists, doctors, artists, photographers—both men and women—into space."[5] By 1975, with Rockwell International contractors having just begun constructing Space Shuttle *Columbia*, NASA managers had defined three types of astronauts who would fly on the shuttle. Crews would include two pilots. The Commander in the left-hand seat of the cockpit would perform the flying while having the traditional responsibilities of mission success and crew safety. The Pilot sitting in the right-hand seat would provide assistance in flying the vehicle. But crews would also include several Mission Specialists (MS) who would make EVAs, operate equipment, and perform experiments, and occasionally Payload Specialists (PS) who came from outside the astronaut office to operate a payload on one specific flight. The projections of how often the shuttle would

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[4] Victor K. McElheny, "End of *Apollo* Opens Way for the Shuttle," *New York Times*, July 25, 1975.

[5] Amy E. Foster, *Integrating Women into the Astronaut Corps: Politics and Logistics at NASA, 1972-2004* (Baltimore: Johns Hopkins University Press, 2011), 77.

fly at this time turned out to be nonsensical: 60 flights per year by 1984 and a total of 572 flights by 1992, meaning pilots would fly six missions per year and Mission Specialists three missions per year.[6] But the mission roles endured. Each type of astronaut would need to be selected and require new materials to study and simulation facilities on the basis of their roles.

Since the Space Shuttle was the most complex machine ever built, the groups of astronauts selected for the program (1978, 1980, 1984, 1985, 1987, 1990, 1992, 1994, 1996, 1998, 2000, and 2004) began their training by listening to classroom instruction and studying workbooks to learn the operation of the systems. Today, the *Apollo* moon landings usually attract more attention as a feat that demonstrated American exceptionalism in carrying out a complex engineering task. The *Apollo* CSM was indeed the most complex machine ever built during the 1960s, but *Apollo 11's* Mike Collins made a telling statement when he returned to JSC years after his retirement to research a book. He found that one shuttle orbiter was equivalent in complexity to about four *Apollo* CSMs.[7] The orbiter contained more than 2.5 million parts, which included almost 230 miles of wire, more than 1,060 plumbing valves and connections, over 1,440 circuit breakers, and more than 27,000 insulating tiles to protect it from the heat of reentry.[8] Though the operation of many of those components would be automated, JSC training personnel (the office known as DT) expected astronauts to learn them. Crews

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[6] McElheny.

[7] Michael Collins, *Liftoff: The Story of America's Adventure in Space* (New York: Grove Press, 1988), 213.

[8] "The 21st Century Space Shuttle," *NASA Human Spaceflight*, http://www.spaceflight.nasa.gov/shuttle/upgrades/upgrades5.html (accessed December 3, 2016).

would have checklists to work through in operating the systems (95 pounds of checklists flew on each mission), and knowledge of the systems would benefit them in carrying out these steps and especially in solving a malfunction. Thus studying the workbooks created for each system, from electrical, to environmental, to propulsive, to guidance and navigation, to software, and more, marked the first step in an astronaut's path toward flight readiness.[9]

While moving through the workbooks, newly selected astronauts (called ASCANs during the shuttle era) began a training flow of classroom instruction that contained seven tiers. A supervisor took them through these steps with an eye toward encouraging astronauts not to memorize shuttle systems, but to understand them "at a 'big picture' level." For instance, the astronauts might have to configure an instrument panel without the Flight Data File (FDF) in front of them. The supervisor could provide them with leads in performing these tasks if necessary. After observing their performances, the supervisor rated their task completion level on a form as "easily, O.K., with difficulty, didn't complete, or didn't attempt" and noted the approximate time to complete the tasks. The form also provided space for the supervisor to note whether the ASCAN seemed prepared, was cooperative during class, was open to suggestions from others, and worked well with a partner. Like university professors, JSC personnel referred to this initial instruction as the 1000 and 2000 levels of courses.[10] Astronaut

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[9] Henry S.F. Cooper, *Before Liftoff: The Making of a Space Shuttle Crew* (Baltimore: Johns Hopkins University Press, 1987), 31 and T.A. Heppenheimer, *Development of the Shuttle, 1972-1981* (Washington, D.C.: Smithsonian Institution Press, 2002), 392.

[10] "Shuttle Crew Training Catalog, Revision J," June 1996, Box 21, Folder 2, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA, 1-1 to 1-2 and "ASCAN Performance Checklist," in

training had begun as a highly experimental task during the *Mercury* era, with a few techniques abandoned after that first program. It became gradually less so during *Gemini* and *Apollo*, until taking on its most standardized form during the shuttle era. The development of tiers of instruction and evaluation forms reflected the many more years of experience that training personnel had with the shuttle program than its predecessors, and the far greater number of astronauts.

Jim Voss and Susan Helms remember the challenge of that first indoctrination into the astronaut corps. As the holder of a master's degree in Aerospace Engineering, an Army Officer, a teacher at the U.S. Military Academy, and a JSC employee since 1984, Voss had an impressive background when he became an ASCAN in 1987.[11] He did not find any one topic especially difficult, "but when you put them all together it becomes a real challenge. Being an astronaut is like becoming a jack of all trades in spacecraft and operations." For the ASCAN classes that followed his, Voss did manage to offer additional assistance as the Astronaut Office Training Officer. "There was an astronaut who supervised the class, monitored the training, and was there to be an experienced voice that they needed," he explains. "They could ask questions that I could answer as an experienced astronaut. This person also made evaluations, not only for training but for their interactions with others and things like that."[12] Helms, the Air Force officer with whom he eventually served on the ISS, found the computer systems

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"Astronaut Candidate Training, 1991-2002," Box 17, Folder 25, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[11] "James S. Voss Astronaut Biography," *NASA*, http://www.jsc.nasa.gov/Bios/htmlbios/voss-ji.html (accessed December 28, 2016).

[12] Jim Voss, Phone Interview by Author, December 28, 2016.

especially challenging as a 1990 ASCAN. "The computer systems were confusing to me, because they were so old and the software was really machine language," she recalls.[13]

Also during this first year in the corps, ASCANs especially remembered traveling across the country to visit every NASA center from California to Maryland. "You need to know that every last NASA employee stands behind you," explained Mike Massimino of the 1996 class. "They also need to meet you so they can put a face to a name and know who they're protecting up there." Unlike the original *Mercury* astronauts, the shuttle ASCANs had grown up witnessing the reality of space travel but still needed to sense the grandeur of the effort they were undertaking. The best place to do this was at the Kennedy Space Center, where they could see one of the largest buildings in the world (the Vehicle Assembly Building [VAB]), the crawler-transporter, and the shuttle stack itself.[14]

Astronauts needed to acclimate themselves to flying the T-38 aircraft during their first year as well. Only a portion of the astronauts selected for the shuttle program were pilots, but the tradition since *Mercury* of requiring all astronauts to fly jets remained. As with the 1960s astronauts, traveling around the country in jets required shuttle astronauts to maintain generic flying and crew coordination skills in an environment that (unlike a simulator on the ground) could take their lives. Several also flew the T-38 as a chase plane during shuttle landings. For this reason, NASA spent several million dollars per

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[13] Susan Helms, Phone Interview with Author, January 29, 2017.

[14] Mike Massimino, *Spaceman: An Astronaut's Unlikely Journey to Unlock the Secrets of the Universe* (New York: Crown Archetype, 2016), 107-108.

year maintaining a T-38 fleet throughout the shuttle program and to this day. Because of the risks that had claimed Ted Freeman, Elliot See, Charlie Bassett, and C.C. Williams during the 1960s, shuttle astronauts had to go through a long process to gain pilot certification. Many Mission Specialists did not have a strong aviation background, meaning they went to a five day ground school during which they received instruction in basic aeronautical knowledge. All astronauts went through three days for land survival training, three days for water survival training, five days at a more advanced ground school that familiarized them with the T-38 in particular, and ejection seat training that familiarized them with usage, parameters, and parachute landing falls. Finally, the astronauts placed their knowledge to the test by carrying out a syllabus of T-38 flights covering navigation by instruments, aerobatics, formation flying, night flying, and low lift to drag flying.[15]

A few documents preserved by Sally Ride illustrate what the astronauts without an aviation background learned about flying. Upon her selection in 1978, Ride was part of the new breed of astronauts. Not only was she one of the first six women ever selected, she had spent her adult life working toward a Ph.D. in physics instead of flying aircraft. At the age of just 26, she had to take a multiple choice exam that proved her proficiency in this new task and repeat it annually. She even preserved her handwritten notes from ground school, containing tips such as, “Think your way through each maneuver before performing it. During the maneuver, stay ahead of the airplane. Be

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[15] “T-38 Operating Procedures,” January 2000, Box 9, Folder 1, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA, 42-43.

alert to any hazardous condition that may develop and know how to get out of it safely."[16] As a Mission Specialist with no high performance flight experience, she was required to fly the T-38 for at least 100 hours per year. Those who already had more than 200 hours of experience could get by with as little as 48 hours per year. The requirement drastically increased for Shuttle Commanders and Pilots beginning six months prior to the launch of a mission, as they needed to average 20 hours per month until their mission began. As a result of T-38 policy, astronauts who filled every seat on a shuttle mission had prior experience in the dynamic operations of an actual flight. Their use of this aircraft also afforded them the convenience of flying across the entire United States without waiting for a commercial airline.[17]

The first year in the corps for shuttle astronauts was not entirely about training for technical duties. Shuttle astronauts were the first to receive formal training for speaking to the media and making public presentations (the *Mercury*, *Gemini*, and *Apollo* astronauts who were better known ironically did not receive this). NASA hired Bill Wallisch to teach a class to the astronauts on this subject. "Since retiring as a professor of English and Communication at the United States Air Force Academy in Colorado Springs, I now help business executives, astronauts, physicians, cops and government staffers put together tight messages that communicate complicated ideas in a flash," he writes on his website.[18] He knew that even though shuttle era astronauts

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[16] "NASA Aircrew Annual Instrument Refresher Exam," March 1985, Box 5, Folder 10 and "Ride's Handwritten Aerobatics Notes," Box 6, Folder 3, Sally K. Ride Collection, Smithsonian National Air and Space Museum, Chantilly, VA.

[17] "T-38 Operating Procedures."

[18] Bill Wallisch, "Wallisch Session: A Quick Review,"*Your Main Point*, http://www.yourmainpoint.com/wallisch_session.htm (accessed December 26, 2016).

lacked the iconic status of John Glenn or Neil Armstrong, they still held one of the most exciting and unusual jobs in the world. Thus they would give televised interviews and travel to schools across the country with the goal of inspiring both children and adults. Each astronaut rehearsed his or her presentation skills in Wallisch's class and gave interviews with mock reporters.[19]

The astronauts also learned several examples of common mistakes when speaking to reporters that they should avoid. The most common mistakes included not remembering what was in their media briefing books, forgetting their key messages, talking too long or too briefly, talking too technically, talking too defensively, placing blame, and not taking seriously enough the necessity of proper preparation. Wallisch told his students to never say "no comment," to never fake knowledge, to never repeat the negatives of a question in their answers, and to never show anger. He also instructed them to beware of hypothetical questions, which they need not answer, and reporters' false facts, which they should correct before answering a question. Astronauts did receive specific instructions about dealing with the media after being assigned to a mission in some cases. One of the most notable examples of this came after the terrorist attacks of September 11, 2001. The *STS-107* crew received instructions not to speculate to the media about how the United States should respond to the incident and to assure reporters that NASA had taken proper security precautions to protect astronauts at Houston and the Cape. Astronauts throughout the shuttle program generally succeeded

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[19] Massimino, 215.

in enhancing the image of the government agency that employed them.[20]

With the completion of the classroom instruction, KC-135 aircraft flights to experience an initial taste of weightlessness, T-38 flights, media training, and technical training at the 1000 and 2000 levels, the ASCANs moved onto more advanced courses for specific systems. Each course had a different supervisor. First came the Crew Systems Training course, which called on the ASCANs to learn how to use the equipment responsible for maintaining a living environment on the orbiter, operate experiments, perform inflight maintenance, and make an emergency egress. This took place in a classroom and a replica of the orbiter crew compartment. The ASCANs began using the Shuttle Mission Simulator (SMS) for courses on ascent, orbit, and reentry operations. Next came trips to additional simulators that familiarized them with EVA, robotic arm operation, rendezvous with another spacecraft, and several common shuttle payloads such as the *Spacelab* and *Spacehab* modules. These courses all led to the course on integrated simulations, when the ASCANs began working in the SMS with flight controllers. A year or two after their selection, the ASCANs graduated and became fully fledged astronauts eligible for flight assignment.[21]

Thus the training personnel introduced several devices during this advanced phase that each deserve individual consideration. One was a new innovation when the program began in the 1970s: a computer called a Regency trainer. This computer featured a programmable 64 by 64 spot touch screen. Astronauts could view detailed

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[20] "Media Interview Training and Personal Notes, Undated," Box 22, Folder 47, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[21] "Shuttle Crew Training Catalog, Revision J," 1-1 to 14-1.

graphics of controls and displays on this screen and interact with them by touching the screen. The software would respond accordingly. The presence of this tool at JSC reflected a useful development in teaching throughout the United States: computer-assisted instruction. University of Illinois scientists had produced the Illinois Automatic Computer in 1952, the first computer built and owned entirely by a U.S. educational institution. In 1960, the scientists began running a program on it called Programmed Logic for Automatic Teaching Operations (PLATO). PLATO could assist students with coursework through then novel features such as text overlaying graphics and feedback for user input. By the late 1970s, with the program running on several networked mainframe computers throughout the U.S., JSC instructors decided to teach shuttle systems to astronauts using software based on PLATO. This system demonstrated just how far training had come since the *Mercury* era, because the “Original Seven” had worked in a far less electronically advanced world without such a convenient teaching tool. It also demonstrated that astronaut training was not an isolated field; developments in teaching at institutions like the University of Illinois could influence it.[22]

Another of the devices that ASCANs began using after graduation from the 2000 level was the Single System Trainers (SSTs). Contractors at Ford Aerospace in Newport Beach, California provided these $1.5 million facilities, which were medium fidelity recreations of a single orbiter system powered by a minicomputer. The rise of minicomputers throughout the U.S. in the 1960s had reflected the smaller units that had become feasible with the advance of transistors and core memory technology. They

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[22] Tomayko, 280-281 and Cooper, *Before Liftoff*, 31.

would be largely replaced by personal computers that took advantage of microprocessors during the 1980s, but when the shuttle program began minicomputers were still in vogue. The minicomputers in the SSTs allowed ASCANs their first chance to actually touch the hardware they had been studying, see its operation for themselves, and eventually learn to respond to malfunctions. "You can read books and ask questions about a system, and nobody has the answers yet," John Young recalled about the importance of the SST. "But then you get in the Single Systems Trainer, turn on the switch and it will tell you what the answer is. The learning curve when you first get into the training goes straight up."[23]

Having completed the most rudimentary forms of training, astronauts then tackled the most high-fidelity devices designed to simulate the individual tasks of a mission. After ASCANs completed the 2000 level, one of the first devices they encountered was the Crew Compartment Trainer (CCT), weighing in at over 23,000 pounds and built by Rockwell International in 1979. The CCT featured a replica of the flight deck and middeck so that training personnel could familiarize astronauts with the basic tasks of living and working on the orbiter. The vehicle could tilt straight up to simulate launch, when the astronauts would have to strap into their seats and monitor instruments while lying on their backs. It would then return to a level position so they could rehearse procedures in the middeck for waste collection, dining, personal hygiene, sleep, trash management, and the many experiments they would have to perform. The instructors could even install a treadmill and place biomedical sensors on the astronauts

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[23] Heppenheimer, 392.

for this purpose. Instructors could also force a crew to respond to a sudden loss of cabin pressure, fire, or contaminated atmosphere. An emergency like this might require them to make a quick egress through the side hatch and then onto the ground via an inflatable slide. One astronaut estimated spending nearly 500 hours in the CCT in training for two missions.[24]

Crews would also need to rendezvous and dock the orbiter with other vehicles, which called for a device that could simulate dynamics between two spacecraft. Though successful rendezvous dated back to the *Gemini* program, shuttle rendezvous carried important technical differences that astronauts needed to account for in their training. The plan upon the creation of the program called for the orbiters to rendezvous with satellites so that astronauts could service them, which did happen several times during the 1980s. By the 1990s, the orbiters made some of their most significant accomplishments by rendezvousing with the *Hubble Space Telescope*, the Russian space station *Mir*, and the ISS. Many of the satellites had not been designed to support this servicing, so they did not have the transponders or lights that *Gemini* and *Apollo* crews had counted on. Some satellites were also smaller than the orbiter chasing them, another change from rendezvous in previous programs.[25] Crews thus needed to maximize their knowledge of the resources available to them to find their target and minimize those disadvantages. Their resources included star trackers that provided optical tracking of

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[24] "Shuttle Crew Training Catalog, Revision J," 3-1 and "Space Shuttle Crew Compartment Trainer," *National Museum of the U.S. Air Force*, http://www.nationalmuseum.af.mil/Visit/MuseumExhibits/FactSheets/Display/tabid/509/Article/195845/space-shuttle-crew-compartment-trainer.aspx (accessed December 10, 2016).

[25] Goodman, 69.

their position in space, radar that provided data on their distance to the target, a Crew Alignment Optical Sight and CCTV cameras through which the Commander could view a target, and a hand controller by which to control translation and attitude. The Commander would have to make use of these resources to approach a target at the proper velocity and time.[26] What device could allow an astronaut to build confidence in doing this prior to a mission?

The Systems Engineering Simulator (SES) became that device. The SES featured a dome into which engineers inserted the orbiter cockpit. Astronauts could then climb inside, sit in front of a replica instrument panel, and watch a scene generator project images onto the dome's interior. Few developments in astronaut training better reflected the progression of technology than this simulator. As previous chapters have indicated, engineers grappled with the problem of scene generation in *Mercury*, *Gemini*, and *Apollo* simulators. But by 1968, an innovation had improved computer generated imagery by providing for the addition of three-dimensional objects onto a two dimensional textured surface. The SES entered operation that year with a set of two Object Generating Units, each capable of generating 20 such objects. This capability increased until, in 1976, the computers could gather as many as 900 polygons to form these objects.[27] Thus an engineer or astronaut could watch a three-dimensional representation of the Earth or another spacecraft move across the dome, over an expanse as great as 240 horizontal degrees and 180 vertical degrees. Engineers were the first to

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[26] Ibid, 83-91.

[27] David C. Christianson, "History of Visual Systems in the Systems Engineering Simulator," *Graphics Technology in Space Applications* (August 1989): 219-228.

benefit from this, because they could analyze the Space Shuttle's flying characteristics as it rendezvoused and docked with another spacecraft. What if a thruster plume from the orbiter impinged on the vehicle it approached? What if the orbiter approached too fast and collided with it? The SES allowed engineers to place these questions to the test and validate procedures, then allowed astronauts to place their knowledge and flying skills to the test through the end of the Space Shuttle program. Astronauts are still using this device to train for the upcoming flights of the *Orion* spacecraft.[28]

Astronauts first used this facility as ASCANs, but then had a certain number of hours to fulfill once assigned to a crew. For a mission that rendezvoused with the *Hubble* Space Telescope, *Mir*, or the ISS, the training time required for the Commander, Pilot, and one Mission Specialist assigned to rendezvous support varied according to whether they had received any training in the past. If they had not, they needed to receive eight hours of briefings, 28 hours of simulation in the SST devoted to rendezvous, 72 hours in the SES, and 28 hours in the SMS. If they had received previous training, those respective numbers fell to 1, 12, 20, and 20.[29] Crewmembers needed to rehearse rendezvous even if they had previous experience because new missions brought new maneuvers and, as Training Team Lead and Simulation Supervisor Lisa Martignetti reflects, they had to perform the necessary maneuvers within a strict timeline. Failure to make the maneuvers within a short timeframe could have meant missing a target or a catastrophic collision with a target. This is why rendezvous

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[28] "Systems Engineering Simulator (SES): Simulator Planning Guide," *NASA*, http://www.nasa.gov/centers/johnson/pdf/639500main_Systems_Engineering_Simulator_TPG.pdf (accessed December 5, 2016).

[29] "Shuttle Crew Training Catalog, Revision J," 9-7.

remains a more challenging aspect of mission training than experiment operation, for instance.[30]

The Remote Manipulator System (RMS), or robotic arm, also called for high-fidelity simulation. In 1975, NASA and the Canadian National Research Council agreed that Canadian engineers would develop this unprecedented device: a 50-foot arm that could maneuver along six joints and grasp objects weighing several thousand pounds with an end effector. The arm would serve three functions that each increased the flexibility of shuttle operations: grasp other spacecraft, anchor and carry an astronaut on an EVA to a distant work station, and inspect the orbiter through the television camera on the arm. But making use of this robotics capacity would require precise human operation by a Mission Specialist. This person would stand in the aft flight deck maneuvering the six joints of the arm via rotational and translational hand controllers, while entering commands on a keyboard and monitoring a panel displaying arm status data. Since operating the arm required knowledge of this human interface, and since no *Mercury*, *Gemini*, or *Apollo* astronaut had ever operated anything like it on a past mission, shuttle astronauts required an ambitious new training facility. Beginning in 1977, engineers verified the performance of the arm in the Real-Time Simulation Facility (SIMFAC). This contained a replica of the aft flight deck and several computers to replicate the precise motions of the arm and produce visual displays for the operator.[31]

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[30] Lisa Martignetti, Phone Interview by Author, December 1, 2016.

[31] J.R. McCullough, A. Sharpe, and K.H. Doetsch, "The Role of the Real-Time Simulation Facility, SIMFAC, in the Design, Development, and Performance Verification of the Shuttle Remote Manipulator System (SRES) With Man-In-The-Loop," (Presentation, The 11th Space Simulation Conference, January 1980), 94-112.

But when the 1980s arrived, ASCANs and astronauts selected to missions trained in two even more ambitious locations: the SES and the Manipulator Development Facility (MDF). The SES contained a dynamic model of the arm along with that impressive visual simulation, but could only simulate a limited number of malfunctions. The MDF had a major strength of its own, as it contained a mockup of the orbiter's payload bay, the massive 60 by 15 feet enclosure behind the crew compartment where the arm was located. Mission Specialists stood in a replica of the aft flight deck, grabbed the hand controllers, and maneuvered the arm to grasp large helium-filled balloons that replicated payloads. Three time flyer Mike Mullane remembered that this was not as easy as it sounded, which was why the MDF was so necessary: "Using these hand controls while tracking a moving target on a display screen (how we would grapple a free-flying satellite) was like patting your head and rubbing your stomach at the same time. It required lots of practice."[32]

The facility did have limitations to its fidelity. In the one-G environment of the ground, the replica arm needed to be thick to lift itself and not slender like the real one. The replica arm was also more erratic than the real one, as it shimmied back and forth after the operator stopped its motion. But the MDF allowed astronauts to rehearse their hand-eye coordination until they could feel assured of operating the arm without causing damage to a payload. If they made a mistake and dented a payload, they would pop a balloon, giving them an emphatic indication of their error. Though the astronauts could

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[32] Mike Mullane, *Riding Rockets: The Outrageous Tales of a Space Shuttle Astronaut* (New York: Scribner, 2006), 73-74.

also train to operate a computer generated arm in the SMS, the MDF had that advantage over the SMS as a physical training tool. Missions often called for two crewmembers to share tasks in operating the arm, so astronauts could rehearse their teamwork here as well.[33] Susan Helms compliments the facility when asked today, remembering, "I thought the MDF did a fantastic job of preparing us for the real job on orbit."[34]

When ASCANs operated the robotic arm for the first time, two training personnel and one astronaut already experienced in arm operation watched them. The instructors gave them a rating from 1 (unsatisfactory) to 5 (outstanding) in several categories. The categories given the most weight were the student's smoothness in maneuvering the arm, situational awareness, and hand controller techniques. Instructors also evaluated the student's attitude, systems knowledge, ability to follow procedures, target usage, ability to follow flight rules, and camera configuration. On the basis of these ratings, instructors assigned an overall rating that they immediately gave the student and within a few days gave the student a written evaluation form. ASCANs needed to receive a 3 or greater to participate in simulations as a robotic arm operator. Even after proving their ability as ASCANs, astronauts still needed to take part in an annual proficiency evaluation in order to be considered as a robotic arm operator on a crew. Knowing that Canadian engineers had supplied an arm for each orbiter at a cost of over $100 million each, the training personnel wanted proof that an astronaut's skills in operating it had not degraded. The rating system and rubric offered further evidence that

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[33] Cooper, *Before Liftoff*, 70-72.

[34] Author Phone Interview with Helms.

astronaut training had become more standardized during the shuttle era.[35]

Shuttle astronauts would also need to make EVAs, which called for a much more ambitious training facility than any used before in Houston. Spacewalkers did continue to train in the KC-135 aircraft and Air Bearing Table. But pool training for EVAs still reigned supreme, so engineers removed the Water Immersion Facility and replaced it with the Weightless Environment Training Facility (WETF) that was more similar in size to the pool in Huntsville where *Skylab* astronauts had trained: 75 feet long, 50 feet wide, and 25 feet deep. This allowed engineers to submerge a replica of the orbiter's payload bay and the equipment with which the astronauts would have to work. Upon its completion in 1980, the WETF contained several features that ensured the safety of astronauts and offered them high-fidelity training, building on the experience of *Gemini*, *Apollo*, and *Skylab*. Astronauts went on each session with heavy lead weights stuffed in their suits to produce neutral buoyancy. Television footage of the astronauts allowed engineers in the control area to easily monitor their performances and give them feedback, including the person with a microphone who could speak to the astronauts as a CapCom. A fellow astronaut who would serve as an Intravehicular Activity (IVA) officer during a mission, choreographing the movements his or her colleagues would have to make, could also monitor the sessions. Five divers went underwater for each session: two to attend to the astronauts, one to serve as a gofer, and two to operate television cameras. The presence of the divers, along with an ambulance parked by the

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[35] "RMS Evaluation Program," in "Astronaut Candidate Training, 1991-2002," Box 17, Folder 25, Rick Husband Collection, Texas Tech University, Lubbock, TX.

pool, meant no astronaut had to fear for his or her safety and there were no serious accidents. When a close call happened, such as James Van Hoften's oxygen hose pulling out of his suit, the divers pulled him out of the water and pulled his helmet off in thirty seconds.[36]

ASCANs received their introduction to EVA training shortly after their selection. After the neutral buoyancy personnel observed the ASCANs in the pool, they assigned each student a rating from 1 to 5. A rating of 1 meant the training personnel recommended the astronaut for lead on a scheduled EVA (every EVA in the shuttle program called for multiple astronauts to step outside), because the astronaut had a cooperative attitude, good technique, was well prepared, and attentive. Astronauts could still feel good about receiving a 2 or 3, because this meant the instructors considered them competent enough to make an EVA. But a 4 or 5 meant the instructors could not recommend them for an EVA, either because they were difficult to work with, had an awkward technique, had difficulty working with the suit, or struggled with physical endurance. "I think Paul told us if we get a 3, we are doing well," wrote one astronaut. "The scoring process is shrouded in mystery," he admitted, but urged his colleagues "to have a very clear mental picture of what you need to do. This is like many activities that involve lengthy sequences of psycho-motor skills, like precision skydiving, karate, ballet, ice skating, surgery, etc...You only get your four runs. ASCAN EVA training is a once per career experience, and you probably won't get another chance to prove yourself

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[36] Cooper, *Before Liftoff*, 101-106.

if you perform poorly."[37]

Until the WETF closed in 1998, astronauts and training personnel learned numerous lessons for the benefit of their successors. Before heading into the pool, astronauts learned that they should increase the strength of their hands, wrists, and forearms because these were the muscles that gave them the most fatigue in the pool and in space. In the pool, they learned that the greatest training benefit they could derive was to rehearse techniques that would give them a stable body position. This was "the most significant part of every task," according to a 1994 document on lessons learned. While keeping in mind that general idea, astronauts could increase their proficiency in several ways: translating to and from worksites (best done through slow, deliberate movements) handling large masses (best done by using only light forces and moving objects in one degree of freedom at a time), and coordinating their movements with the IVA crewmember and robotic arm operator (best done by developing unambiguous communication protocol). Astronauts also learned general rules of thumb that would increase the fidelity of training, such as accept aid from divers only when "absolutely necessary," do not kick or swim, do not use water drag in moving, and never hurry in moving. The rookie spacewalkers on each mission learned to seek the opinions of more experienced astronauts and training personnel and be candid in sharing any problems in maneuvering or operating hardware.[38] As long as astronauts followed these lessons,

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[37] "EVA Training Ratings Scale and Definitions" and "General Observations on ASCAN EVA Training," in "Extra-Vehicular Activity Training and Notes, 1988-1997," Box 10, Folder 16, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[38] "EVA Lessons Learned," October 1994, Box 12, Folder 4, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA, 1-5 to 1-13.

working in neutral buoyancy "allows you to be pretty prepared by the time you actually perform a spacewalk," Jim Voss remembers.[39] The following chapters will summarize the spectacular and unprecedented results of this training during shuttle missions.

Astronauts still needed to keep in mind the ways that real EVAs differed from the WETF, however, and experience taught them many examples of this. Working underwater reversed the physics of motion in that astronauts found it difficult to initiate motion and easy to stop in the pool, whereas they found it easy to initiate motion but difficult to stop in space. Astronauts had different situational awareness in the pool than in space, due to the panoramic visual environment of the latter. Training for some of the most complex operations in the pool, such as coordinating one's actions with the robotic arm operator, also had shortcomings in replicating the real experience. "EVA/RMS ops is another area where training falls short because there is no easy way to fully integrate all orbiter, RMS, and EV operations except on orbit," the 1994 document stated. The pool only contained a limited amount of room in which to integrate all of those activities. Training personnel could mitigate this problem by having astronauts train in a larger pool or in virtual reality simulations, both of which happened beginning in the 1990s. But especially during the first decade of the Space Shuttle era, spacewalkers needed to recognize the differences between training and flight, speak to more experienced crewmembers about the differences, and rehearse tasks while in orbit if necessary.[40]

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[39] Author Phone Interview with Voss.

[40] "EVA Lessons Learned."

The shortcomings of the WETF resulted in the decision to replace it with the Sonny Carter Neutral Buoyancy Laboratory (NBL, named after the astronaut who died in a 1991 civil aviation accident) in which astronauts train today. Astronauts and training personnel had each recognized that the WETF could not hold the large modules planned for the upcoming ISS. Even during the shuttle era, the insufficiently small size of the facility required astronauts to make multiple runs to simulate an EVA. They could not simulate all of their tasks in one underwater session, so they had to rely on this less efficient idea called "part-task training." This resulted in "high reconfiguration overhead and excessive EMU suited events." Astronauts had also complained that the lack of a functional robotic arm had hurt the fidelity of sessions in the WETF. Thus groundbreaking began in 1995 on the NBL, which solved both of these problems. Not only is this pool 202 feet in length, 102 feet in width, and 40 feet in depth, it featured a full-scale working model of the shuttle robotic arm and still features a working model of the ISS robotic arm. Today, NASA officials proudly proclaim the ways that EVA training has improved from the 1960s to the present on the agency website. Astronauts who have trained in the NBL since the 1990s have benefited from "reduced part-task training, increased integrated training, increased training quality, better timeline fidelity, and improvement in facility loading."[41] Thus astronauts who train for EVAs today can thank their predecessors who contributed the lessons learned that spurred the creation of the NBL.

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[41] "EVA Lessons Learned," 2-49 to 2-51, "Sonny Carter Training Facility: The Neutral Buoyancy Laboratory," *NASA*, https://www.nasa.gov/centers/johnson/pdf/167748main_FS_NBL508c.pdf (accessed December 6, 2016), and "NBL History: Timeline of the NBL," *NASA*, https://www.dx12.jsc.nasa.gov/history/nblTimeline.shtml (accessed December 6, 2016).

Astronauts also needed to train for the operation of shuttle payloads, because this was the benefit of the program. Payloads for the first operational shuttle flights, from 1982 to 1986, were often satellites since the vehicle was then intended to launch all civilian and military payloads. After the *Challenger* accident and the realization that the shuttle could not fly more than a few missions per year, expendable launch vehicles began lifting satellites again and the shuttle lifted more unique payloads (science laboratories, the Wake Shield Facility, the Spartan astronomical spacecraft, the Tethered Satellite System, etc.) that benefited from a trained crew that could operate them. About one year before a mission launched, the Payloads Section of the JSC Training Division submitted a form defining the payload, the payload's code name, and the template to be used for crew training. The crew would then go through a lesson flow for payloads requiring their interaction, from familiarization, to normal and contingency operations, to a review. This provided yet another indication of how standardized training became in the shuttle era. Whereas mission objectives and payloads changed so quickly and dramatically during the *Mercury*, *Gemini*, and *Apollo* eras, the shuttle era extended so long that instructors could develop a template for subsequent crews to follow.[42] The next chapters will describe the benefits of the flexibility that trained crews brought to the operation of shuttle payloads.

This especially applied to the science laboratories. The *Spacelab* and *Spacehab* modules fit inside the orbiter payload bay on over twenty missions, allowing astronauts to utilize their knowledge in making discoveries from *STS-9* in 1983 to *STS-107* in 2003.

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[42] "Shuttle Crew Training Catalog, Revision J," 12-1.

Crews for these missions needed to train by listening to briefings by Principal Investigators on the experiments they would perform, but also by familiarizing themselves with the laboratories. Astronauts gained much experience with this in the course of their careers. As ASCANs, they gained their initial taste of laboratory work by attending classroom briefings, studying workbooks, using an SST, and even using a Personal Computer called the Spacehab Intelligent Familiarization Trainer (SHIFT) when Spacehab began flying in the 1990s. But the best test of their skills came when they stepped inside the full-scale *Spacelab* and *Spacehab* simulators. These simulators gave crews experience in operating a diverse collection of instruments: the Electrical Power and Distribution System, the Environmental Control System, the Command and Data Management System, the High Rate Data Assembly, the Instrument Pointing System, the caution and warning system, and the viewport. Instructors especially watched to see how quickly astronauts could follow checklists, either in collection of data or in reacting to caution and warning alarms.[43]

The last aspect of shuttle missions that called for a new training device was the landing. All previous astronauts had returned to Earth by falling toward the sea in a small conical vehicle underneath parachutes. But Commanders could exert control over a returning orbiter, because the ship converted from being a spacecraft reentering the atmosphere to an airplane descending toward a runway landing. While in orbit, the ship flew at about 23 times the speed of sound and 190 to 330 miles high, depending on the mission. On landing day, the twin Orbital Maneuvering System (OMS) engines fired to

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[43] Ibid, 11-1 and 13-1.

send it toward reentry. During the long deceleration that followed, the onboard computers controlled the ship's pitch, roll, and yaw in such a way that most of the heat of reentry was directed toward the belly where the thermal protection tiles offered the most protection. RCS engine firings did this at first, but as the atmosphere thickened the ship converted into an airplane in that elevons, a rudder, and body flap exerted control. When the ship slowed to below Mach 1, at 9.5 miles high, the Commander finally took the hand controller and flew the ship for the next four minutes until the two main landing gear kissed the runway at about 215 miles per hour. In this respect, the job of astronaut was more applicable to that of test pilot than ever before. But the test pilots who joined the astronaut corps to fly these landings still needed training to acclimate themselves to three critical ways the orbiter differed from strictly Earthbound airplanes. First, the orbiter approached the runway several times steeper and faster. Second, the orbiter did not use engines during the approach. This meant the ship glided toward a landing and the Commander had only one chance to make an accurate touchdown. Third, the orbiter had a lift to drag ratio of only 4.5:1 and thus did not have a great gliding capability. The vehicle became iconic as a "flying brick," despite the best efforts of the delta wings.[44]

The need to train shuttle Commanders for these flying characteristics prompted the decision to jury rig an aircraft so it would mimic them. Aerospace engineers did have experience with this idea. Since the 1950s, the Lockheed NT-33 had made use of flight controls to mimic vehicles from bombers, to stealth fighters, to even the X-15.

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[44] "The Aeronautics of the Space Shuttle," December 29, 2003, *NASA*, https://www.nasa.gov/audience/forstudents/9-12/features/F_Aeronautics_of_Space_Shuttle.html (accessed December 10, 2016).

The LLTV had successfully emulated the *Apollo* LM. Finding an aircraft that could emulate the Space Shuttle required finding one with several features that narrowed down the choices: a spacious cockpit, a robust structure, delta wings, an ability to deploy reverse thrust in flight so as to reproduce the drag of the orbiter, and an affordable price for NASA to acquire it. The T-38 that astronauts traditionally flew had too slim a cockpit. John Young and Joe Engle traveled to Seattle, Washington to fly the Boeing 737 and found it an attractive choice, but it was out of NASA's price range. The Gulfstream G-II, a ten seat business jet, met all the criteria. In 1974, pilots flew two of these jets from the Gulfstream factory in Savannah, Georgia to the Grumman factory in Long Island, New York for conversion into the Shuttle Training Aircraft.[45]

The modification process produced its share of challenges, enough so that the program was six months behind and 50 percent over budget by 1976. Grumman engineers made several modifications to the cockpit, fitting it with orbiter instruments including the hand controller and speed brake. They also bolted two large vertical fins underneath the vehicle to mimic the sideways forces of the orbiter. They engineered the wing flaps to hinge up, instead of the usual backward and down, to mimic the high drag and low lift of the orbiter. They also placed a computer in the rear of the plane that controlled its reverse thrust at 90 percent power. Finally, the engineers strengthened the airframe so it could handle the wind shears and turbulence it would encounter on repeated dives. Though the Grumman team completed these tasks successfully, several

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[45] Rowland White, *Into the Black: The Extraordinary Untold Story of the First Flight of the Space Shuttle Columbia and the Astronauts Who Flew Her* (New York: Touchstone, 2016), 136-137.

problems hampered them. One was the effort to install a digital autopilot that precisely reproduced the handling qualities of the orbiter.[46] Dick Koos, one of NASA's original Simulation Supervisors who ended up staying with the space agency until 1998, still remembers this and other issues: "People were really afraid of the doggone thing. It was difficult to get that to work the way it was supposed to in the flight control system. We did get the system to work. It was a struggle, but we did get it accepted. Then we found out we had a control switch problem. It was used in the system beyond the electrical rating of that switch. A couple of contacts burned and closed that switch. Some of the control surfaces in the wings went hard over, thankfully in the hangar. There was a black box that controlled the surfaces of the wings…After a time, the performance of the box degraded. This had to be corrected."[47]

One other problem especially connected to the astronauts was a phenomenon called pilot-induced oscillation. This meant that the STA pilots often made an input to the hand controller and then, without feeling its immediate effect, made the input again. The pilots thus overcorrected in flying the vehicle, a problem that was exacerbated by the fly-by-wire technology of the STA and the orbiter it emulated. Since pilots sent inputs to the plane via electronic signals rather than the old fashioned method of sending them directly to a mechanical actuator, pilots were more likely to feel a delay in their actions that prompted this problem. One pilot at Edwards Air Force Base called this the "JC maneuver," because pilots tended to shout "Jesus Christ!" when this happened.[48]

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[46] Ibid, 158-159 and Young with Hansen, 220.

[47] Author Interview with Koos.

[48] White, 158-159 and Young with Hansen, 220.

John Young remembered that the problem of pilot control especially manifested itself during the early STA flights. He made his first flight in February 1977, sitting in the left-hand seat with instructor Ted Mendenhall in the right-hand seat. But even America's most prolific astronaut—a man who had test flown Navy jets, set world time-to-climb records, and made four spaceflights including an *Apollo* Moon landing—initially struggled to make approaches in the STA. After the instructor flew the plane to 35,000 feet and activated the hand controller on the left side of the cockpit, Young tried to hold the ship's airspeed at about 320 miles per hour and make an unusually steep glide to replicate a returning orbiter. He quickly found that orienting himself in making these steep glides had been easier while looking out the cockpit of a T-38. Doing so in the spacious STA proved so difficult that he aborted nine times in his first fifty flights, forcing the instructor to take back control and climb out of the dive. Since the orbiter would have no engines running and thus only one chance at a safe landing, this success rate of about 80 percent was not enough. But the addition of new software into the STA computer allowed the vehicle to reproduce orbiter qualities much more precisely, while the astronauts benefited from more experience with the situational awareness required to make such a steep approach. As a result, Young aborted in only three of his last 50 flights prior to his command of the *STS-1* mission.[49]

Young began a training routine that extended all the way until fellow naval aviator Chris Ferguson commanded the *STS-135* mission in 2011. Newly selected pilot ASCANs went through a basic syllabus in one year. This began with classroom

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[49] White, 158-161 and Young with Hansen, 224 and 228.

briefings on shuttle systems pertinent to approach and landing, STA systems, simulation procedures, flight rules and safety requirements, and egress. Then the astronauts trained to make simulated approaches in the SMS and real approaches in the T-38 before they were finally ready to tackle the STA. The basic syllabus called for 20 STA flights, with 12 approaches made for each flight. Four of the flights needed to be at night, with a night lighting system on the runway, because 26 of the 133 shuttle landings happened during nighttime. After each session, the astronauts learned of their touchdown parameters and hand controller printout analysis and received comments on their energy management and any simulation anomalies from the instructor sitting next to them. After the pilot ASCANs graduated, they were required to make flights on a monthly basis. This increased during the time they were assigned to a mission until by the time Commanders actually landed the orbiter, the requirement called for them to make at least 1,000 STA approaches.[50] But even after Mark Kelly had made at least 1,600 in advance of landing *Discovery* in 2008, he did not believe the training was excessive. His belief stemmed from the knowledge that Commanders only had one chance at a landing, which happened successfully 133 times out of 133 on the strength of such a thorough regimen that gave them situational awareness.[51] Adds Eileen Collins: "I think the fact that we had a Shuttle Training Aircraft was why we had so many safe shuttle landings, and why they were so accurate."[52]

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[50] "STA Ground School," in "Shuttle Training Aircraft Flight Session Plans," Box 12, Folder 17, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[51] Hale, et al., 100.

[52] Author Phone Interview with Collins.

Shuttle Commanders and Pilots also built their confidence in making landings by stepping inside a machine that still bears the distinction of having the greatest range of motion of any flight simulator in the world: the Vertical Motion Simulator (VMS). In the 1970s, engineers at Ames Research Center in Mountain View, California constructed a simulator cabin and placed it within a 120 foot tower. Two astronauts sat inside the cabin, looked at a visual display of the sky and runway with a field of view accurate to the orbiter windows, and made inputs to a hand controller to replicate an orbiter's approach and landing on the runway. But what made the simulator groundbreaking was that those inputs prompted the cabin to move 60 feet within the tower, at up to 16 feet per second. The cabin could also move laterally and longitudinally to a lesser extent, as well as tilt in response to an astronaut's inputs in pitch, roll, and yaw. The magnitude of the motion underscored just how far flight simulation had progressed since Edwin Link's efforts in the 1920s, or even since the dawn of the *Mercury* program. Astronauts could now feel the sensation of motion to a greater extent than ever before.[53]

Beginning with the first runs in 1980, astronauts followed an approach and landing sequence in the VMS that emphasized different elements than the STA did. Since the STA was smaller than the actual orbiter and gave the astronaut a lower eye point upon landing, the value of this vehicle came in training for a shuttle approach rather than an actual landing. The astronauts completed their runs without actually touching down. But the VMS could mimic what the touchdown would feel like and look

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[53] Steven D. Beard, et al., "Space Shuttle Landing and Rollout Training at the Vertical Motion Simulator" (Presentation, American Institute of Aeronautics and Astronautics Modeling and Simulation Technologies Conference and Exhibit, August 18-21, 2008), 3-4.

like out the windows, so simulations in this device emphasized this very last phase of a shuttle mission with more fidelity. VMS simulations began at 10,000 feet, as opposed to 35,000 feet in the STA. The Commander had to make a descent while intercepting the heading alignment cone (the path that placed the orbiter in the correct position to make the final approach to the runway), following the correct glide slope, and dissipating just the right amount of energy. The Pilot had the responsibility to arm the main landing gear, which deployed at 300 feet. Then the Commander aimed for a touchdown 2,500 feet down the runway, upon which the Pilot deployed a drag parachute and the Commander derotated the vehicle until bringing the nose gear to a touchdown. The combination of tire brakes and the parachute then slowed the vehicle until the Commander could call out “wheels stop.” The VMS thus had two advantages over the STA: it provided an accurate simulation of the touchdown and rollout and did so at less expense or risk than an actual flight in the STA.[54]

The Commanders and Pilots for every Shuttle mission therefore stepped inside this revolutionary machine before landing an orbiter, after a lengthy planning process. When Commanders and Pilots earned their assignments to a mission, the Astronaut Office had a list of training objectives that the crew should fulfill in the VMS. These included sessions where tires failed, the drag chute failed, the nose wheel steering failed, high crosswinds hampered a landing, or a launch abort forced an emergency landing at an alternative runway. On the basis of this list, engineers developed a training matrix that contained all the information needed for the VMS personnel to equip the simulator

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[54] Ibid, 6.

so it could replicate the performance of the vehicle and visual scenes under these anomalous conditions. The VMS staff received the matrix two weeks prior to a crew's arrival at Ames, which allowed them time to prepare. For instance, the staff could configure the simulator to account for different mass properties, wind profile, and landing performance predictions. The staff also took on the labor intensive task of creating a visual database for over 20 landing sites for day, night, and dusk conditions. This allowed astronauts to simulate emergency landings at locations from North Carolina, to New York, to Delaware, to Canada, to France, to Spain, to Bermuda, to West Africa.[55]

Once the device was ready, Commanders and Pilots who made the trip to Ames benefited not only from the remarkable capability of the VMS itself but also the feedback the staff provided them. Their training for each mission consisted of 25 to 30 runs, each of which lasted four hours. The crew could ask questions and make comments throughout this time, which helped to eliminate any confusion and boost their confidence. After finishing, the crew received graphs of their performance that let them know critical details such as their rate of descent, touchdown speed, and lateral distance at touchdown and during rollout. The graphs also included these results for the entire astronaut pilot corps who had already flown missions, so the astronauts in training could compare their performance against their peers. A week later, the VMS staff sent to JSC a wealth of data on the astronauts' runs: 941 time history data points, 782 static variable data points, and video of every run. In return, Commanders gave their feedback to the

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[55] Ibid, 9-11.

VMS staff after returning from a real shuttle landing that helped the instructors improve the fidelity of the simulator. The end result was an operation so efficient that the VMS facilitated 65,000 runs from 1980 to 2011, which helped every shuttle crew train as well as engineers evaluate changes in landing procedures (the device remains in use today, ready to support a crew of a future vehicle).[56] Chris Ferguson remembered how much his first real shuttle landing reminded him of the VMS: "At that exact moment in time, I was back in the VMS and I knew what I had to do in order to get the shuttle stopped in the remaining runway. It was an instantaneous flashback and that's exactly what you want in a good training tool."[57]

But the SMS was the one simulator that had the greatest utility in preparing a shuttle crew for flight. The aforementioned simulators could prepare crews for phases of flights from rendezvous and docking, to robotic arm operation, to EVAs, to payload operation, to landing, and many of them offered higher fidelity than the SMS in their one specific area. But only the SMS could prepare crews to rehearse cockpit procedures across an entire mission from launch to landing. NASA managers were already thinking about this quintessential tool of shuttle training in 1970, when the space agency sent out a request for proposal to build the machine and program director Robert Thompson formed a committee to monitor its development. The contractors who studied the RFP quickly found that this would be a daunting challenge, because it called for a simulator that was fully digitally generated rather than a hybrid between analog and digital as in

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[56] Ibid, 11-15.

[57] Bill Moede, "STS-135 Crew Trains on Vertical Motion Simulator at NASA Ames," YouTube video, 3:06, Posted November 28, 2015, https://www.youtube.com/watch?v=N-iT0JdaSEQ (accessed December 17, 2016).

Apollo. NASA did not even receive a response initially, but Singer-Link contractors eventually produced a detailed analysis of the problem and won the contract as they had for every primary spacecraft simulator since *Mercury*. This contract came with two simulator versions: one fixed-base in which crews trained for on-orbit activities and one motion-base in which crews could train for dynamic events like launch, reentry, and landing.[58] How could these contractors build on the experience of their decades in flight simulation to give shuttle crews the most realistic facsimile of the most complex machine ever built?

The experience served them well in recreating the orbiter's controls and displays, but the SMS also broke new ground by demonstrating the vast advance in electronics since the *Mercury*, *Gemini*, and *Apollo* eras. The orbiter carried 5 IBM computers called AP-101s. Their average speed was 480,000 instructions per second, compared to 7,000 per second for the *Gemini* computer. The contractors decided these computers could not be interpretively simulated, as the *Apollo* guidance computer had been, so the SMS became the first simulator to employ the same type of computer as the spacecraft it simulated. Along with the AP-101s, the simulator housed four Sperry 1100/40 mainframe computers that hosted 15 Perkin-Elmer minicomputers. These units generated digital images for the simulated views out the windows. The Singer-Link company contained over 200 computer programmers out of 611 employees, indicating the labor-intensive nature of producing enough of these computers that could synchronize with each other on a 20 millisecond cycle. As crews trained throughout the

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[58] Tomayko, 278.

1980s, several of the AP-101s reached 30,000 hours of operation, which was much greater than the design life of the computers for the real orbiter. Thus computers did fail and cause training delays, but the simulator engineers always had 12 or 13 available and benefited from a contract to provide maintenance.[59]

One day in September 1976, the years of contractor work in Binghamton, New York finally reached fruition in Houston. John "Denny" Holt remembered standing in a frigid JSC Building 5 that day as NASA received the SMS from Singer-Link, the Lunar Module Simulator having just been discarded to make room for this: "I think I've never been in that building when it was that cold. I know Singer-Link had it down as cold as they could get it just to make sure everything that had electronics in it was not going to overheat. They were bound and determined they were going to sell that simulator." This first SMS supported the training of the four astronauts who flew the 1977 Approach and Landing Tests in the Space Shuttle *Enterprise*: Fred Haise, Gordon Fullerton, Joe Engle, and Dick Truly. In 1978, Singer-Link delivered to Building 5 the fixed base and motion base simulators that supported astronauts through 2011.[60]

Experience and the speedy pace of computer technology served the contractors well in improving upon what had only been crudely simulated for earlier aircraft or the *Mercury*, *Gemini*, or *Apollo* vehicles. Two decades after the *Mercury* astronauts had consistently complained about the visual scene outside the simulator window, shuttle astronauts benefited from computers that could generate real-time color images at thirty

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[59] Ibid, 93-94 and 279-280.

[60] John D. "Denny" Holt, Interviewed by Rebecca Wright, December 1, 2004, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/HoltJD/HoltJD_12-1-04.htm (accessed December 19, 2016) and Heppenheimer, 393.

frames per second and affix them to television screens mounted to the windows. One historian describes them as "somewhat cartoonish in quality" during the 1970s, resembling early video games like Pong, but astronauts could see the curvature of Earth with continents and landforms as well as the Sun, Moon, stars, and the orbiter payload bay as viewed from the aft flight deck. They could even see the payload bay doors open and close, a necessary procedure on every mission. While seeing these sights, they heard sound synthesizers replicate the thunderous roar of the main engines, the whine of the OMS or RCS engines, the noise of reentry, and the thump of landing gear extension and touchdown.[61]

Motion provided another vital sign that the world of "make believe" had become more consistent with reality. Extendable pistons allowed the SMS to stand vertically during launch simulations. The machine lurched forward and backward after main engine ignition at T-5 seconds, reproducing the orbiter's famous twang, and then produced robust vibrations to simulate SRB ignition. The Morton Thiokol company in Utah had produced ground firing data of their SRB rocket motors which allowed SMS personnel to simulate the rough ride. An aerospace journalist who climbed into the SMS in 1980 described the launch as producing a "paint shaker" motion similar to what astronauts later felt on real missions. The simulator could even yaw sharply to simulate the thrust imbalance between the two SRBs. After the SRBs burned out and separated two minutes into the flight, at a height of 146,000 feet, the ride became smoother. The SMS could then revert to horizontal to simulate the vehicle in orbit and pitch, roll, and

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[61] Heppenheimer, 393-395.

yaw to simulate an approach and landing. The sight, sound, and motion meshed together to produce a sensation that *Mercury* astronauts could not have imagined, and with good reason. The crew might need to perform an emergency abort amid the motion of launch and the 3 Gs they would feel, for instance, so the simulator did well to desensitize them to the feelings.[62]

The sheer number of malfunctions that SimSups could inject into shuttle hardware also would have overwhelmed the *Mercury* astronauts if they could have peered twenty years into the future. A team of SimSups sat at their consoles in a room close to Building 5 with light pens that they could use to introduce up to 860 equipment problems to the crew.[63] For each mission, the Training Team Lead and his or her colleagues met in a small conference room and developed a script of malfunctions for the crew to respond to in the SMS. Each script contained the time and the altitude of the orbiter above Earth when the training team would inject a certain malfunction into the simulator, a short description of the malfunction, and what the team intended it to teach the astronauts. Sometimes the malfunctions were intended to meet the syllabus of training tasks and sometimes to exploit the weaknesses of a crew. For instance, the *STS-41G* crew neglected to reengage the backup computer during one simulation and Ted Brower made sure to revisit this in the future. The 860 malfunctions that the training team had at their disposal and the need to test the astronauts' abilities in responding to them meant that astronauts spent far more time in the SMS than any other device. When

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[62] Ibid, 393-395.

[63] Ibid, 395.

operational missions began in 1982, crews spent as many as 12 hours per week there.[64]

Launches were the most exciting and time critical phase of training in the SMS, because the orbiter accelerated from 0 to 17,500 miles per hour in only 8.5 minutes. The vehicle made automated movements throughout this time, from the ignition of the engines, to the attitude adjustments, to the separation of the SRBs and ET, to the engine cutoff in orbit. But crews still needed to train to carry out their checklists on the instrument panel prior to launch and monitor the panel during launch, knowing their lives could depend on their ability to make an abort before time ran out. The Commanders trained to monitor trajectory, the computers, the flight control system, the environmental system, and vehicle control. The Pilots kept their eyes on the performance of the main engines, the OMS and RCS engines, the Auxiliary Power Units (APU), and the fuel cells. The two Mission Specialists sitting behind them in the flight deck trained in switch/item entry confirmation, failure recognition, and backing up their crewmates. All astronauts learned the general techniques they should follow through all of this: use a two person rule to verify the correct position of switches, verify panel configuration before a critical event, make timely, clear, and informative calls to the CapCom, and use any lull time to review failure impacts, get all crewmembers back on an appropriate timeline, or pre-brief the next events. If all went according to plan, the launch would not require any extraordinary crew action.[65]

But what if an emergency required their intervention? Due to the high risk of a

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[64] Cooper, *Before Liftoff*, 56-57 and 32.

[65] "SMS Briefing Guide," in "Orbiter Crew Resource Management," Box 22, Folder 76, Rick Husband Collection, Texas Tech University, Lubbock, TX.

malfunction, astronauts answered this question by going through a program called "Ascent Skills" during their ASCAN experience. This allowed them to undergo generic training, then they performed mission specific training with the crew they were assigned with and the software for their mission. According to the JSC training catalog, "The number of lessons to be repeated depends on the time elapsed since the crew's last flight and on the time required for a new combination of experienced crewmembers to achieve an adequate level of cockpit coordination."[66] The lessons required them to respond to malfunctions and, if the malfunctions included a failure of at least one of the three main engines, abort the launch to make an emergency landing or bailout. "It was not unusual for ascent simulations to include an average of one malfunction per minute for the 8.5 minute ascent to orbit," explains Pete Beauregard, who was part of the JSC training staff from 1979 to 2013.[67]

There were four types of launch aborts that would result in the vehicle returning intact and additional contingency aborts that would result in the crew bailing out of the vehicle. If a main engine failed during the first four minutes of flight, a crew could undertake a Return to Launch Site Abort (RTLS) by turning the vehicle around, pitching down so the tank could be safely jettisoned, and making a landing back at KSC. After velocity, altitude, and distance downrange from KSC increased to the point that a return there was no longer possible, a crew would have to perform a Transoceanic Abort Landing (TAL) in case of an engine failure. This required landing at a predesignated

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[66] "Shuttle Crew Training Catalog, Revision J," 4-1.

[67] Pete Beauregard, E-Mail Correspondence with Author, November 19, 2016.

site across the Atlantic Ocean, which was why the VMS recreated images of overseas landing sites. After this became impossible, a crew did have a brief chance to undertake an Abort Once Around (AOA), meaning circle the Earth once and land due to an inability to reach a stable orbit. Finally, a crew could undertake an Abort to Orbit (ATO) by reaching a lower stable orbit when the shuttle could not reach its intended orbit. If more than one main engine failed, the crew would have to make a riskier contingency abort. This required making a pullout maneuver to bring the orbiter to a gliding flight so the astronauts could bail out. Only one launch abort ever actually happened during a shuttle flight: Gordon Fullerton's ATO, the least dramatic possibility, during *STS-51F* in 1985. But right until the 135th mission, every crew rehearsed the aborts in the SMS with the knowledge that one might prove necessary.[68]

Andy Foster, a specialist in ascent abort procedures from 1984 to 1994, felt confident in the ability of crews to respond to these emergencies by the time missions actually happened. "Understand that the intact aborts were automated and the crew tasks were more along the lines of systems management and performing a landing if there was one," he explains today. "We did teach the Commanders and Pilots how to fly a manual ascent and how to fly the aborts manually, though it was a very low probability you'd need it. The aborts that held the most risk and the most doubt about successful completion were the contingency aborts. These were often flown at the margins of controllability with brutal entry conditions and were all manual until they were automated in the post-*Challenger* timeframe." He adds, "Crew coordination was a

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[68] Hale, et al., 234-235.

factor because the Commander controlled the vehicle attitude (via the Rotational Hand Controller) and the Pilot controlled the main engine throttles during the ascent and speed brake and landing gear during the return."[69] These aborts that would end in a bailout, then, epitomized why Singer-Link had built and NASA had invested in this expensive SMS. Only skilled astronauts could exercise the teamwork and piloting skills amid narrow control margins to save themselves, and the SMS allowed them to become skilled on the ground with no risk to their lives. Crews rehearsed abort procedures for launch more than any other phase of a mission, because serious malfunctions were most likely to occur during this most dangerous phase.[70]

The value of the SMS extended beyond launch simulations, however. Crews worked together to rehearse orbital activities such as RCS engine maneuvers, computer operation, and star sightings for navigational purposes. The number of sessions a crew needed to perform depended on how recently each crewmember had flown. After crews gained proficiency in these basic tasks of life in orbit, later sessions in the SMS forced them to respond to malfunctions that tested their understanding of mission rules and the FDF.[71] For instance, the training team could fail a sensor in an oxygen tank that fed a fuel cell. The astronauts would have to identify the crewmember responsible for the fuel cells, who would check to see if the problem was real or only a faulty sensor reading. If this person found the problem was real and insurmountable, the crew would have to prepare for an emergency deorbit and reentry. While this person was troubleshooting,

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[69] Andy Foster, E-Mail Correspondence with Author, November 13, 2016.

[70] Cooper, *Before Liftoff*, 115

[71] "Shuttle Crew Training Catalog, Revision J," 5-1.

the training team often decided to create another of those 860 possible malfunctions. The crew thus had to decide which problem had the greatest priority and how to divide the work in solving all of them. The Training Team Lead had the authority to speed up or slow down the pace of the malfunctions. The idea was to test the crew's weaknesses until the Team Lead felt convinced that given several of them, the astronauts would not stand around in the SMS looking at each other but instead play off each other like a well-trained unit.[72]

The one other mission phase that crews rehearsed in the SMS was deorbit and reentry. During a normal session, the crewmembers had their unique responsibilities for the return home. The Commander focused on the parameters of the OMS engine burn that sent the vehicle out of orbit and control of the vehicle, while the Pilot concentrated on the configuration of the two OMS engines and failure recognition. The crew could then rehearse the flight back through the ionized gases of Earth's atmosphere, which blocked communication with Mission Control for several minutes. Here again, the Commander, Pilot, and Mission Specialists had their own mission events and section of the instrument panel that they were responsible for, from roll reversals, to deployment of the air data probe, to finally deployment of the landing gear and drag parachute.[73] But SimSups also concocted elaborate malfunctions for this phase. A cabin leak could force an emergency deorbit, for instance. The crew had to respond by shutting the payload bay doors, setting up the seats in the cabin, finding out which of the several landing sites

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[72] Cooper, *Before Liftoff*, 82-89.

[73] "SMS Briefing Guide."

around the world they could reach in this emergency situation, and firing the OMS engines before it was too late. They would be on their own during the radio blackout that accompanied their subsequent trip through the atmosphere, which added to the challenge. Henry Cooper alluded in his book about the *STS-41G* mission to the incidents in which the training team piled on so many malfunctions that the crew failed to reach a runway, landing on water instead.[74]

No matter what phase of the mission they were rehearsing, the astronauts benefited from their sessions in the SMS by being taught one technique that derived from the aviation industry. "In the late eighties or early nineties, NASA also started including their own versions of crew resource management training, which was adopted from the airlines," Andy Foster explains. As mentioned in an earlier chapter, the idea of teaching pilots to improve their teamwork skills had first taken hold within the aeronautics section of NASA in 1979. After the *Challenger* accident, instructors sent astronauts into the SMS with the intention of teaching them an adaptation of this concept called Spaceflight Resource Management (SFRM) training. Shuttle missions often carried seven people, which increased the need for teamwork and coordination of crew activities compared to earlier programs, and the SFRM concept reflected that.[75]

Under SFRM, instructors taught crewmembers to embrace six general skills and the more specific sub-elements within each skill. The first was called Command, which called on Commanders to exercise their authority in ensuring mission safety, ensure all

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[74] Cooper, *Before Liftoff*, 90-101.

[75] Foster, E-Mail Correspondence with Author and "Crew Debrief Facilitation Guide," in "Orbiter Crew Resource Management," Box 22, Folder 76, Rick Husband Collection, Texas Tech University, Lubbock, TX.

crewmembers understand assigned responsibilities, confess errors, establish an authority-assertiveness balance, and prioritize crew activities. The second was called Leadership, which called on the astronauts to encourage crewmember interaction and discussion, demonstrate professional standards and best practices, and resolve any conflict among themselves. The third was called Communication, which called for them to communicate information clearly before taking action and create an environment conducive to open discussion and participation. The fourth was called Situational Awareness, which called for them to predetermine roles for high workload events, maintain vigilance during times of high workload, and recognize a colleague's stress, fatigue, and complacency. The fifth was called Decision Making, which called for them to select the most appropriate decision type, evaluate risk, time and expected outcomes, and implement the best course of action. The sixth was called Workload Management, which called for them to maintain an awareness of mission status and timeline, anticipate upcoming tasks, identify task saturation, and reassign tasks to off-load over utilized crew members. Crews of shuttle missions therefore had a formalized guide to becoming effective team members that *Mercury*, *Gemini*, *Apollo*, and *Skylab* astronauts did not have. Thus SFRM was yet another of the many examples of how training became more standardized in the shuttle era.[76]

Training in the SMS followed a general pattern as crews moved closer to launch. The astronauts typically received word of their assignment to a crew one to one and a half years prior to launch. The Training Team Lead and a group of colleagues spent the

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[76] "Crew Debrief Facilitation Guide."

next several months leading crews through standalone simulations. "The lesson objectives were either successfully met, or repeated in total or piecemeal," Pete Beauregard remembers. "For example, did the crew follow the correct checklist procedure and execute it correctly based on the malfunctions or scenarios presented? Each training lesson was debriefed (normally immediately) with individual astronauts or crew and the instructor or training team." But these sessions were different from real missions, because the small Training Team acted as the flight controllers. A few months before launch, crews began working integrated simulations with the real controllers who would work their mission. At this point, a team of SimSups (a higher level training position) worked closely with the flight directors to decide on how to test the astronauts' abilities during these sessions. "The SimSups would, however, have the final say as to the exact nature of the malfunctions to be introduced in the simulations," Beauregard clarifies. "Once again, the SimSups had training objectives required to be included in integrated training. Some were considered standard and some were developed based on the mission's unique activities and objectives." The rehearsals usually culminated in a long duration simulation which ranged from 24 to as much as 56 consecutive hours and required the four control teams for a mission to "hand off" to one another just as they would during the real flight.[77]

Flight controllers thus remained an essential component of astronaut training, as they had been since *Mercury*, but like the astronauts their job evolved during the shuttle era. The amount of data available to them increased from previous programs. Many of

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[77] Beauregard, E-Mail Correspondence with Author.

the numerical parameters from the vehicle were displayed on the controllers' consoles but not on the instrument panel for the astronauts. The controllers also had access to directions from NASA management, weather observations and forecasts, engineering test data, systems performance histories, and radar tracking data. This meant that controllers could usually see a trend in their data before the crew heard an alarm and could advise the crew on the best course of action. Controllers in the shuttle era could also electronically uplink information to the orbiter, commonly to send navigation updates, OMS burn targets, and alternate landing site information. Finally, controllers could also communicate with a remote Payload Operations Control Center (POCC) that was in charge of a payload on a particular flight.[78] NASA also hired many more controllers for the shuttle era than previous programs. During the early 1980s, there were about seven hundred counting front and backroom personnel, and new hires frequently joined the cadre to account for the attrition rate of about 15 percent per year. Given the new forms of information available to them which they would have to decipher and report to the crew, and the fact that there were so many new additions to the cadre who would have to work very different missions, the controllers needed the training that integrated simulations offered them. Some NASA managers wanted to do away with these sessions given their length, but Henry Cooper wrote, "Anyone who had ever been through them—astronauts, instructors, and flight controllers—was determined to keep them."[79]

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[78] "Flight Crew Duties and Coordination," in "Shuttle Crew Operations Manual 1," Box 12, Folder 14, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[79] Cooper, *Before Liftoff*, 155-184.

By the 1990s, the JSC training catalog had standardized the objectives of integrated simulations. Controllers began their careers by taking part in generic simulations designed to instill in them a set of qualities. Some of them dealt with technical proficiency: demonstrate an awareness of a mission's status under all situations, accurately and concisely convey system failures to other affected controllers and the Flight Director, define plans for resolving and managing problems, demonstrate the ability to work with all console tools, guide the crew through all actions required for mission success and crew safety, demonstrate a knowledge of the interactions of other systems with their own systems, and demonstrate confidence and ownership of their own systems. But technical proficiency was not enough; the controllers also needed to have the right attitude. They needed to demonstrate a positive attitude toward console operations and fellow controllers, demonstrate accurate and cordial team communication, demonstrate the ability to adjust to the capabilities and deficiencies of backroom personnel, demonstrate that they accept responsibility for all of the disciplines of the system, and willingly admit when they have erred. The job defined during the *Mercury* era had thus evolved to take on a more clear definition of standards. When controllers met all of them, they could progress (like the astronauts they would work with) to flight specific integrated simulations.[80]

The objectives for these simulations shortly before flight also became more standardized during the shuttle era. These sessions gave the controllers and astronauts a chance to gel as a team by exercising the prime mission objectives and timelines, but

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[80] "Shuttle Crew Training Catalog, Revision J," 14-5 to 14-6.

also by preparing for anomalies. These included alternative timelines brought upon by a launch slip or equipment failure that caused a minimum duration flight, scenarios that tested their ability to cope with the replanning of mission objectives, scenarios that stressed mission constraints such as water dumps or thermal attitudes, or tradeoffs between mission objectives and operational capabilities. For instance, a controller might notice a degraded system in power generation, vehicle control, or navigation and decide whether a crew could complete their objective or needed to return home. The communication between the controller responsible for the degraded system and the rest of the team, as everybody searched for the data that could help them make the right decision, helped to mold the team into a cohesive unit that astronauts could trust. So much depended on the controllers making the right decision, from the satisfaction of a customer flying a payload on a flight, to America's image as a human spaceflight superpower, to the astronauts' lives, that it was easy to see why Henry Cooper reported on the strong desire to keep integrated simulations.[81]

Wayne Hale, a Flight Director for forty-one missions from 1988 to 2003 and later Space Shuttle program manager, remembered the frustrations of these sessions. "On a busy day, the sim team had to make sure that multiple flight controllers saw multiple failures in each eight and a half minute shuttle launch profile," he explained. "We generally did six launches in one day. Or we did entry sims that simulated the last 15 minutes of reentry; four of those cases filled up a day." The controllers had to deal with hundreds of possible malfunctions during these sessions and as they gained

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[81] Ibid, 14-7 to 14-8.

confidence in doing this the SimSups raised the level of difficulty with dual combinations and even triple combinations of failures. Then came debriefings, which sometimes took two hours to decipher what had happened and what the proper responses had been. The SimSups even assigned action items that might take weeks of research to answer. No person had a harder job at these times than the Flight Director, because this person was the nexus for all malfunctions. "Sometimes it felt like the Flight Director was wading through a class of excited grade school students all calling for his attention at once," Hale remembered. "Flight Directors, usually this one, tended to get testy on days like that. We would say, 'Not realistic, SimSup,' or 'We will never have an ascent with that many failures, SimSup,' or other brief communications that we cannot reproduce in a family oriented publication." But by the end of his time as Flight Director, experience on real missions taught him to complain less about failure filled simulations.[82]

While 135 shuttle crews trained for missions across three decades, the JSC DT expanded to teach them the skills they would need. The office contained 164 members during the early 1980s. There were always more training personnel than astronauts, meaning that unlike standard universities, JSC contained more faculty members than students.[83] "The instructors were largely engineers and people with other technical degrees (math, physics, etc.) that learned a specially assigned portion of the spacecraft before themselves training astronauts," Beauregard explains. "Instructors that trained

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[82] Wayne Hale, "Practicing for Disaster," October 21, 2014, *Wayne Hale's Blog*, https://www.waynehale.wordpress.com/2014/10/21/practicing-for-disaster/ (accessed January 7, 2017).

[83] Cooper, *Before Liftoff*, 16.

astronaut crews were unlike many other areas of flight training in that they never actually did the job they were responsible for training. In other words, astronauts are not assigned to later become instructors. There were neither enough astronauts nor missions to provide that ability. As the years progressed, more emphasis was placed on hiring people that would be good at teaching. In general, if you wanted to do hard core engineering, astronaut training was not for you. Using your engineering abilities to understand complex spacecraft operations and being able to explain that in a teaching environment where the students were highly motivated, was more the rule." He also explains that JSC benefited from the "NASA co-op program, where college students would work from two to five semesters within NASA disciplines across the board, including training. This worked well as each co-op student had essentially an extended interview to see how well they fit the various jobs. Then, after graduation, they would normally be hired as full time civil servants."[84] Lisa Martignetti, who worked in training from 1989 through the end of the shuttle program, also remembers the emphasis on teaching. She explains that new additions to the training office gave teaching demonstrations when they were hired so the managers could feel confident in their ability.[85]

Women infiltrated what had been an entirely male JSC training office beginning early in the shuttle era, just as in the astronaut corps. Anne Accola was one of the earliest additions. Right after earning her B.S. in Mathematics at Colorado State

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[84] Beauregard, E-Mail Correspondence with Author.

[85] Author Phone Interview with Martignetti.

University, she traveled to Houston in 1967 to work in the Dispersion Analysis Section. She joined the Simulation and Training Branch in 1972 and trained flight controllers for the last few moon missions, the three *Skylab* missions, and one *Apollo-Soyuz* mission. But in 1978, she earned a more prestigious position as a Lead Instructor for the SMS. During her earlier years, she remembered some of her colleagues in the male dominated training office being very friendly to her, while "a couple went out of their way to be a problem."[86] But men had to adjust very quickly to working in a mixed gender environment as the late 1970s and early 1980s progressed, as in many other technical professions around the country. "I was fortunate to be a young instructor on teams led by very competent women on more than one occasion, as well as having a female direct supervisor in one of the organization sections early in my career," Beauregard recalls. "Some of these women went on to be senior NASA managers and even a flight director."[87]

Astronaut training became a more mature institution, with clearer guidelines for participants to follow, during the shuttle era. But would the shuttle flights follow the pattern of the *Mercury*, *Gemini*, *Apollo*, and *Skylab* eras by demonstrating the mental and physical flexibility that trained humans could bring to missions? America had retreated from the Moon, but had developed a more complex vehicle than the *Apollo* spacecraft that President Nixon had approved on the basis that it would revolutionize transportation from Earth to about 200 miles above it. The onus fell to crewmembers to

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[86] Anne L. Accola, Interviewed by Rebecca Wright, March 16, 2005, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/AccolaAL/AccolaAL_3-16-05.htm (accessed December 28, 2016).

[87] Beauregard, E-Mail Correspondence with Author.

draw on their training in performing the work on orbit that would make Nixon's approval worthwhile. Whether they could do this remained unclear as Denny Holt stood in that cold room in Houston in September 1976, waiting for a new generation to bear fruit.

CHAPTER XIII

STS: "I DON'T KNOW HOW THEY DID IT, ACTUALLY"

Four years after President Richard Nixon approved the program, the day of fulfillment still appeared far in the future. In America's Bicentennial year of 1976, the country that had sent 12 men to the lunar surface could no longer even send astronauts into Earth orbit. Rockwell contractors had only begun constructing the crew module of Space Shuttle *Columbia* that year, with the rest of the orbiter still awaiting assembly. Less than 30 astronauts remained on flight status. But two events in the Bicentennial year gave hope that astronauts would someday take to orbit in a winged vehicle and return to a runway landing. Singer-Link delivered the SMS to JSC Building 5, giving astronauts their most realistic flight simulator to date. On September 17, a tractor pulled a Space Shuttle bearing the name *Enterprise* from the Rockwell facility in Palmdale, California. This vehicle lacked the engines, thermal tiles, middeck amenities, and many of the instruments and displays that *Columbia* would need to reach orbit, but *Enterprise* did have the airframe and wings to take flight within the atmosphere and land after detaching from a 747 jet called a Shuttle Carrier Aircraft (SCA). Chief of the Astronaut Office John Young and Director of Flight Crew Operations George Abbey thus had to select crews of two to fly aboard *Enterprise* for its Approach and Landing Test program. They decided on Fred Haise and Gordon Fullerton as one crew and Joe Engle and Dick Truly as the other. The selection of these four and the delivery of their simulator is the best place to begin a chronology of Space Shuttle astronaut training.[1]

Haise, Fullerton, Engle, and Truly had several methods by which to train. The four traveled to the McDonnell Douglas plant in St. Louis to step inside two simulators that prepared them for the separation of *Enterprise* from the SCA. One of the simulators mimicked the cockpit of the SCA that would carry *Enterprise* to altitudes as high as about 30,000 feet. The other mimicked the cockpit of *Enterprise* itself and rested on movable supports that simulated the accelerations that astronauts would feel upon being launched free of the SCA. The astronauts needed to feel prepared to climb to 120 feet above the SCA just three seconds after detachment. When the four needed the experience of an actual flight to rehearse the steep, unpowered landing they would need to make aboard *Enterprise*, they climbed into the STA that had just been configured for this purpose.[2] Meanwhile, Engle took the lead in preparing the new SMS to simulate approaches and landings. Lead Simulation Instructor John "Denny" Holt remembered that the early SMS often developed computer glitches that caused simulations to be delayed. With each new glitch, Engle and Truly waited patiently while crooning the lyrics to a new Kenny Rogers song: "You picked a fine time to leave me, Lucille." But amid the frustration, the four astronauts rehearsed in four hour blocks in the SMS. The men succeeded in building their confidence for approaches and landings, especially because the simulator allowed them to land, take off, and land again in quick succession. Engle, who had already flown the X-15 aircraft from the edge of space to a landing in

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[1] Heppenheimer, 101-104.

[2] Ibid, 105-106.

the 1960s, especially impressed the instructors. Jerry Mill believed he "could have brought a claw-foot bathtub to a safe landing" given his prowess ingiving the simulator just the right amount of hand controller input.[3]

The first flights of *Enterprise* from the dry lake bed at Edwards Air Force Base improved the fidelity of the simulations. In February and March 1977, SCA pilots Fitzhugh Fulton and Tom McMurtry took the vehicle on five flights that tested its handling qualities and airworthiness while strapped to its carrier. The flight data created a benchmark for the SMS in replicating factors such as separation forces, flutter, and buffet. The flights also gave the astronauts confidence that the combination of *Enterprise* and its carrier could handle several contingencies, from engine-out takeoffs, to aborted takeoffs, to loss of power in an engine during flight, to an emergency descent, to a missed approach, to a go-around following a refused landing, to a short-runway landing. But those were only the "captive-inert" flights, with *Enterprise* unpowered and unpiloted. The two crews did take turns sitting inside for three more "captive-active" flights in June and July, finding that *Enterprise's* systems such as the APUs and fuel cells worked properly. The main event finally came on August 12: the day that Haise and Fullerton separated from the SCA and brought *Enterprise* to its own landing.[4]

This revolutionary flight provided evidence of how training could contribute to the success of flying and vice versa. When Haise fired the explosive bolts that separated *Enterprise* from the SCA on August 12, he quickly heard a master alarm and found he

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[3] Interview with Holt and White, 153-157.

[4] Heppenheimer, 106-114.

had lost a computer. But having worked with the real computers in the SMS, he knew the vehicle could still function well with the remaining units working. The flight controllers then gave him an erroneous message, stating that *Enterprise* remained steady in altitude during a practice landing flare and had a low lift-to-drag ratio, which meant he would have to land very soon. But the vehicle had actually climbed several hundred feet and had more lift than expected. Haise realized during his approach that *Enterprise* was too high and too fast and had no choice but to touch down two thousand feet beyond his aim point. But the experience of flying under a variety of conditions in the SMS and STA prepared him for this anomaly and he even made the pleasant discovery that flying the real vehicle was easier than the SMS. "It was tighter, crisper, in terms of control inputs and selecting a new attitude in any axis and being able to hold that attitude, it was just a better handling vehicle than we had seen in the simulations, although they were close," Haise recalled.[5] In turn, the two glitches on this flight held value by improving the training process for future crews. Engineers used the SMS to trace the computer loss to a synchronization problem brought along by an improperly soldered circuit board. Thus the engineers knew to replace the circuit board for future crews. *Enterprise's* flight also benchmarked the shuttle's true lift-to-drag ratio for the SMS.[6]

The remaining four *Enterprise* flights provided even more much needed experience that aided the training of shuttle Commanders and Pilots. Joe Engle, Dick Truly, Fred Haise, and Gordon Fullerton demonstrated the ability to land at a precise aim

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[5] David Hitt and Heather Smith, *Bold They Rise: The Space Shuttle Early Years, 1972-1986* (Lincoln: University of Nebraska Press, 2014), 84.

[6] Heppenheimer, 115-116.

point on the lake bed. The last two flights presented a new challenge, as engineers removed the tail cone that had covered the three main engines and two OMS engines. This reduced the lift-to-drag ratio from 8.5:1 to 4.5:1. The glideslope angle increased from 11 to 22 degrees, meaning the crew would have to glide toward the runway several times more steeply than in any other aircraft they had flown. They would also only have about two and a half minutes from SCA separation to touchdown, which placed a greater premium on their reflexes and problem solving ability. The astronauts utilized their training devices to overcome all of these challenges, albeit with one predicament on the last landing. On October 26, Haise brought the ship within inches of Edwards's Runway 04 and then rose again while rolling from left to right. Fullerton realized that his colleague was struggling with pilot induced oscillation and told Haise to relax his grip on the hand controller. *Enterprise* ended up bouncing on the runway and then staying in the air for two thousand feet, but Haise benefited from Fullerton's advice and brought the ship to a safe touchdown before hard braking brought *Enterprise* to a stop with a comfortable amount of runway in front of him. This brief scare during a rehearsal for spaceflight taught future crews to overcome the problem of pilot induced oscillation and allowed engineers to modify the SMS to account for the lower than expected drag that caused Haise to land too fast and too long. The next time a shuttle made a landing, the rehearsals would be over and *Columbia* would be returning from orbit.[7]

As *Columbia* moved close to final assembly in Palmdale, the astronaut corps needed its first infusion of new personnel since 1969. JSC Director Chris Kraft and

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[7] Ibid, 117-121.

Director of the Office of Manned Spaceflight John Yardley were the two people most instrumental in forming the requirements for the new group, which would be the most revolutionary in altering the demographics of the astronaut corps. Kraft's letter to Yardley in March 1975 stated his belief that the current members of the corps were likely to retire within the next ten years and that a younger group of Pilots and Mission Specialists should replace them. He set up an Astronaut Selection Board the following year. The panel that would select the pilots consisted of ten members, including Deke Slayton and John Young. The panel for mission specialists consisted of ten members, also including a few astronauts. The possibility of selecting women, African-Americans, and Hispanics, first raised by Jim Fletcher with President Nixon in 1972, gradually earned acceptance among NASA managers including Kraft. Twelve Air Force nurses rode a centrifuge at the Ames Research Center and easily handled 3 Gs of acceleration, providing evidence that women could be assets to the astronaut corps. Thus Kraft made sure that both selection panels also included members of the JSC Equal Opportunity Program Office, Joseph Atkinson and Carolyn Huntoon. The announcement that NASA was seeking new astronauts came in 1976, to ninety aerospace firms, nearly a thousand colleges and universities, and a hundred minority organizations. Out of 8,000 applicants, the panels selected 208 finalists who traveled to Houston for interviews and medical examinations. Kraft made the final decision to select 35 new astronauts in January 1978.[8]

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[8] Ibid, 387-390.

The addition of the "Thirty-Five New Guys" (TFNGs) affected training in several ways. This included their backgrounds, which contained elements that helped them become proficient astronauts. About half of the 35 were Vietnam War veterans, which meant experience in the high pressure flying of combat just as many of the *Apollo* astronauts had that experience from Korea.[9] Many of the Mission Specialists had backgrounds in the experiments that Principal Investigators hoped to pursue on shuttle missions, such as chemistry, physics, and physiology, which eased the task of training them in science. One new consideration in selection and training concerned the size of crews and amount of time they would be together. Crews of up to seven (or eight, in one case) would spend a full year together in training, as opposed to just three in the *Apollo* era who typically spent no more than about six months in training. Thus the selection board placed an emphasis on interpersonal skills in forwarding their recommendations to Kraft. The panel members did this by considering the results of applicants' psychiatric and psychological tests, their interview answers, the recollections of people who knew the applicants, and how the applicants interacted with each other. After the successful applicants graduated from ASCAN status, interpersonal skills were one of their strongest assets in earning selection to a crew and becoming an effective team member over the following year. "You don't necessarily want the guy who's the hyper-brilliant lab bench or computer guy if he does not even have the social connective tissue in mind," explained Kathy Sullivan, one of the TFNGs.[10]

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[9] Lynn Sherr, *Sally Ride: America's First Woman in Space* (New York: Simon & Schuster, 2014), 97.

[10] Foster, 92-93.

But the new group mostly attracted attention by including the first six women astronauts, the first three African-American men, and the first Japanese-American man. The additions of Anna Fisher, Shannon Lucid, Judy Resnik, Sally Ride, Rhea Seddon, and Kathy Sullivan required alterations to the training process. When the group traveled across the country during their time as ASCANs, they required separate sleeping and showering accommodations for the women. The JSC gymnasium to which astronauts had priority access required a women's dressing room and restroom. Besides the physical modifications to JSC, the male astronauts needed to adjust to a culture in which they were training alongside women. Most of the males still came from a military background, which did not prepare them for this. But beginning in 1978, all astronauts would have to adjust to a mixed gender environment in classroom lectures, the WETF, the SMS, T-38 aircraft, and eventually the shuttle itself. As the 1980s progressed, the men from the group agreed that women had earned their place in the corps just as much as they had and deserved to be remembered not as women astronauts, but simply as astronauts who did their jobs well.[11]

The astronauts spent their time not only training for missions, but also continuing the tradition established during *Mercury* of providing astronaut input on spacecraft development. Those who had joined the corps during the 1960s, some of whom were still waiting for their first taste of spaceflight, worked especially closely with engineers at NASA and Rockwell as the vehicle took shape. Ken Mattingly was the first assigned to such a role, having been named to Astronaut Office support of the program in 1973.

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[11] Ibid, 98-105.

This allowed him to attend meetings where engineers made decisions on cockpit controls and displays, a key bit of experience that aided him in training and flying the orbiter. Hank Hartsfield assisted with the development of wind tunnel models, Don Peterson with the computers, and Don Lind with the robotic arm. Among the TFNGs, Terry Hart assisted with the main engines, George "Pinky" Nelson with the new EVA suits, and Bryan O'Connor with simulation. Mattingly believed that the level of cooperation between engineers designing the vehicle and those in training to operate it was rare and highly beneficial for both groups. Compared to *Apollo*, "Our involvement was far more extensive and pervasive, and a heck of a lot more fun," he said.[12] This involvement was especially crucial for the robotic arm, to the point where engineers in Toronto, Canada designed the hand controller for the arm to the physical dimensions of Lind's hand. TFNGs John Fabian and Sally Ride then spent hundreds of days in Toronto performing simulations of arm motion, with Ride writing the procedures for the first use of the arm during *STS-2* on the basis of her work. The Space Shuttle era thus provided the clearest indication yet that astronauts needed to be more than passengers; their expertise helped to guide key engineering decisions.[13]

In March 1978, the day all astronauts had waited for arrived: selection of a crew for the first mission. George Abbey selected John Young as the Commander of *Columbia's* maiden voyage: *STS-1*. Young would fly the first mission alongside Bob Crippen, who had not yet flown in space but had worked on *Skylab* and *Apollo-Soyuz*

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[12] Hitt and Smith, 21-53.

[13] Ibid, 48-50 and 75-76.

and then became one of the leading experts on shuttle computers in the Astronaut Office. Joe Engle, Dick Truly, Fred Haise, Gordon Fullerton, Ken Mattingly, Hank Hartsfield, Jack Lousma, and Vance Brand were also in line for the first test flights of *Columbia* before the ship would begin carrying payloads for paying customers and more vehicles would be added to the fleet.[14] The first voyages would arguably surpass even the *Mercury* and *Apollo* flights in danger. *Columbia* contained more than 2.5 million parts, a portion of which were Criticality 1 items that could cause a loss of life or vehicle if they failed, and would not make any unmanned test flights. Young and Crippen would climb onboard and trust that both their training and the work of engineers was enough to send them into orbit and back again. Fred Haise explained, "There was…initially a planned unmanned flight. But…with a crew aboard…to be there in a systems diagnostic and be able to handle the multitude of things that you could work around, just inherently made the success potential of a flight a lot greater."[15] Young and Crippen thus needed to train to develop their diagnostic skills and prove the truth in Haise's words.

The early state of the SMS made this a daunting task. Though astronauts had used the first version in preparing for the *Enterprise* flights and had returned data from those flights to improve its performance, *Columbia's* upcoming flight would differ dramatically. The vehicle would accelerate to 17,500 miles per hour, partly on the strength of SRBs, which had never been used before in a piloted launch. Two days later, the ship would also have to reduce its speed from 17,500 miles per hour to a stop on an

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[14] Heppenheimer, 392 and Young with Hansen, 223.

[15] Fred W. Haise, Interviewed by Doug Ward, March 23, 1999, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/HaiseFW/HaiseFW_3-23-99.htm (accessed December 29, 2016).

Edwards Air Force Base runway, another unprecedented task. When the second version of the SMS arrived in 1978 for Young and Crippen's flight, none of this had happened yet. Engineers had only data from the *Enterprise* flights, ground tests of shuttle hardware, and previous spaceflights to guide them in developing the SMS. Bryan O'Connor, the astronaut from the TFNG group assigned to assist in simulator development, remembered the motion, visual, and oral cues as being especially difficult to simulate before the first launch. "Nobody knew what it would sound like on shuttle, but if they could make it sound like what *Apollo* sounded like, they thought that was a good start," he explained. Thus the few *Apollo* veterans still in the astronaut corps such as Young and Mattingly worked with Roger Burke, the engineer in charge of developing the SMS, to draw on what had worked during the *Apollo* era to make the SMS as high fidelity as possible.[16] Even so, the SMS was in its lowest fidelity state at this point. In addition to the uncertainty about motion, sight, and sound, the SMS often crashed. "Then you'd have to start over again, try to get it restored," remembered Anne Accola, a frustrating process that added to the length of training days.[17]

Training for *STS-1* thus required a supreme work ethic and a desire to be the "guinea pigs" who would form the initial shuttle training procedures without any shuttle having launched before. John "Denny" Holt, who became the first Lead SimSup for a shuttle mission, remembered that he and his colleagues spent eight hours per week writing scripts for ascent, orbit, and reentry. This was a challenging process for several

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[16] Hitt and Smith, 77-79.

[17] Interview with Accola.

reasons. These SimSups did not have a track record of flight data to fall back on in choosing the list of malfunctions with which to challenge the crew. They found that some switches in the cockpit were inaccessible to the crew during launch and reentry, which complicated the procedures the crew could implement. On top of this, they had to deal with the frustrations of the SMS crashing and the need to modify the simulator to keep up with the hundreds of modifications to *Columbia* itself. But the SimSups managed to develop their list and insert them into the SMS. "I was the overall instructor, watching them, saying, "'Oh, no, you can't put that malfunction in, because they haven't figured out this previous one, and it's going to complicate things,'" Accola recalled. After accounting for all potential pitfalls, the SimSups were able to spend about thirty hours per week working with Young and Crippen. "After about six months, you started to see procedures coming together," Holt explained. "Rules were written, responsibilities were then aligned, and the team formation came through."[18]

Accola recalled that by 1979, the SimSups were able to focus heavily on integrated simulations. Many flight controllers had not worked a mission since *Apollo 17* in 1972 and many were new hires who had not worked any mission, so the onus fell upon the SimSups to hone their skills until they could make decisions in life or death circumstances. This took place in sessions of increasing length, many of them thirty and even fifty-six hour marathons (roughly matching the length of *STS-1*). The *STS-1* mission went through so many delays that the controllers had more of these sessions

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[18] Interview with Holt, Interview with Accola, and Robert L. Crippen, Interviewed by Rebecca Wright, May 26, 2006, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/CrippenRL/CrippenRL_5-26-06.htm (accessed December 29, 2016).

than expected to analyze problems, communicate workarounds to Young and Crippen, and even plan for multiple day operations. The SimSups developed ingenious ways to test the controllers, such as inserting a failure between the responsibilities of two of them so the two would have to decide who would solve the problem. Thanks to the delays, the tandem of astronauts and controllers grew so proficient with situations like these that they taxed the SimSups in seeking new ways to challenge them. Accola remembered inserting about 150 malfunctions over one 56 hour session, an indication of how much more complex training had become since the 1960s. The Rockwell contractors and shuttle program managers observed all of these situations, offering their help when necessary just as they would during a real mission.[19]

Young and Crippen prepared vigorously for the grimmest scenarios that could confront them, even if they doubted that the proposed method for overcoming them would succeed. The two trained in the operation of the ejection seats, which engineers had lifted from the SR-71 Blackbird aircraft to give them a chance of survival in case of a catastrophic malfunction. This required quick thinking and reflexes, because the astronauts would have to operate safety pins while wearing bulky suits to eject just before the range safety officer gave the order to detonate the vehicle. Neither of them felt confident that the ejection seats would save their lives, with Young noting sarcastically in his memoir, “I was also thinking about what a grand time it would be if Crip and I used those ejection seats just to fly through the 5,000 degree plumes of the solid rocket motors!” But they did build confidence in their actions during this potential

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[19] Interview with Holt and Interview with Accola.

contingency as well as a launch abort that ended in a bailout. The two paddled in rafts inside JSC Building 29 to prepare for this. Their integrated simulations came to an end with a run-through of the entire mission, complete with pressure suits. Young remembered that this last one especially challenged him during reentry. While traveling at nearly 8,000 miles per hour, he noticed a major malfunction with multiple computers. He went to the backup system, which required him to fly manually to an Edwards runway. Although he remembered thinking that the simulations had grown too far-fetched, an issue that SimSups would have to grapple with in the future, he and Crippen showed such skill in preparing for the worst that Accola described them as "overtrained" by the time the much delayed launch was imminent.[20]

One other issue that would become a recurring problem during the shuttle program reared its head during *STS-1* training. After *Columbia* traveled from the Rockwell factory to KSC in 1979, engineers had to remove and densify more than 24,000 thermal protection tiles. Many had failed in tests at far below the dynamic pressure that would have to withstand during a launch. This led to concern about what Young and Crippen could do in case they spotted damage to the tiles in orbit and determined they could not return safely (ironically, neither engineers nor astronauts worried about the issue that doomed *Columbia* over two decades later: damage to the Reinforced Carbon Carbon [RCC] on the leading edge of the wing).[21] The two went to the Martin Marietta plant in Denver to test a repair method, donning suits and climbing

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[20] Young with Hansen, 223-228, White, 231, and Interview with Accola.

[21] Hitt and Smith, 90-91.

into a zero-gravity suspension system that was part of the company's Manned Maneuvering Unit simulator. The suspension system carried them to bottom of a simulated orbiter, where they tried to repair damaged or missing tiles. But training provided a negative answer to this "what if" question. Young and Crippen did not have a restraint system to hold them in place while they touched tiles in zero gravity, and one of the lessons of the *Gemini* program had been the need for well positioned restraints to perform tasks during EVAs. Thus Young concluded that they would have damaged more tiles than they could have fixed and asked not to take the MMU on this mission. He and Crippen did train successfully for an emergency EVA to close and latch the payload bay doors. They would have to open the doors in orbit to radiate heat, but could not return home without closing them. If the doors did not shut automatically, they could have stepped outside to do so using an emergency latch tool, on the strength of their training in a large water tank using procedures developed by TFNG astronaut Jim Buchli.[22]

Like astronauts of every new program dating back to *Mercury*, the first crew benefited from hardware checkout as well as simulation. Young and Crippen, along with backups Joe Engle and Dick Truly, spent about 150 hours performing tests on *Columbia* at the Rockwell plant through 1979, and then at KSC through 1981. Young remembered climbing into *Columbia* for a test of the ship's three APUs in October 1979, when these hydraulically powered devices fired for 30 minutes while the crew moved the elevons, rudder, and speed brakes. The crew sat inside the ship again for a series of

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[22] Young with Hansen, 227.

five simulated flights in December. They ran through an entire mission, performing activities such as opening and closing the payload bay doors, deploying radiators, operating computers, purging fuel cells, and responding to emergencies. Young remembered the tests as so thorough that they featured an end-to-end test of the primary and backup flight software, which was never done again on any other orbiter. The KSC engineers knew that it was Young and Crippen's lives that would be on the line and thus welcomed their input or questions. The two asked plenty of questions about the tiles and main engines, the two most revolutionary piece of hardware that had been most responsible for the launch delays, until they felt satisfied they could trust their lives to them. A tow vehicle pulled *Columbia* from the KSC Orbiter Processing Facility (OPF) into the VAB in November 1980, then a crane hoisted it onto its ET and SRBs. The crew climbed into the cockpit for another test in December, this time to simulate launches in a fully assembled and powered vehicle. *Columbia* finally rolled out to Launch Pad 39A on December 29. Young was adamant in his memoir about counting these experiences as training. He estimated that by the following spring, he and Crippen finished with over 2,000 hours of training.[23]

The two astronauts rode into a new era on April 12, 1981, undergoing an experience that would benefit the training of future crews. Right until the last day of training, Young had mentally rehearsed the procedures he would have to follow to use the ejection seats, to abort back to KSC, to abort across the Atlantic Ocean to Rota, Spain, or to bail out of the vehicle. Training had taught him that the highest risk would

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[23] Ibid, 227 and Heppenheimer, 400-402.

come during those first 8.5 minutes of the mission. But the combination of SRBs and main engines took *Columbia* into orbit with no grimscenario coming to fruition.[24] Better yet, Young and Crippen made comments about the motion, sight, and sound so that engineers could modify the SMS based on reality and not a "best guess." For future crews, the SMS mimicked the sudden jolt of *Columbia's* initial burst from the pad. The shaking during SRB flight became more pronounced, to the point that the view of the instrument panel became blurry. The visual scene included an accurate depiction of SRB separation out the windows. The firing of RCS thrusters mimicked the shaking that had startled Young, reminding him of "muffled howitzers."[25]

Training helped Young, Crippen, and the flight controllers in several ways during the two-day mission that followed. The astronauts reported that other than the weightlessness, moving around the flight deck and middeck and operating the equipment felt just like the simulations. The extensive knowledge of systems instilled in them for several years helped them diagnose problems, just as Haise had predicted. The crew reported on the loss of a few tiles on front of an OMS pod, a dual heater failure in one of the APUs, a few unexpected maneuvers caused by inadvertently bumping the hand controller, and inadequate flow in the toilet, then made recommendations in the mission debriefing on the strength of their knowledge.[26] In the opinion of the crew, training helped the flight controllers improve substantially. "I noticed when we first started out doing sims, it was just like we were working with three teams, like the teams weren't

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[24] Young with Hansen, 229-231.

[25] Hitt and Smith, 105-106.

[26] Young with Hansen, 231-234.

passing information to each other," Crippen argued. "And I didn't see that during the flight. As far as I could tell, we were all talking about the same thing at the same time." The controllers even coordinated with the Department of Defense (DOD) to have a DOD satellite take classified photos of *Columbia's* underside, in order to make sure tile loss had not damaged the ship irreparably.[27]

Much anxiety remained concerning the reentry and landing, but Young and Crippen passed this last test with flying colors at Edwards on April 14. Young switched from the autopilot to manual control several times starting when the ship slowed to Mach 7, making sure to precisely control all axes with his hand controller to minimize the possibility of any unwanted motion during the roll reversals that dissipated *Columbia's* speed. He also used the trim integrator to damp out a sideslip angle of 4 degrees that otherwise would have killed the crew. He took control for good at Mach 1 and flew the ship so well from that point that *Columbia* touched down at a speed less than two miles per hour away from what he intended and at a miniscule sink rate of 1.5 feet per second. Given the trouble that Young had during his first experiences flying the STA in 1977, it is doubtful he could have done this without his hundreds of approaches in this vehicle and in the VMS at Ames. Only the repetition of several years of training could give himself and the entire space agency confidence that he could pull off an unprecedented task in energy management.[28] Training a Commander to do this helped to demonstrate the value of sending humans into space, because certifying the autopilot

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[27] [*STS-1* Technical Crew Debriefing, Box GH-139, *Shuttle* series], JSC History Collection, University of Houston-Clear Lake, Houston, Texas, 12-3 and Hitt and Smith, 108.

[28] Young with Hansen, 234-236.

to land the vehicle would have required much more cost and development time. Even if this had happened, a trained Commander had the flexibility to respond to malfunctions that could have been crucial in bringing about a safe landing, such as eliminating the sideslip.[29]

Training grew more ambitious for each subsequent mission, but the crews had advantages to draw upon that grew more pronounced as each returned safely. Before Joe Engle and Dick Truly flew *STS-2* in November, their mission appeared daunting. In addition to learning all the systems and aborts their predecessors had to know, Truly had to learn how to operate *Columbia's* robotic arm for the first time. Engle had to learn how to fly the entire reentry and landing manually, in order to fly the thirty different maneuvers that were part of this test flight. Both crewmembers trained for a new tile repair method that proved more successful than the futile method tested in Colorado: making an EVA to apply a rubber material that could fill a void between tiles. Yet these two had an updated SMS and the recollections of Young and Crippen to draw upon as they trained. The more astronauts who flew on the shuttle and spoke to rookie crewmembers, the more that the rookies knew what to expect. As Chief of the Astronaut Office, John Young rode with crews in the SMS for hundreds of hours and often flew with Commanders and Pilots in the STA. Although Truly would have to pioneer robotic arm operations, he could do so by working with the engineers who had designed the arm, who were eager to assist him as he trained to maneuver it in the SMS and MDF. The training paid off, because Truly took the arm through its envelope and Engle overcame

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[29] Hitt and Smith, 95-96.

the loss of a fuel cell, a lack of sleep, dehydration, and a 20-knot headwind to add considerably to the database on orbiter approach maneuvers. “They were just like they were bred into me,” Engle said of the maneuvers, due to his training.[30]

On July 4, 1982, the first era of the shuttle program ended when *Columbia* completed its fourth and final test flight. John Young and Bob Crippen (*STS-1*), Joe Engle and Dick Truly (*STS-2*), Jack Lousma and Gordon Fullerton (*STS-3*), and Ken Mattingly and Hank Hartsfield (*STS-4*) occupy a unique spot in shuttle history because they had to perform thorough tests of *Columbia’s* systems with crews of two. “It was a full-time job to keep that thing going with just two people and carry out some kind of a mission,” argued TFNG astronaut George “Pinky” Nelson. “I don’t know how they did it, actually.”[31] They could only do so with training, some of which was unique to the test phase and some of which set a precedent for the operational phase. The unique parts were the two-person crew, the emphasis on systems testing rather than payloads, and the crewmembers attaining an enormous amount of engineering knowledge from *Columbia’s* development and testing in California and Florida. But Mattingly and Hartsfield identified the best precedents in their mission report: hundreds of hours in the SMS throughout the flow, the desirability of in-flight maintenance training on shuttle equipment, the desirability of weekly STA flights during the last months before launch, the desirability of long integrated simulations at the end of the flow, and the desirability of Terminal Countdown Demonstration Tests at KSC to rehearse launch day procedures.

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[30] Ibid, 118-125 and Young with Hansen, 240.

[31] Hitt and Smith, 130.

Mattingly and Hartsfield devoted about 75 percent of their training time to malfunction procedures they did not implement during the real mission. Shuttle program managers still envisioned the vehicle making several launches per month at this time, which would have altered some of these precedents in the direction of airline pilot training: less ambitious and time intensive. But since the vehicle never launched more than nine times in one year, the precedents stuck.[32]

Some of Mattingly and Hartsfield's recommendations became unrealistic due to misguided flight rate projections. For instance, the crew complained, "Until the number of FDF procedures is reduced, crew training time cannot be substantially reduced." But the number of missions remained much lower than expected at this time, the FDF remained long and complex, and the training time for each mission remained lengthy. The two men did make useful observations such as increasing the number of SMS reset points and simulating malfunctions for the prelaunch period. One other observation became especially vital. During the first four missions, "a considerable amount of the Commander's time was occupied in defining training goals and mapping out a plan of study. Certainly the mission Commander should have a voice in this process, but it should not be his task to develop a plan at the same time he is trying to execute it. This condition was unavoidable in the early STS development, but the time has come to develop a core training program. These program goals should be phrased in terms of skill and proficiency levels rather than number of hours or lessons."[33] Pete Beauregard

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[32] Michael A. Collins, Jr. and R.A. Colonna, *STS-4 Orbiter Mission Report Supplement* (Houston, TX: JSC-18553, 1982), A-4 to A-8.

[33] Ibid.

explains that this did happen: "Each lesson or training session that the astronauts or entire flight crew go through had specific training objectives…The lessons themselves are part of a training flow developed and continually updated by the training organization."[34] This allowed training to become more standardized for the crews that followed Mattingly and Hartsfield.

Another change benefited crews after the operational flights began. The first few shuttle crews made their sessions in the SMS with randomly assigned instructors, meaning the astronauts saw a variety of training personnel. But after the test flights ended, each crew worked a Training Team Lead and a group of colleagues specifically assigned to a mission. This resulted in the astronauts seeing the same group of instructors over about a year, meaning the two groups could develop a rapport. "The old way, we never got to know the crews so well," instructor Ted Browder recalled for Henry Cooper's book in the early 1980s. "We see them on a daily basis now. We see them personally—we go out for beers together on Friday evenings. The crews always remember their roots—they are always the first to share their accomplishments with their instructors."[35] But more importantly, the instructors came to know the strengths and weaknesses that certain astronauts had in performing tasks and could design simulations accordingly. The innovation of one training team following one crew thus gave the crew a resource that *Mercury*, *Gemini*, *Apollo*, and *Skylab* crews did not ha

Another change starting with *STS-5* was the training of four person crews.

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[34] Beauregard, E-Mail Correspondence with Author.

[35] Cooper, *Before Liftoff*, 86.

Mission Specialists would fly for the first time on this mission alongside a Commander and Pilot, so the astronauts needed to know who would be responsible for what tasks and train for them. TFNG astronauts John Fabian and Judy Resnik helped to establish a system where MS 1 had the overall responsibility for payloads and experiments, MS 2 had the responsibility of being a flight engineer who would help the Commander and Pilot during launch and reentry, and MS 3 had the responsibility for independent experiments and EVA. This affected crew selection and training. It meant that MS 1 had the greatest burden in terms of achieving a mission and should be the most experienced of the Mission Specialists on the crew. MS 2 had the greatest burden in terms of simulation time, due to the many malfunctions that could happen during launch and reentry. MS 3 also had a great burden in terms of training for EVAs in the WETF, but this person was generally the least experienced.[36] The training of all of these people became more streamlined due to two changes that reflected the confidence of shuttle managers in the vehicle's operational status. Crews starting with *STS-5* did not have ejection seats or any other escape method to learn about prior to launch. Crews also abandoned the full pressure suits that all previous American astronauts had worn, instead wearing light-blue coveralls with only a helmet to provide breathing air in case the cabin lost oxygen.[37]

The *STS-5* crew was the first to implement this procedure. The crew consisted of Vance Brand as Commander, Bob Overmyer as Pilot, Joe Allen as MS 1, and Bill Lenoir

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[36] Hitt and Smith, 77.

[37] Ben Evans, *Space Shuttle Columbia: Her Missions and Crews* (Chicester, U.K.: Praxis Publishing Ltd., 2005), 102 and Young with Hansen, 244.

as MS 2 (Allen and Lenoir finally became the first from the group of 1967 scientist-astronauts to fly, fifteen years later). Thus Lenoir invented the job of flight engineer during launch. He trained in the SMS seat behind Brand and Overmyer, looking over their shoulders at the instrument panel, making sure they avoided any mistakes, and assisting them with malfunction procedures. Lenoir also took the lead in training for the first EVA in shuttle history, since there was no MS 3 on this mission.[38] Allen trained to spend the launch in the middeck below his crewmates, which did not contain any window for him to look outside or any means for him to influence the launch. On the thirty-sixth launch of American astronauts, this was a new reality: an astronaut who was only a passenger during launch. "I've requested of my shipmates that they not send any radio transmissions or ask any questions on the intercom that end like, ‘What was that?,’" Allen joked of his passenger role. But he did have two major responsibilities in orbit: photography and the primary payload for the mission, the first two satellites ever launched from a Space Shuttle. *Columbia’s* payload bay carried two communications satellites called *Satellite Business Systems (SBS) 3* and *Anik C3*. Allen also went to the flight deck to serve as flight engineer during reentry, though for future missions the same crewmember would serve in this capacity during both launch and reentry.[39]

Lenoir recalled that the deployment of the two satellites required unprecedented simulations. First, “We had to look at the schematics, work up the procedures, work

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[38] William B. Lenoir, Interviewed by Rebecca Wright, November 18, 2004, Staunton, Virginia, http://www.jsc.nasa.gov/history/oral_histories/LenoirWB/LenoirWB_11-18-04.htm (accessed January 4, 2017).

[39] Joseph P. Allen, Interviewed by Jennifer Ross-Nazzal, March 18, 2004, Washington, D.C., http://www.jsc.nasa.gov/history/oral_histories/AllenJP/AllenJP_3-18-04.htm (accessed January 4, 2017).

with the customer for how it goes." With the shuttle then envisioned as the sole means of launching all satellites into orbit, executives at companies like *SBS* and *Telesat Canada* (responsible for the *Anik C3*) wanted assurance that crews could deploy their equipment safely. The *STS-5* crew became the first to work with customers for that purpose. The two satellites would go into orbit mounted on a table. Then the table would spin, the crew would point the orbiter in the right direction, and at the right point of the orbit the crew would release arms holding the satellites to the tabletop. Springs would then release the satellites, which spun free to be propelled into a geosynchronous orbit (about 22,500 miles high) by a kick motor. In this orbit, the satellites could remain in the same position in the sky as seen from Earth and allow people to communicate via signals from them. Unmanned rockets had taken care of this for the past two decades. But with *STS-5* came a new role for astronauts: what Lenoir called an "Orbital Launch Director." The crew would observe issues like the condition of the spinning table, the satellite, and solid rocket in the kick motor and would have the final say in whether to make a deployment or not. In this era before the Tracking and Data Relay Satellites (TDRS) were launched, the crew was only in contact with Mission Control for a portion of each orbit and this made their trained judgment even more essential. Lenoir remembered that an Air Force major named Chuck Shaw served as SimSup for the deployment simulations, inserting malfunctions that tested the crew's knowledge of the mission rules.[40]

The first operational mission of the shuttle era succeeded over five days in

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[40] Ibid and Interview with Lenoir.

November 1982, with one exception. The fan in Allen's suit failed, forcing a cancellation of the EVA that he and Lenoir had planned to make. But the crew proved a point with the successful deployment of *Columbia's* two satellites. Training had given the astronauts the knowledge of the mission rules that guided the satellite deployments. They had spent numerous hours in the SMS rehearsing the procedures to deploy the satellites on the basis of this knowledge. Thus when they reached orbit, Brand, Overmyer, Allen, and Lenoir had the mental and physical flexibility to make sure the satellites were in good condition to deploy safely or carry them back to Earth if they detected a malfunction and determined this was not possible. Unmanned vehicles could carry satellites into orbit safely, as they had in the past and would in the future. But unmanned vehicles did not have the trained judgment that astronauts brought to orbit beginning in 1982.[41]

But could shuttle astronauts prove their flexibility during EVAs? Answering this question fell to Story Musgrave and Don Peterson on *STS-6*, the maiden voyage of Space Shuttle *Challenger*. After Allen and Lenoir lost their chance due to the suit fan malfunction, Peterson received a call from NASA Associate Administrator Jim Abrahamson asking if he and Musgrave could pioneer this activity and accepted. The late notice challenged the two astronauts to become proficient in time, but Musgrave had already spent about four hundred hours in the WETF as he worked to assist engineers in the development of EVA suits. Peterson recalled making 15 to 20 pool sessions of his own. When he stepped outside *Challenger's* airlock on April 7, 1983, he remembered

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[41] Hitt and Smith, 142-149.

vividly how the experience differed from the pool. When he turned upside down in the WETF, he felt the weight of his body on his head and shoulders. But when he did so in space, he experienced the more comfortable feeling of floating inside his suit.[42] Despite the painful experience of training in a pool where his suit pressed on him, the WETF held great value as a tool for maneuvering around the orbiter's massive payload bay. No astronaut had ever translated across such a massive vehicle, as the orbiter exceeded *Skylab* in length (122 feet) and height (58 feet). Over four hours and seventeen minutes, he and Musgrave translated to *Challenger's* aft bulkhead using handrails, translated with a massive object, inspected the payload bay, tested their mobility in the suits, and tested their ability to use tools. Peterson found that the gloves were rather stiff and recommended hand exercises as another form of training. But by carrying out all of these tests, the men verified the ways by which trained humans could exercise physical flexibility in performing unprecedented work outside a spacecraft. It was only a taste of the wonders to come in the 1980s, 1990s, and 2000s.[43]

The *STS-7* mission presented another set of firsts. Sally Ride became the object of worldwide attention as the first woman selected to an American space crew, but remained largely shielded from the media. Except for a couple days of interviews, she stayed focused on her training. She understood that even if outside attention focused almost entirely on her, she was part of the first crew of five and needed to integrate herself into this team as effectively as possible rather than fixate on herself. As MS 2,

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[42] Donald H. Peterson, Interviewed by Jennifer Ross-Nazzal, November 14, 2002, Houston, Texas, http://www.jsc.nasa.gov/ history/oral_histories/PetersonDH/PetersonDH_11-14-02.htm (accessed January 7, 2017).

[43] *STS-6 Space Shuttle Program Mission Report* (Houston, TX: JSC-19020, 1983), 16.

she had a busy schedule that demonstrated how this generation of astronaut needed to become a "jack of all trades." She spent many hours in ascent and reentry simulations with Commander Bob Crippen and Pilot Rick Hauck, to test her flight engineer skills. She then rotated to orbit simulations with fellow Mission Specialists John Fabian and Norm Thagard, to rehearse the main events of the mission: the deployment of two communications satellites and the first ever deployment and retrieval of a spacecraft from the orbiter: the Shuttle Pallet Satellite (SPAS). The crew would become the first to undertake "proximity operations," meaning fly *Challenger* in formation with SPAS and then rendezvous with it so Ride could grapple it with the robotic arm and place it back in the payload bay. Thus the Systems Engineering Simulator and Manipulator Development Facility became vital for the first time in shuttle training. Throughout all of this, Crippen played a vital role as the first person to be assigned to a second shuttle mission, as he could share advice with the four TFNG rookies on his crew.[44]

Those training tools received vindication after *Challenger* soared to orbit on June 18, 1983, though with one other first that was far less welcome. "The simulators did a really good job of simulating the robot arm," Ride explained. "It felt very comfortable and familiar." Though the MDF and SMS cost money to build and maintain, these devices helped her grapple SPAS and avoid hitting a far more expensive satellite. She did not need to make any major recommendations to the instructors about the arm. Meanwhile, Crippen and Hauck maneuvered about a thousand feet away from SPAS and

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[44] Sally K. Ride, Interviewed by Rebecca Wright, October 22, 2002, San Diego, California, http://www.jsc.nasa.gov/history/oral_histories/RideSK/RideSK_10-22-02.htm (accessed January 7, 2017) and Interview with Crippen.

made a rendezvous without impinging on it with thruster fire. On the strength of their SES training, they placed *Challenger* in position for Ride to operate the arm and made observations of the orbiter autopilot that they returned for engineers.[45] The mission did include the first really notable mistake by a shuttle crew. The two satellites in *Challenger's* payload bay included boosters that would take them to a higher orbit. But the crew threw the heater switches for the boosters out of sequence. They had always done this in simulations, when the order did not matter. But on the real ship, they did not realize that engineers had rewired these switches to perform a secondary function. Their switch throws caused the early extraction of several pins on the tabletop where the satellites were mounted. Flight controllers commanded the pins back in, but the incident demonstrated that training teams needed to inform crews about situations like this one. A more serious mistake could be life threatening.[46]

STS-9 broke still new ground in training. The last shuttle mission of 1983 was the first focused primarily on scientific research, the first to be international in scope, and the first to carry Payload Specialists. In these ways, the effort to prepare for and execute this mission was a precursor to many shuttle voyages through the 21st century and then the ISS currently in use. *Columbia* carried the *Spacelab* module in its payload bay. In accord with a 1973 agreement, an 11-nation consortium headquartered in Paris, France called the European Space Agency (ESA) had responsibility for this facility. *Spacelab* gave the crew a shirtsleeve environment 13.5 feet in diameter, so that

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[45] Interview with Ride and Interview with Crippen.

[46] Hitt and Smith, 161-162.

astronauts could utilize their research skills to the greatest extent since the *Skylab* crews a decade later, only this time with improved technology and in more disciplines.[47] The laboratory had gloveboxes, furnaces, and freezers with which to conduct 73 experiments in life sciences, technology, astronomy, solar physics, Earth observation, plasma physics, and materials processing. The goal of conducting all of them in a 10-day mission proved so daunting that Abbey assigned the first six-person crew to *STS-9* and split them into two groups. Commander John Young (making the sixth and last flight of his legendary career), MS 2 Bob Parker and PS 1 Ulf Merbold would work on a 12-hour shift as the Red Team. Then they would rest and be replaced with the Blue Team for the next 12 hours: Pilot Brewster Shaw, MS 1 Owen Garriott, and PS 2 Byron Lichtenberg.[48] The training process thus had to answer some vital questions. Could the astronauts adjust to working with Merbold and Lichtenberg? Could they convince a group of Principal Investigators from around the world of their research abilities? Could they adjust to working in separate shifts?

Merbold and Lichtenberg were a breed apart from the other four members of their crew, or anybody who had yet flown aboard an American spacecraft. All of those people had been Americans, but Merbold was born in East Germany before defecting to West Germany just before the construction of the Berlin Wall and earning a Ph.D. at the University of Stuttgart. ESA selected him as a candidate to fly as a PS aboard the shuttle in 1978, on the strength of his work at the Max Planck Institute for Metals Research in

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[47] Hale, et al., 14-15 and 71-73.

[48] Evans, 71.

Stuttgart. Lichtenberg was an academic at the Massachusetts Institute of Technology who had been working on vestibular experiments for *Spacelab* since 1978. Neither of these two had gone through the rigorous process to be selected into the astronaut corps or work full time at JSC. One might assume that consternation would therefore develop between the two and their four crewmates, but Garriott confirmed that this was not the case. “Are they really motivated to fly, can they hold their own, and so forth?” he asked. “And I very quickly found out that yes, indeed, they could. They were on par with all of us…and after thirty years, they’re still some of my best friends.”[49] The six formed a strong team during simulations from the fall of 1982 to launch in November 1983, while Merbold and Lichtenberg received the training they needed. “The PSs were of course trained in the basics of the shuttle in terms of ingress, egress, personal hygiene, communications, photography equipment, and more,” Pete Beauregard explains. “They would train with the entire crew less than the MSs, as PSs did not participate in training that largely involved flying the shuttle. They would participate in training that covered several consecutive hours of the mission timeline in which they had responsibilities,” especially the *Spacelab* experiments for Merbold and Lichtenberg.[50]

The international training also marked a new departure in American human spaceflight. When Garriott had trained to fly on *Skylab*, he had mainly stayed in Texas. But meeting with the Principal Investigators for much of the *Spacelab* materials processing work required traveling to Europe, while learning about an electron beam

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[49] Hitt and Smith, 199-200.

[50] Beauregard, E-Mail Correspondence with Author.

emission experiment required traveling to Japan. The crew also went to MIT for life science experiments and the Universities of Michigan and Utah for Earth observation studies. This allowed the astronauts to see the researchers in their home laboratories, which contained the equipment the crew would use in space, and better understand the experiments by observing and asking questions. The pattern of intense travel to become a "jack of all trades" in operating science experiments follows astronauts to this day.[51]

Simulations took another step forward during *STS-9* training to reflect the plan for around the clock research. The crew worked together in the SMS during training for dynamic flight phases, like all previous crews, but split up during training for *Spacelab* operations. Young and Shaw operated the vehicle in the SMS while the other four went to the Payload Crew Training Complex at MSFC in Huntsville, complete with a mockup of *Spacelab*. These sessions lasted up to twelve hours, so that Young and Shaw could solve complex malfunctions such as a Main Bus failure while the four scientists solved problems with the experiments. Another simulation close to launch lasted three days, so that the crew could rehearse coordinating their actions with flight controllers in Houston and scientists at the Payload Operations Control Center in Huntsville. This differed from previous missions in that crews now had more time with which to speak to controllers and scientists. The TDRS deployed during *STS-6* could now relay voice and data signals between an orbiter and the ground, eliminating gaps in coverage. This meant astronauts needed to rehearse coordinating their work with Principal Investigators

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[51] Owen K. Garriott, Interviewed by Kevin M. Rusnak, November 6, 2000, Houston, Texas, http://www.jsc.nasa.gov /history/oral_histories/GarriottOK/GarriottOK_11-6-00.htm (accessed January 8, 2017).

who could speak with them far more often than earlier crews, while more data flowed to Mission Control.[52]

The first *Spacelab* mission demonstrated that the flexibility of shuttle astronauts extended to science as well. These six crewmembers who had trained for years to advance scientific knowledge and for the past year to do so on this specific flight could perform work that automatons could not. This included communicating with scientists in real time thanks to the TDRS, replanning observations, and fine-tuning their instruments.[53] Parker even used a screwdriver to repair a reel on a damaged high speed data recorder and freed stuck film on a camera. University of Naples physicist Luigi Napolitano therefore argued, "One of the biggest lessons we have learned this week is that nobody has the right to ask anymore why a man is needed up there. You know, without those guys, the mission would have been a failure the first day."[54] When the mission ended on December 8, the flight had downlinked more data in 10 days than *Skylab* had during six months of crew operations: two trillion bits of raw data. As Commander, Young argued that the training done in collaboration with MSFC was essential in making this possible.[55] Thanks in part to the success of *STS-9* and the lobbying of NASA Administrator Jim Beggs, President Ronald Reagan challenged the space agency to build Space Station *Freedom* in his 1984 State of the Union address.[56]

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[52] Young with Hansen, 247-248.

[53] *Science in Orbit: The Shuttle & Spacelab Experience, 1981-1986* (Washington D.C.: NASA NP-119, 1988), 44.

[54] John Noble Wilford, "Shuttle Will End Space Trip Today," *New York Times*, December 8, 1983 and John Noble Wilford, "Astronaut Mends Mapping Camera," *New York Times*, December 5, 1983.

[55] David M. Harland, *The Story of the Space Shuttle* (Chicester, U.K.: Praxis Publishing Ltd., 2004), 34 and Young with Hansen, 250.

[56] See "Spacelab to Space Station: A Legacy of International Cooperation," October 11, 2002, *SpaceRef*, http://www. spaceref. com/ news/viewpr. html?pid=9503 (accessed January 8, 2017).

Young and Shaw benefited from training in different ways than their four crewmates, with one rather embarrassing lesson learned. While the other four worked on *Spacelab*, these two spent most of the mission on the flight deck, where their expertise guided them in making a record 216 maneuvers of *Columbia*, making 15,000 keystrokes to do so. They had also trained to operate a new device called the Shuttle Portable Onboard Computer, one of the first laptop computers ever used, which displayed *Columbia's* track on a world map. The malfunction filled simulations they had received over the past year received vindication on the last day of the mission, when two of the ship's computers failed. "I turned to jelly," Young recalled, but he and Shaw worked on computer recovery procedures just as they had in the SMS. If the computers had failed to prevent a sideslip angle of just a couple of degrees from occurring, *Columbia* and crew would have been lost. *Columbia* did return safely, though when Young made an input on the hand controller, the orbiter responded differently than it had during his training. Software engineers had tightened the gains on this device prior to flight, so that when he moved the controller to pitch the nose to a touchdown and brought it back into detent, the nose stopped pitching unexpectedly. When he finally did bring the nose down, the landing gear smacked unexpectedly hard onto the Edwards runway. "The lesson was, never let them change the software in the flight control system without having adequate opportunity to train for it," Shaw explained, a lesson that benefited future Commanders.[57]

Shuttle astronauts delved even further into their expanding bag of tricks in 1984,

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[57] Young with Hansen, 249-252 and Hitt and Smith, 204-205.

guided by outstanding training facilities. First came *STS-41B*, during which Bruce McCandless and Bob Stewart became the first to venture outside the orbiter and use the MMU backpack to fly free of their ship. "It was supposed to be an early-day Buck Rogers flying belt, if you know what I mean, except it didn't have the person zooming real fast," explained Vance Brand, the *STS-41B* Commander. "It used cold nitrogen gas coming out in spurts to thrust you around at about one or two or three miles per hour."[58] McCandless was an ideal candidate to pioneer the backpack, as he had participated in a backpack experiment performed by the *Skylab 3* crew inside that space station and represented the astronaut office in MMU development. But zipping through space in his own portable spacecraft for *STS-41B* required training to precisely control his motion. He and Stewart would have to climb out *Challenger's* airlock, don their backpacks in the payload bay, and then control their position (forward/backward, left/right, up/down) with their left hands while controlling rotation with their right hands. They could travel up to 450 feet away from the orbiter by this method, a far cry from the tether method of EVAs. McCandless and Stewart developed their proficiency by receiving 18 hours of training with an MMU simulator at the Martin Marietta plant. The simulator featured a large-screen television display to mimic what they would see in orbit and a carriage that moved across six degrees of freedom. One journalist who used the device wrote, "The precision flying features were demonstrated by my ability, with only a few minutes

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[58] Hitt and Smith, 170.

practice, to maneuver the unit safely in close proximity to fixed objects."[59]

On February 7, McCandless and Stewart maneuvered over 300 feet away from *Challenger* and back again on the strength of their training in the MMU simulator and WETF. The two astronauts reported that the increasingly intense schedule of their WETF sessions especially helped them, with runs scheduled at a rate of one per month early but then ramped up to one per week. The crew did make some recommendations for WETF training as well: that the television showing the astronauts working in the pool should be controllable by their fellow astronauts working in the SMS, and that underwater helmet lights and flashlights were needed when working in poorly lit areas. Although training in this facility was an evolving process based on recommendations from each crew, McCandless and Stewart needed the experience to confidently maneuver farther away from an orbiting spacecraft than anyone before. Brand and Pilot Robert "Hoot" Gibson also trained to not let the spacewalkers move so far away from *Challenger* that orbital mechanics separated them. "We didn't want to come back and face their wives if we lost either one of them up there," Brand explained. The astronauts and their equipment did their jobs well, paving the way for future astronauts to use MMUs to retrieve and service satellites hundreds of feet away from an orbiter.[60]

This happened on the very next mission, *STS-41C*. This crew called themselves the Ace Satellite Repair Company, because for the first time they would demonstrate one

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[59] Anne Millbrooke, "More Favored than the Birds," in Pamela E. Mack, ed., *From Engineering Science to Big Science: The NACA and NASA Collier Trophy Research Project Winners* (Washington, D.C.: NASA SP-4219, 1998), 314-315.

[60] "EVA Lessons Learned," 2-47 to 2-50 and Hitt and Smith, 170-173.

of the shuttle's most unique capabilities: servicing of another spacecraft by skilled astronauts on an EVA. The *Solar Max* satellite had been in orbit since 1980, but the fuses that powered the attitude control electronics failed and thus the satellite could not remain stable enough to return data for scientists studying the Sun. Engineers at the Goddard Spaceflight Center in Maryland had attached a grapple fixture to the satellite prior to its launch, however, so the *STS-41C* crew could service it.[61] The mission proved instructive from a training perspective, because more than any crew before them these astronauts would have to draw on a bevy of devices to do this. Commander Bob Crippen and Pilot Dick Scobee trained to rendezvous with the *Solar Max* satellite via the SMS and SES. They reported that they doubled their actual training over original projections and that this "was necessary and should be included in future training plans." MS 1 Terry Hart trained to deploy the Long Duration Exposure Facility (LDEF), grapple *Solar Max*, and then redeploy it after his crewmates serviced it using three devices: the SMS, SES, and MDF. The training forced him to "develop good techniques with smooth inputs," according to the flight crew report.[62]

Meanwhile, James van Hoften and George "Pinky" Nelson trained to service *Solar Max* at several facilities. They traveled to Denver for one session per month on the MMU Simulator, which they reported had excellent fidelity and prepared them well for malfunctions during the last three months before launch. The only recommendation they had was for the device to simulate the effect of MMU plumes on *Solar Max*. They

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[61] Hitt and Smith, 175.

[62] "*STS-41C* Flight Crew Report," 1984, Box 13, Folder 1, Sally K. Ride Collection, Smithsonian National Air and Space Museum, Chantilly, VA, 20-21.

also complimented the Martin Marietta staff on their response to the astronauts' technical questions. Their WETF sessions in Houston allowed them to rehearse maneuvering to *Solar Max* and operating their two power tools to service the satellite. The pool contained a mockup of the satellite that the two astronauts called "outstanding" in fidelity. Since their procedures were frozen and all training hardware was on hand six months before the flight, van Hoften and Nelson had time to climb into the pool and build their confidence in performing their unprecedented feat. After making one-G walkthroughs with flight hardware, KC-135 aircraft flights, Air Bearing Floor simulations, and even one trip to the Goddard Spaceflight Center to look at flight tools, the two men were finally ready.[63] Although these astronauts would not travel as far away from Earth or receive as much public acclaim as the *Apollo* crews, the volume and variation of their training demonstrated how far the profession had advanced since the 1960s and 1970s.

The actual task proved worthy of the training, especially because it required the crew to overcome adversity. On April 8, van Hoften and Nelson donned their MMUs and maneuvered about 200 feet from *Challenger* to *Solar Max*. But when Nelson tried to grasp the tumbling satellite with his Trunnion Pin Acquisition Device, he failed to do so three times. "I could see myself spending the next six months in Washington explaining why we didn't grab that satellite," Crippen explained. But the *Solar Max* flight controllers send commands to stabilize it and cleared the way for another attempt. On April 11, the entire crew placed their training in dynamic operations to the test in a

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[63] Ibid, 21-23.

way none of their predecessors had done. Not only had the five astronauts trained individually in numerous facilities, they had developed the teamwork to implement their training so it would flow together. Crippen and Scobee maneuvered *Challenger*, Hart grappled *Solar Max* with the robotic arm, and Nelson and van Hoften went to work on replacing the satellite's attitude control system and electronics. This required the fine work of undoing electrical connectors, not easy using bulky gloves, but the WETF sessions had prepared them for this.[64] Hart redeployed the satellite the next day and it resumed its study of the Sun. "The most obvious reason that the EVA repair activities went smoothly was the extensive amount of training," the crew argued in their report.[65] Since they had prepared so thoroughly, they demonstrated the value of sending humans into space. No robot of the time could have performed the fine work of Nelson and van Hoften, or adapted to the problems of their first EVA. Launching another satellite to replace *Solar Max* would have cost $235 million, but sending trained astronauts to replace it cost far less.[66]

The shuttle program went through a more troubling first that summer that related to training. The *STS-41D* crew of Hank Hartsfield, Mike Coats, Mike Mullane, Steve Hawley, Judy Resnik, and Charlie Walker was just four seconds away from the maiden launch of *Discovery* when the main engines shut down (one of them had failed a valve position check). The controllers at KSC's Launch Control Center then noticed a fire on the pad, caused by hydrogen fuel that had collected around the engine nozzles following

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[64] Hitt and Smith, 176-179.

[65] "*STS-41C* Flight Crew Report," 22.

[66] Hitt and Smith, 179 and Young with Hansen, 261.

the shutdown. They considered having the crew leave *Discovery*, climb into baskets attached to a slide wire, and evacuate the pad. But neither these astronauts nor any others had trained to ride this Emergency Egress System, which factored into the controllers' decision not to give this order. Hartsfield remembered this as a "bad situation" given that he and his crewmates were attached to millions of gallons of rocket fuel. This one ended well because the pad deluge system combated the fire and the crew managed to leave the pad via the elevator. But the incident prompted the first test of the slide wire system with a human occupant (astronaut Charlie Bolden) and additional training in "safing" the orbiter following aborts. This lack of preparedness prior to this twelfth shuttle flight contributed to the rigorous preparation that subsequent crews had in dealing with launch aborts.[67]

Discovery did make its maiden voyage from August 30 to September 5, 1984, with the crew deploying three satellites and making a valuable demonstration of the value of Payload Specialists. Charlie Walker was the first commercial PS, being an engineer at McDonnell Douglas in St. Louis who specialized in a shuttle electrophoresis experiment for which this company provided the apparatus. He had taught crews of four previous shuttle flights in operating this experiment, but McDonnell Douglas manager Jim Rose pressed shuttle program manager Glynn Lunney to fly Walker himself on a mission. Lunney agreed, meaning Walker spent over a year training for *STS-41D* and set a standard for future Payload Specialists. NASA and McDonnell Douglas negotiated so that he could spend part of each month at the company plant in St. Louis but two

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[67] Hitt and Smith, 236-237.

weeks of each month training at JSC. Shuttle managers decided that he did not need to train on equipment he would not use in flight, which saved time and money. But he did enter *Discovery* trained to respond to emergencies and to make more of a contribution to electrophoresis research than a Mission Specialist who could only spend a small portion of the training sequence focusing on this experiment. He then operated it for more than 100 hours on this mission, which proved so successful that he flew again on *STS-51D* and *STS-61B* over the next two years. Walker believed his experience proved that spaceflight training had reached a point where a "working passenger" could safely fly after following an abbreviated training syllabus.[68]

The last two missions of the year offered strong evidence that the state of training remained strong. *Challenger* roared into space in October on the *STS-41G* mission, carrying the first crew of seven: Bob Crippen, Jon McBride, Kathy Sullivan, Sally Ride, David Leestma, Paul Scully-Power, and Marc Garneau. Five of the astronauts were making their first missions, and after being assigned in January they had gone through the first half of the training sequence without their Commander. Crippen did not join this crew until after finishing his *STS-41C* mission.[69] But the other astronauts proved they could become proficient while working with their Commander only for a few months. When Crippen did join them, the crew benefited from having a Commander in training for his fourth mission. Training Team Lead Ted Browder exclaimed, "With Crippen there, we had a harder time fooling the crew. Crippen has seen about every

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[68] Ibid, 231-235 and Chris Dubbs and Emeline Paat-Dahlstrom, *Realizing Tomorrow: The Path to Private Spaceflight* (Lincoln: University of Nebraska Press, 2011), 75.

[69] Cooper, *Before Liftoff*, 22

training scenario there is!"[70] Browder also monitored the entire crew through all of their mistakes early in the process until feeling that the seven gelled in their last, three-day integrated simulation. He believed that the crew was ahead of the flight controllers in reacting to simulated malfunctions, the best sign that they were ready to fly.[71]

But as always, the mission itself offered the best evidence of the state of training. Browder observed all eight days from the Simulation Control Area, because his job involved evaluating simulations in light of the mission results. The results pleased him. He noticed that the crew remained ahead of Mission Control and remained gelled, as the astronauts helped each other and almost always retained their patience in the face of problems. McBride had no prior space experience, but when Browder asked him if anything had happened during the mission that he wished he had examined more thoroughly in simulations, he said no. This was a quite a statement, because *STS-41G* tested their problem solving abilities.[72] The crew had difficulty folding a radar antenna in *Challenger's* payload bay, which they needed to do before Sullivan and Leestma made an EVA. But Ride improvised, setting the robotic arm down on one of the antenna leaves and pushing down on it far enough that it latched. More urgently, when the crew deployed the Earth Radiation Budget Satellite (ERBS), only one of the two solar arrays unfurled. Ride had to shake the array free with the arm, moving the arm joints at a faster rate than mission rules allowed. The crew had simulated both of these problems in advance, contributing to their success and demonstrating again that trained humans

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[70] Ibid, 114.
[71] Ibid, 197.
[72] Ibid, 223-225.

could solve problems that automatons could not. "Clearly, missions played into training as much as training played into planning and into missions; missions, training, and planning formed a tight, interlocking triangle," Henry Cooper rightly argued in his book about the mission.[73]

The year ended with *STS-51A*, one of the program's greatest triumphs in terms of EVA training. Spacewalkers Joe Allen and Dale Gardner went through at least fifteen major exercises in the WETF to rehearse the capture and retrieval of two communication satellites that had been launched on *41B* earlier that year but failed to reach their proper orbits. Allen and Gardner trained to maneuver to them with their MMUs, grapple them using a capture device they called a "stinger," and return them to Earth in *Discovery's* payload bay. But in orbit that November, the tool designed to fit on top of the *Palapa B2* satellite did not fit. Anna Fisher used the robotic arm to maneuver the satellite around to where Allen could grab it and hold it while Gardner then attached a large clamp to the bottom of the satellite. According to Allen, Gardner "did the impossible" in pulling off this feat thanks to his strength, persistence, and training over the next two hours, then placed the *Palapa B2* in its payload bay cradle. The same qualities allowed him to retrieve the *Wester VI* two days later. On November 16, *Discovery* landed carrying these two satellites so they could be relaunched and sent to proper orbits.[74] Astronauts had again accomplished what no automaton could have achieved and the crew was quick to credit several features of their training in making this possible. Allen

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[73] Ibid, 206-240.

[74] Young with Hansen, 265 and Hitt and Smith, 192-194.

had already trained in the WETF for *STS-5*, which gave him a head start in tackling *STS-51A* simulations; this was a factor to consider in selecting crews for challenging future missions. He and Gardner also benefited from Pilot David Walker's training to choreograph their EVA movements; this allowed Gardner to concentrate on his manual tasks while Walker choreographed. Finally, hands-on experience with actual flight hardware on the ground helped the spacewalkers handle the satellites in orbit.[75]

The shuttle entered the busiest year in its entire history when 1985 began. The nine missions produced a bonanza of satellite deployments and scientific research that enhanced America's status as a space superpower, but not without several burdens on training. The first new burden was the need to train for classified Department of Defense missions. The *STS-51C* crew of Ken Mattingly, Loren Shriver, Ellison Onizuka, Jim Buchli, and Gary Payton needed to keep all details of their training secret prior to their launch on January 24. The astronauts wondered whether this would work given that successful astronaut training had always depended on open communication in addressing any issues that needed to be resolved. The training personnel placed cipher locks on all facilities used by this crew and reserved a room for storing classified documents and making classified telephone conversations. When the crew needed to travel to a contractor associated with the mission, they had to fly equal time in day and night, use unpredictable routes to reach destinations, and check into hotels using cover names. "But within that classification shell, so to speak, the system was able to find a way to operate and operate very efficiently, I thought," Shriver argued. Though details

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[75] "EVA Lessons Learned," 2-52 and 2-54.

about exactly what the crew did remained classified, he and Mattingly have said in interviews that the information necessary to become skilled crewmembers reached them without jeopardizing national security. The crew is believed to have deployed a *Magnum* satellite used to monitor military transmissions from the Soviet Union and China, enhancing American intelligence in the latter days of the Cold War. The shuttle flew several more classified missions through 1992, producing what Mattingly called "spectacular" results worthy of the secretive training procedures.[76]

Another burden was the training of more outsiders who served as Payload Specialists. Saudi prince Sultan bin Salman Al Saud flew aboard *Discovery's STS-51G* mission in June after receiving training to take photos of his home nation and operate some experiments that were part of NASA's Getaway Special program (payloads contributed to a mission by educational, foreign, commercial, or U.S. government entities). The other six crewmembers trained with him to help him with setup for his camera work and experiments. Although the crew featured five Americans, one Frenchman, and one Saudi prince, the astronauts did not find any friction develop between them during their training or mission. Training helped the crew avoid the kind of tension that would have placed a damper on the image NASA wanted to project.[77]

Two other shuttle crews trained with sitting U.S. Congressmen, who only had especially brief exposure to the usual regimen astronauts went through. Utah Senator Jake Garn had about ten thousand hours of flight experience as a naval aviator when he

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[76] Hitt and Smith, 222-228.

[77] Ibid, 56.

lobbied James Beggs for a flight, making him a natural choice in terms of training. He was only selected to the *STS-51D* crew a few months before launch and had to fly to JSC for training on weekends while serving as a Senator in Washington, D.C. on weekdays. Garn's presence did spark some grumbling in the Astronaut Office, but Commander Karol Bobko praised his willingness to work with the crew in understanding shuttle operations and participating in simulations. He could also draw upon veteran shuttle travelers Bobko and Charlie Walker to learn about aspects such as weightlessness, eating, sleeping, or emergency procedures.[78] Florida Representative Bill Nelson had a similar experience with the *STS-61C* prior to his flight in January 1986, except that he was a lawyer who did not have Garn's aviation experience. His crewmate "Pinky" Nelson remembered that he faced a steep learning curve in just a few months, "but that didn't stop him from trying, and I think he knew what his limitations were. He wanted to jump in and help a lot of times, but just didn't have the wherewithal to do it, but worked very hard and was incredibly enthusiastic."[79] The decision to give flights to Garn and Nelson is questionable, given that the shuttle remained a dangerous vehicle and their minimal training did not prepare them to make a major contribution to a vital area like EVAs, robotic arm operation, or science research. But according to their crewmates, they did prove a person could live safely on the shuttle and respond to potential emergencies with just a few months of training.

Even as politicians took up seats, the list of malfunctions on shuttle flights made

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[78] Ibid, 247-248.

[79] Ibid, 271-272.

painfully clear that the vehicle remained experimental and in need of skilled crewmembers. An external tank door motor, payload bay door latches, flash evaporator system, fuel cells, thermal protection tiles, and RCS heaters, regulators, and thrusters all suffered damage during 1985 flights alone.[80] During the *STS-51F* launch on July 29, one of the three main engines shut down when a temperature sensor incorrectly indicated that the fuel turbine discharge temperature exceeded the limit. If this malfunction had happened thirty-two seconds earlier in the ascent, Commander Fullerton would have had to make an abort landing at a site across the Atlantic Ocean. Fortunately, *Challenger* was high and fast enough that he could perform the much easier Abort to Orbit. He confirmed with Mission Control on this abort mode, rotated the Abort Selector switch to ATO, pushed a button, and watched in relief as the vehicle reached a lower orbit than planned but still high enough to perform an eight day *Spacelab* mission. This event lent credence to the malfunction filled simulations that tested the resolve of Commanders, Pilots, and Mission Control. The latter especially applied in this case, because flight controller Jenny Howard told the crew to throw a Main Engine Limits switch. This inhibited the shutdown of further engines, which could have happened since other sensors were malfunctioning, and possibly the loss of the vehicle and crew. Her success in making this call just in time was a tribute to the simulations and instructors followed up by discussing this particular switch with later crews, as Andy Foster remembers.[81]

Other incidents that cropped up during the flood of 1985 missions proved the

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[80] Young with Hansen, 267-268.

[81] Ibid, 268 and Foster, E-Mail Correspondence with Author.

value of having trained Mission Specialists. The best example came during Garn's *STS-41D* mission. After the crew deployed a satellite called SYNCOM IV-3, the spacecraft sequencer failed to initiate. The crew scavenged about *Discovery's* cabin to construct two "flyswatter" like devices that flight controllers thought an astronaut could use on an EVA to flip a switch to start the sequencer. This required Commander Karol Bobko and Pilot Don Williams to rendezvous with the satellite, Jeff Hoffman and David Griggs to step outside the orbiter and attach the two devices to the robotic arm, and Seddon to operate the arm. The crew unfortunately found that flipping the switch did not solve the problem, but controllers traced the satellite's troubles to an electronics issue and the *STS-51I* crew repaired it later that year. The point here from a training perspective was that the crew had the ability to improvise from the skills they had developed for several years as astronauts. The crew had not even done a rendezvous simulation for several months and had to rely on instructions sent to them via teleprinter, but their skills went beyond what they had simulated for just this mission. "This was all done just with the skills that the crew had been trained with generically," Payload Specialist Charlie Walker explained. "And yet we pulled it off; the crew pulled it off expertly, did everything, including throwing the switch."[82]

The most frightening malfunction of the year took place at the end of that same mission. When Bobko brought *Discovery* to the Kennedy Space Center runway on April 19, he was making the fifth landing at this facility but the first with crosswinds that could affect it (the several runways available at Edwards were wider, meaning there was

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[82] Hitt and Smith, 249-251.

less concern about crosswinds there). Even with a modest wind speed of about 9 miles per hour, Bobko had to apply differential braking to keep the vehicle on the centerline. The differential loads stressed the landing gear so much that one of the tires blew out, another eroded, and one of the brakes jammed. Bobko did bring *Discovery* to a safe stop, but if the tire failure had happened earlier, the vehicle could have swerved into the Florida scrub rather than rest safely on the runway. His actions lent much credence to STA and VMS training, because he had rehearsed landings in these simulators that could mimic the conditions he faced when his life depended on keeping *Discovery* on a 300 foot wide runway with crosswinds.[83]

As crewmembers applied their training to the myriad of vehicle malfunctions, they also gained a clearer understanding of what their future had in store near the end of 1985. Jerry Ross and Sherwood Spring made two EVAs outside the new orbiter *Atlantis* during the *STS-61B* mission to experiment with assembling structures in space. While riding on the robotic arm, the men simulated maneuvering a truss segment, running an electrical cable through one, and repairing one. Ross confirmed that the experience yielded data about in-space construction that helped the engineers working on Space Station *Freedom*. But one problem needed to be solved before astronauts could build a space station: the WETF was not large enough to train them for this. “In the facility we had when we built the ACCESS truss, we could only build like one and a half bays before it started sticking out of the surface of the water,” Ross said. “And the EASE experiment, when we did it, basically our backpacks of our suits when we were at the

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[83] Harland, 41.

top of the structure were right at the surface of the water. So if you're going to build anything that's anywhere close to being big on orbit, that wasn't going to get it." *STS-61B* had helped lay the foundation for the demise of the WETF and installation of the NBL, although Congress did not approve funds for the new training facility until the 1990s.[84]

Although the performance of the astronauts remained exemplary throughout the nine flights of 1985, one question that bears consideration is whether the rapidly expanding flight rate placed too much of a burden on crew training. When asked today, Pete Beauregard argues that the processing of the shuttles at KSC was a far greater concern than training crews. But he does admit, "Higher flight rates were challenging in various aspects. From a training standpoint these were usually related to competition (not literally) for specific training facilities, or the ability to develop a computer simulation of a new payload with the most desired timeframe before launch. Also, simulation time was generally prioritized by how close a given crew was to flying. The further out your flight was, the more late night sim sessions there would be. The main effect on training was usually the availability of the flight specific simulation configuration for each mission as per the desired training schedule. That sometimes had little effect as some missions were almost copies of previous missions, allowing the use of a prior flight simulation configuration early in the training flow. But sometimes this had significant impact. The high flight rate also resulted in more rookies on some crews. As the training lead for *STS-61B*, my team affectionately referred to the crew as

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[84] Hitt and Smith, 265-268.

‘Brewster and the kids.’ Brewster Shaw, as Commander, was the only one on the seven person crew to have previously flown except Payload Specialist Charlie Walker. Interestingly, my training team somewhat reflected the crew as the team was also mostly rookies. As Lead, I had previously led the training for *41C*, but three of the other four team members were training their first crew. Again, a reflection of a very busy time.”[85]

One group that considered this question and gave a discouraging answer was the Rogers Commission that investigated the Space Shuttle *Challenger* accident. The group noted that during the 1984 to 1986 period, crews generally trained over a 25 week period. The first 14 of those weeks consisted of standalone training using software loads for other missions, while the last 11 consisted of integrated simulations with the flight specific software and SMS configuration. As Beauregard remembers today, attaining that flight specific content was a bottleneck toward the goal of attaining a high flight rate. A trend began with the *STS-51I* mission in summer 1985 towards a late start of that content arriving and the integrated training phase beginning. The trend worsened until the crews of the two 1986 missions, *STS-61C* and *STS-51L*, began this phase three weeks late. This placed a burden on the astronauts, flight controllers, and instructors who needed to train, to the point that these people worked at least 60 hours per week during the last few weeks before launch. This ran the risk of sending tired crews into orbit and having tired controllers to support them. “It was not a pace we could sustain forever and

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[85] Beauregard, E-Mail Correspondence with Author.

we knew it," ascent instructor Foster comments when asked about this today.[86]

The Rogers Commission pointed to other bottlenecks toward a high flight rate as well. About the SMS itself, the report read, "It has been a constant source of problems throughout the entire program. Today, the facility computers and equipment are old and obsolete." A study by JSC training personnel concluded that the SMS could not support more than 12 to 15 flights per year and even then needed funding for equipment upgrades and maintenance. About the STA, the report noted that only three of these vital training tools for Commanders and Pilots were available, which also placed a limitation on the number of flights per year. Nonetheless, the original flight manifest for 1986 called for NASA to fly 15 missions and more in future years, overriding the recommendation of that JSC training study.[87] The concern about this extended not just to government investigators, but also to the astronauts themselves. "Had we not had the accident, we were going to be up against a wall," Hank Hartsfield commented. "For the first time, somebody was going to have to stand up and say we have got to slip the launch because we are not going to have the crew trained."[88] Though the astronauts successfully avoided any serious mistakes during 1985 missions, this could not continue if the trend toward increasingly compressed training and serious malfunctions on the actual missions continued. It was just one more reason, along with the infamous SRB O-Rings, that expectations for the Space Shuttle exceeded what was realistically possible as

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[86] William Rogers, et al., *Report of the Presidential Commission on the Space Shuttle Challenger Accident* (Washington, D.C.: GPO, 1986), Volume II, Appendix J, J-26 to J-28 and Foster, E-Mail Correspondence with Author.

[87] Rogers, J-26 to J-28.

[88] Cooper, *Before Liftoff*, 252.

January 1986 began.

After Representative Nelson's *STS-61C* flight aboard *Columbia,* which overcame four launch delays to fly successfully from January 12 to 18, the much anticipated Teacher in Space mission was next. President Reagan had announced in 1984, "I'm directing NASA to begin a search in all our elementary and secondary schools and to choose as the first citizen passenger in our space program, one of America's finest, a teacher." Out of about 11,000 teachers who sent completed applications to NASA, a selection committee of seven decided in July 1985 on a New Hampshire social studies teacher named Christa McAuliffe. She traveled to JSC in September to meet the rest of the *STS-51L* crew, already assigned in January: Commander Dick Scobee, Pilot Mike Smith, MS 1 Ellison Onizuka, MS 2 Judy Resnik, MS 3 Ron McNair, and PS 1 Greg Jarvis. The crew planned to take *Challenger* on a six-day flight to deploy the second TDRS satellite, deploy and retrieve a Spartan astronomical spacecraft to study Halley's Comet, and perform some middeck experiments while McAuliffe taught two lessons from orbit to a worldwide television audience. Their well documented training offers another window into how crews rehearsed for missions during the busiest phase in the history of the Space Shuttle.[89]

The training sequence largely met expectations and resulted in a well-trained crew, despite the schedule pressure. During the standalone sessions from L-37 to L-9 weeks, the five crewmembers who were not Payload Specialists even exceeded the

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[89] Grace Corrigan, *A Journal for Christa: Christa McAuliffe, Teacher in Space* (Lincoln: University of Nebraska Press, 1993), 97-100 and John Noble Wilford, "Teacher is Picked for Shuttle Trip," *New York Times*, July 20, 1985.

number of hours planned for them to spend on various training courses. This meant that a lesson took longer than planned or a crewmember repeated a lesson, which instructors encouraged if astronauts deemed this necessary. Scobee and Smith spent 478 and 482 hours, respectively, on courses ranging from orbiter systems, to ascent, to orbit, to entry, to crew systems, to the Inertial Upper Stage (IUS) that would propel the TDRS into its geosynchronous orbit, to payload deployment and retrieval, to proximity operations with the Spartan, to rendezvous with the Spartan. Resnik had the next greatest training load as the flight engineer, 467 hours, because she would have to assist Scobee and Smith in the flight deck with those last three areas. Onizuka and McNair did not have those responsibilities, so they trained for just 281 and 332 hours, respectively. These two did have the extra burden of training for an emergency EVA. Jarvis and McAuliffe trained for just 74 and 53 hours, respectively, with the bulk of them focused on crew systems such as the galley or sleep stations. The flight specific SMS training began at L-9 weeks and the integrated simulations at L-7 weeks, with the crew reaching a high of 34 hours in simulations with flight controllers during the week before launch. The crew and controllers worked together on three simulations to deploy the TDRS, one to deploy Spartan, and two to rendezvous with Spartan. Even the team of TDRS controllers in Las Cruces, New Mexico, the IUS controllers at the Air Force Satellite Control Facility in Sunnyvale, California, and the Spartan engineering support personnel took part in these grueling 12 hour simulations, to make them as realistic as possible.[90]

Thus when the crew traveled to Florida, each of the seven could feel comfortable

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[90] Rogers, et al., Volume II, Appendix J, J-13 to J-17.

that their training had met the standard that had worked very well thus far in the shuttle program. They had withstood compression in their training schedule resulting from the slips in the *STS-61C* launch and their own, and as a result had worked as many as 70 hours per week during December and January. But because of their strong work ethic and the fact that there were no radically new tasks planned for this 25th shuttle mission, they still managed to meet the training time allotted for them.[91] Yet there was one issue they were not prepared for at all: the effect of cold weather on the SRBs that would take them into orbit. Morton Thiokol engineers knew about the problem of O-Rings failing to contain hot gases from their analysis of previous flights, as documented in the infamous teleconference with NASA managers on the night of January 27. The tradition dating back to Alan Shepard's *Mercury* flight had been to keep astronauts in the loop on critical issues such as this. This was normally part of an astronaut's preparation for flight, but the *STS-51L* crew knew nothing about it. One can only guess how Scobee would have reacted to this controversial safety of flight issue. "If I had known these things, I would have made them aware, that's for damn sure," Chief Astronaut John Young recalled.[92]

Thus on January 28, *Challenger* lifted off with seven crewmembers highly trained to respond to emergencies but entirely unaware of a fatal flaw. The crew actions were normal through Scobee's call "Roger, Go at throttle up" seventy seconds into the launch. They did not report any abnormal readings from the instrument panel, nor did

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[91] Rogers, et al., Volume I, 13-15.

[92] Young with Hansen, 275.

flight controllers notice any such readings on their consoles. Even if they did, the Rogers Commission concluded that no abort would have been survivable during those seventy seconds.[93] Then Mike Smith said, “Uh oh,” presumably either in response to an instrument panel reading or the sheet of flame that he would have seen across his window. The evidence indicates that the crew survived the breakup of *Challenger* that took place right at that moment. This gave them a chance to implement their emergency training. Investigators found that three of the four astronauts sitting in the flight deck had their Personal Egress Air Packs (PEAPs) turned on. They also found that several switches on Smith’s side of the cockpit had been moved from their launch positions. Since lever locks protected these switches, the only way for this to happen was for Smith to have moved them. Thus one can form an image of what likely happened in those agonizing seconds. The cabin went dark when *Challenger’s* crew compartment broke apart from the rest of the vehicle. Dick Scobee tried to make calls to Mission Control and manually guide the vehicle, but the radio system and the hand controller no longer worked. Smith flipped switches in an effort to restore electrical power and solve these problems. Ellison Onizuka and Judy Resnik activated their PEAPs, then one of them reached forward to activate Smith’s. Two minutes and forty-five seconds after the breakup, the crew compartment slammed into the Atlantic Ocean and killed all seven onboard.[94]

The lesson of the *Challenger* tragedy from a crew training standpoint is very

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[93] Rogers, et al., Volume I, 18.

[94] Young with Hansen, 274-275 and Mullane, 245-250.

different from the lesson usually cited about the tragedy. Engineering students to this day learn about the tragedy as a lesson in managers failing to heed the warnings of qualified engineers who knew about the O-Ring sealing problem, due to the pressures of groupthink and of meeting a schedule. Schedule pressure did have a direct effect on training, as noted earlier. But the astronauts had prepared for the flight in an exemplary manner in spite of this. Though the Rogers Commission investigators looked for every piece of evidence concerning why the tragedy had happened, the report read, "The flight crew preparations for *STS-51L* were typical and satisfactory and had no effect on the accident."[95] Even when placed in an impossible situation, the crew rapidly went to work troubleshooting the problem before either loss of consciousness or the ocean impact. Fellow astronaut Mike Mullane even wondered if he would have had the presence of mind to reach forward and assist another crewmember with PEAP activation. The lesson from a training standpoint was that a crew could take proper actions even when at the end of a grueling work schedule and when confronted with a shocking, catastrophic event. The crew needed situational awareness to react properly to this. Though no one will ever know exactly how the astronauts reacted, the evidence supports the conclusion that they reacted as a well-trained crew with situational awareness should. Thus even in a national tragedy, one positive lesson emerged.[96]

Over the next few months, the Rogers Commission members (including Sally Ride and Neil Armstrong) developed a list of recommendations for the future of the

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[95] Rogers, et al., Volume II, Appendix J, J17.

[96] Mullane, 275.

shuttle program that had a direct effect on training. Four of them stand out as especially applicable. The report called for the use of more astronauts in management positions. Astronauts who had served in these positions in the past "brought to their positions flight experience and a keen appreciation of operations and flight safety." This would help prevent a repeat of the situation where Scobee's crew had been unaware of the SRB O-Ring flaw. The report also read, "NASA must establish a flight rate that is consistent with its resources." A reduced flight rate meant the shuttle could not meet the lofty expectations originally placed upon it, but also meant instructors could stop compressing the crew training process. This might have resulted in tired and inadequately trained crews if the shuttle had made all fifteen missions planned for 1986. Related to this recommendation, the report argued that the shuttle should no longer be used as the only launch vehicle capable of taking payloads to space. If unmanned launch vehicles returned to launching satellites, this would also reduce the number of missions for the shuttle to accomplish and reduce the burden on crew training. The report also called for NASA to develop a crew escape system for the shuttle. Astronauts had trained to use such a system from *Mercury* through the *STS-4* mission, when ejection seats had been eliminated. If *Challenger* had carried a bailout system, a strong person sitting close to the middeck hatch (like Ron McNair) might have been able to escape after the crew compartment broke apart from the rest of the vehicle. If post-*Challenger* crews were trained in the operation of such a system, they would have a better chance of surviving a similar event.[97]

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[97] Rogers, et al., Volume I, 198-201 and Young with Hansen, 275.

In June, the Rogers Commission delivered the report to President Reagan and the onus fell on JSC personnel to make the improvements that would help ensure the *Challenger* seven had not died in vain. "The findings and recommendations presented in this report are intended to contribute to the future NASA successes that the nation both expects and requires as the 21st century approaches," the commission members declared.[98] By the summer of 1987, NASA could report on the successful implementation of the four recommendations noted above, as well as a redesigned solid rocket motor. The practice of placing astronauts in management positions and trusting their judgment on safety issues, which remains very robust today, was already well underway by 1987. James Adamson, Charlie Bolden, Bob Crippen, Fred Gregory, Rick Hauck, Bryan O'Connor, Sally Ride, Brewster Shaw, Dick Truly, Paul Weitz, and John Young were already in these positions. A Flight Rate Capability Working Group, which included a representative from the JSC training division, met in 1986 and 1987 to determine how many shuttle missions could realistically fly per year. The end result was a program that never again flew more than eight missions in a year, thus removing the burden of heavily compressed training that pre-accident crews had withstood. The shuttle became only one of the vehicles counted on to send payloads to space, not the sole launch capability. Another piece of good news came with the approval of a replacement orbiter for *Challenger*, which eventually became *Endeavour*. Finally, the space agency reported on the several options under consideration as a crew escape system: ejection seats, tractor rocket extraction of seated crewmembers, bailout through

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[98] Rogers, et al., Volume I, 201.

the bottom of the orbiter, and tractor rocket ejection through the side hatch.[99]

Meanwhile, the instructors in JSC's training division were already back at work by the summer of 1986. The Astronaut Office contained about ninety members, so the instructors were busy providing generic and proficiency simulator training at a rate of 110 hours per week. Instructors and astronauts alike felt emotions ranging from anger to guilt to depression at this time, even as the report made clear that the training process had not contributed to the *Challenger* tragedy. Many wondered what they could have done to prevent the loss of their colleagues and made use of the counseling services offered to them. Ted Browder remarked that the instructors had forever lost their sense of innocence in preparing shuttle crews for emergencies. But instructors and astronauts each understood that *Columbia*, *Discovery*, *Atlantis*, and the replacement orbiter had many missions ahead of them that required crewmembers capable of utilizing skills honed during training. None wanted Dick Scobee, Mike Smith, Ellison Onizuka, Judy Resnik, Ron McNair, Greg Jarvis, and Christa McAuliffe to be the last people to "slip the surly bonds of Earth" aboard a Space Shuttle that had shown so much promise.[100]

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[99] Rogers, et al., Volume VI, 32, 72-75, and 62-70.

[100] Cooper, *Before Liftoff*, 249-257.

CHAPTER XIV

STS: "WE ARE TRAINING TO FLY IN OUTER SPACE!"

"It was a beautiful day, and I remember watching the birds go by and just looking out at the tranquil scene," David Hilmers reflected. Two years and eight months after the fiery destruction of *Challenger* and seven of his colleagues, he stood at the same Launch Pad 39B where the tragedy had happened, ready to return America to space. He paused to think about the scenic Florida landscape and the journey he had taken to get here. The *STS-26* crew—Commander Rick Hauck, Pilot Dick Covey, and Mission Specialists John Lounge, David Hilmers, and George "Pinky" Nelson—had been assigned to fly *Discovery* in January 1987, meaning they were one of the best trained crews in the history of American spaceflight. The training process had delivered spectacular results over the last quarter of a century, but the onus had fallen on these five astronauts and their instructors to prove they had heeded the lessons learned from the *Challenger* tragedy in preparing for spaceflight. Several elements of their training differed from the busy days of 1985 and 1986.[1]

Ascent instructor Andy Foster remembers that one change made the process easier in the post-*Challenger* era. As explained in the NASA report on the implementation of Rogers Commission recommendations and as Foster remembers today, "The loss of two or three SSMEs (contingency aborts) has always been

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[1] Rick Houston, *Wheels Stop: The Tragedies and Triumphs of the Shuttle Program, 1986-2011* (Lincoln: University of Nebraska Press, 2013), 15-20.

recognized as a potential event for any shuttle launch, and manual piloting procedures were in place to cover these engine failure cases." But after the accident, "In those cases where piloting techniques are critical, with small tolerance for errors or deviations, automatic techniques are being evaluated for incorporation into the onboard software." Foster confirms that whereas the effort to do this had been "ad hoc" before the accident, afterwards "the program provided funding for procedure and database development and expansion, and the addition of that to crew procedures and training. The crew procedures for aborts were eventually automated, which didn't affect the number of lessons but did affect the amount of manual flying within each lesson that we trained."[2] Making the aborts automated resulted in safer vehicle operations and freed astronauts from having to train for the manual aborts that Foster remembered as "brutal." This was one way that the accident and the Rogers Commission that investigated it had a direct effect on subsequent crew training.

Another way was the new escape system. After rejecting several options based on performance, schedule, or budget, engineers decided in 1986 on an escape pole. If an orbiter suffered a catastrophic problem while in controlled gliding flight, below about 50,000 feet, a post-*Challenger* shuttle crew had procedures to follow that could result in their surviving the loss of the vehicle. They would gather in the middeck, equalize the pressure of the middeck with the outside atmosphere, pyrotechnically jettison the side hatch, and manually deploy an escape pole to extend 9.8 feet downward. Then each astronaut, one by one, would attach the parachute harness they would be wearing to a

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[2] Rogers, et al., Volume VI, 63 and Foster, E-Mail Correspondence with Author.

lanyard on the pole and slide down on a path that took them under the orbiter's left wing, allowing them to descend to a gentle landing by parachute. Engineers tested this system on an Air Force C-141B *Starlifter* aircraft during the spring of 1988, then added it to the orbiters along with a new inflatable escape slide for use during ground evacuations.[3] Mike Mullane remembered that many astronauts considered this escape system inadequate, and as it turned out the system could not prevent the one remaining disaster in the shuttle program (the *STS-107* crew was over 200,000 feet high, leaving them with no chance to use the escape pole). But all astronauts needed to train with this system in the very unlikely case that it would become needed during a mission.[4]

Training for use of the escape pole was linked with one other element of training for and executing missions that returned in the post-*Challenger* era: pressure suits. During the pre-*Challenger* era, only the first four shuttle crews had worn suits. But NASA physiologists decided that astronauts should return to wearing suits to provide protection during emergencies. If an orbiter cabin lost pressure, the suits would keep them alive. If they had to use that escape pole to bail out over an ocean, the suits would also keep them alive while they were bobbing around in cold water and waiting for rescue forces to arrive. The David Clark company thus developed the Launch and Entry Suits (LES). The suits contained not only a means of life support for loss of cabin pressure, but also a parachute pack, a life raft, a survival radio, a strobe light, a signal mirror, a flare kit, motion sickness pills, and a water pouch assembly for use after bailing

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[3] Dennis R. Jenkins, *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Shuttle* (Washington, D.C.: NASA SP-2011-595, 2012), 383-384.

[4] Mullane, 271.

out of an orbiter. The suits were also orange to enhance their visibility by rescue forces. Tests at the Naval Air Development Center showed that the suits could protect astronauts for up to three hours in 40 degree Fahrenheit water, meaning they could indeed save lives. Thus along with training to bail out of the vehicle, astronauts needed to train with the suits that would protect them after they did this. This took the form of training to don and doff the suits as well as wearing the suits in the SMS so astronauts could understand the reach and visibility restrictions that came with wearing them. Jim Bagian, an astronaut who eventually flew two missions, performed a study of this prior to *STS-26* and found a reduction of forward and overhead reach capability, but considered this offset by the survival potential the suits offered.[5]

Astronauts tied together their training with the escape pole and the suits by going to the WETF and later the NBL. John Glenn recalled what this training entailed after his famous return to space as a Payload Specialist on the *STS-95* mission in 1998. “We had about a two hour session in which they laid out on the table all of this equipment and showed us exactly how you work all the different parts of it,” he explained of the survival gear included with the LES. Then came a trip to the pool to rehearse using this equipment. The pool contained a mockup of the side hatch and pole on a platform above the water. The instructors hoisted the astronauts about ten feet above the pool, so they could use the pole and then rehearse falling toward the water as they might one day have to do during a bailout. This “gives you an impact not too different than you would have if you came down in the parachute,” Glenn explained. “You actually inflate your life

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[5] Jenkins, 384-398 and Beauregard, E-Mail Correspondence with Author.

vest before you hit the water. And after you hit the water, of course, you go under and have to come back up again to get in your life raft. For safety's sake, they have a half-dozen frogmen in the pool who are watching everything you do underwater so that they can make sure that you're absolutely safe. And they coach you a little bit also, if you're doing something wrong. We were in the pool and the life rafts for the better part of an hour getting all the equipment out and checking it out and how to use it. It was a lot of fun in the pool and it was excellent training." Though Glenn was only there to make his one flight as a PS, career astronauts had to go through this process every two years to remain flight eligible during the post-*Challenger* era.[6]

In addition to less manual flying in the simulator and more work with new equipment such as the escape pole and pressure suits, Pete Beauregard remembers one other new element of training beginning with the return to flight on *STS-26*. "They also added, at least for a while, a few range safety simulations. These would include the Air Force range safety personnel at Cape Canaveral that had the responsibility to initiate the self-destruction of the shuttle stack in flight if they determined a major malfunction similar to *Challenger* occurred. In these simulations, the SimSup included a malfunction that would result in the shuttle stack deviating from the planned flight path such that people on the ground were in danger. The malfunctions required for this had to result in both the need to issue a self-destruct signal and allow the crew time to execute a fast separation of the orbiter from the ET/SRB stack (which contained the destruct devices).

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[6] "Training Journal Kept by John Glenn," March 7-April 15, 1998, Box 77, Folder 17, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

Typically the SimSups picked an onboard computer guidance malfunction or one or more stuck engine nozzle gimbals as the issue that required the crew and range safety personnel to do this." In the moments after the *Challenger* catastrophe had happened, the two SRBs flew along uncontrolled trajectories away from the fireball. The Range Safety Officer had thus given the self-destruct signal to the SRBs. The memory of this tragedy alerted SimSups to train for the possibility of another disaster. Though there was no point in simulating exactly what had happened to *Challenger*, because there was no chance of crew survival, the simulation Beauregard describes tested the abilities of astronauts and controllers.[7]

New technology allowed one more training innovation during the post-*Challenger* years: the Personal Computer. "PCs were becoming more portable, they're smaller, not the big mainframes, not the huge contraptions they would use to run simulators," explained Lisa Reed, who joined JSC shortly after the tragedy. Thus she and the other instructors began advocating for astronauts and flight controllers to learn about the Space Shuttle via Computer Based Training. Today, a person interested in learning a task can go online and watch a YouTube video. But during the late 1980s and early 1990s, the instructors used a PC to drive a videodisc (a precursor of today's DVDs) that pulled up pictures, graphics, and video. This allowed astronauts, beginning with the 1990 ASCAN class, to learn shuttle systems less expensively than sitting with an instructor in a simulator. In yet another way, the march of technology had taken training

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[7] Beauregard, E-Mail Correspondence with Author.

a step beyond that enjoyed by the *Mercury*, *Gemini*, and *Apollo* astronauts.[8]

The post-*Challenger* era also featured much more of a slow and steady approach to the training and execution of missions than just before the tragedy. This was true for vehicle processing, as *Discovery* underwent more than two hundred modifications at KSC from 1987 to 1988. Whereas orbiters had gone from landing to rollout to the pad in as few as twenty-five days before the tragedy, afterwards engineers always took at least ninety days to do this. This was also true for training, as the first post-accident crew began their simulator sessions nineteen months before a mission that was one of the simplest in shuttle history: deploy a TDRS, perform some middeck experiments, and come home. Thus Rick Hauck, Dick Covey, John Lounge, David Hilmers, and "Pinky" Nelson had the luxury of time in making sure they prepared as thoroughly as possible. The five attended many briefings on the post-accident changes to the training process, then steadily ramped up their SMS training once the simulator was equipped with a software load similar to and then identical to their mission profile. Then came training with the TDRS payload, the IUS that would take it to orbit, and the emergency EVA Lounge and Nelson might have to make. Rick Bush had the honor of serving as their Training Team Lead, with Dudley Long serving as their training manager, Steve Messersmith specializing in computers and navigation, Darrel McGregor in systems, and Bill O'Keefe in control and propulsion. Through all of this, engineers aided training by performing maintenance and restoration of the SMS. As in the case of *Apollo 1*, the

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[8] Lisa M. Reed, Interviewed by Jennifer Ross-Nazzal, May 15, 2015, Houston, Texas, http://www.jsc.nasa.gov/ history/oral_ histories/ ReedLM/ReedLM_5-15-15.htm (accessed January 23, 2017).

downtime after a fatal accident allowed engineers to improve the quality of simulations. On September 29, 1988, *Discovery* returned America to space and the five *STS-26* crewmembers accomplished every mission objective until their landing four days later.[9]

The first post-accident missions focused mainly on deploying payloads for scientific or national security purposes, and the onus fell on the astronauts to make sure they were trained to correct any problems that might emerge with this. Whether the payload was the *Magellan* probe to Venus, the *Galileo* probe to Jupiter, the *Hubble Space Telescope*, or the many classified reconnaissance satellites, SimSups made sure they were informed about payload malfunctions prior to the mission so they could test astronauts' and flight controllers' knowledge about the proper course of action. By the time the real mission began, this placed flight directors like Milt Heflin in a mindset where he expected an emergency to take place anytime.[10] The fact that crews and flight controllers went into a mission in this battle hardened state aided them in solving the glitches that unsurprisingly cropped up on a vehicle as complex as the orbiter or its payloads. The crew of *STS-30* (the mission that deployed *Magellan* in May 1989) became the first to replace a failed computer with a spare, performing an in-flight maintenance procedure that astronauts had long trained to accomplish.[11] When the *STS-31* crew deployed *Hubble* in April 1990, with Steve Hawley having trained to grapple the telescope with *Discovery*'s robotic arm and maneuver it out of the payload bay with

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[9] "Crew Begins Training for *STS-26* Mission," February 20, 1987, *Space News Roundup*, http://www.jsc.nasa.gov/history/roundups/issues/87-02-20.pdf (accessed January 18, 2017).

[10] Houston, 33.

[11] *STS-30 Space Shuttle Program Mission Report* (Houston, TX: JSC-50702, 1989), 3.

very little clearance on either side, the second set of solar arrays abruptly stopped unfurling. Bruce McCandless and Kathy Sullivan had trained to crank the array out by hand and went to the airlock, only to find that their services were not needed because controllers had found a work-around for the computer glitch that hampered the unfurling of the arrays. The tradition of training giving crews the flexibility to increase the chances of mission success was gathering strength.[12]

But one element was missing from those first two and a half years of flying after the accident: EVAs. This changed on the *STS-37* mission in April 1991, when Jerry Ross and Jay Apt went outside *Atlantis*. The *Compton Gamma Ray Observatory* the crew deployed had a high gain antenna that would not deploy, meaning scientists could not receive the data they wanted. Using the robotic arm or firing the orbiter's RCS thrusters to shake the antenna free did not work. But Ross and Apt had trained for hours in the WETF for just this possibility, so they could demonstrate their flexibility in aiding mission success in a way a purely automated mission could not. Ross simply pushed the antenna several times until it shook free. Though some astronomers have criticized the value of human spaceflight over the years, those who studied the observations that this spacecraft made over the next nine years could only do so because a knowledgeable crew had deployed its antenna in orbit, using the skills gathered during WETF training. Ross recalled that *STS-37* was a much needed milestone in training for and executing EVAs, because JSC had lost much spacewalking expertise in the six years since the last one had happened. Both astronauts and WETF instructors had left the space agency in

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[12] Houston, 97-98.

large numbers. Yet “we needed a very robust team to be able to address the looming EVA wall that was coming at us to build the station,” Ross explained. If the elected officials in Congress could see evidence of effective EVA operations, they would be more willing to support funding for Space Station *Freedom*, a project still in planning stages at the time.[13]

One of the most impressive feats along those lines, and instructive from an EVA training standpoint, came on the maiden flight of *Endeavour* in May 1992. The seven members of the *STS-49* crew had spent a tremendous amount of time training to coordinate their actions for the EVA retrieval of an *Intelsat* satellite that had failed to achieve geosynchronous orbit. Rick Hieb and Pierre Thuot had been assigned to perform the EVA, so they had rehearsed their motions in the WETF with a mockup of the satellite. One innovation in their training was the Errant Satellite Simulator (ESS), a low cost facility designed for this mission. The other five crewmembers had tasks to perform as well, so Tom Akers trained to choreograph the spacewalkers’ actions as the intravehicular crewmember, Bruce Melnick trained to operate the robotic arm, Kathy Thornton trained to operate the onboard cameras, and Commander Dan Brandenstein and Pilot Kevin Chilton trained to fly *Endeavour* in formation with the satellite. The seven placed that teamwork to the test successfully in orbit on May 10, but still encountered a snafu. In the WETF, Thuot had placed a capture bar on the bottom of the satellite and it had always remained stationary so he could grab the satellite by the bar and return it to the payload bay. But when he did this in orbit, *Intelsat* quickly wobbled

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[13] Ibid, 44.

out of control. Over two EVAs, he did not succeed in placing the capture bar on *Intelsat*. Would all of this crew's training go for naught? Melnick suggested an idea: Thuot, Hieb, and Akers should go outside to perform the first ever three person EVA. This way there would be an extra set of hands to control all three axes of the wobbling satellite and grab it by hand. Despite initial reluctance, the flight controllers agreed to the idea.[14]

As usual in the now more than thirty year history of American human spaceflight, the training the crew had done helped them improvise successfully. Thuot, Hieb, and Akers took three hours to maneuver into position and grasp *Intelsat* by hand, then five more to install a motor that took it to the desired geosynchronous orbit. Going through the longest EVA ever to that point (today it is the second longest) was a tiring experience and required delicate work to safely grasp a set of rods on the bottom of the satellite while not slicing open a glove. This would have been challenging in any case, but the training the crew had received underwater made it feasible. When the three men made it back inside *Endeavour*, they were not exhausted because they had trained properly. Other astronauts had gone to the WETF ahead of time to determine exactly where the three spacewalkers would need to position themselves, demonstrating the value of this facility as an on-the-fly training tool as well.[15]

During the post-*Challenger* years in general, the lessons learned from missions that related to training were most pronounced in the area of EVAs. This was especially

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[14] Ibid, 49-50 and "EVA Lessons Learned," 2-53.

[15] Houston, 50-51.

true for *STS-49*, not only due to the *Intelsat* capture but also because Akers and Thornton made another 7 hour, 49 minute EVA to assemble a truss pyramid as preparation for space station assembly. The astronauts returned with a whole host of recommendations. They gave a positive report for the Errant Satellite Simulator in the sense that this facility prepared them to learn the feel of an 8,600 pound mass in rotation, but reported that the sensitivity of *Intelsat* was far greater in orbit than in the simulator. The crew attributed this to the fact that the simulator only operated in five degrees of freedom and recommended upgrading to six degrees. They recommended that future astronauts work at a slow pace during WETF training, always train for tasks with two people rather than one, and always be vigilant in understanding the limits of the realism the WETF could offer. This crew had found that water drag resulted in them coming to a stop in the pool earlier than in space, for instance, which future spacewalkers needed to understand. They also called for their successors to make one pool session per month early in their training and one per week during the last month, to ensure proficiency and conditioning. They made a host of suggestions to improve the WETF itself as well: prompt delivery of training hardware in the pool, prompt delivery of spare pins and bolts with that hardware, prompt upgrading of that hardware with the flight hardware, and a full set of cameras in the pool.[16]

The *STS-54* crew undertook their training with these lessons in mind and made an extensive host of recommendations themselves. The crew of Commander John Casper, Pilot Don McMonagle, and Mission Specialists Mario Runco, Greg Harbaugh,

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[16] "EVA Lessons Learned," 2-47 to 2-55.

and Susan Helms had planned to make a standard TDRS deployment mission. But after the EVA to capture *Intelsat* had taken longer than planned and proved more difficult than WETF training had suggested, NASA managers changed their thinking toward EVAs in general. Despite the euphoria for the improvisation that had overcome those difficulties, the *STS-49* experience prompted the scheduling of an additional EVA on *STS-54* to rehearse basic tasks. Just as their predecessors had during the *Gemini* program, these managers worried that past difficulty posed trouble for the more challenging EVAs ahead (first a *Hubble Space Telescope* servicing mission and then dozens of missions to construct what would soon become known as the International Space Station) and perceived a benefit in going "back to the basics."[17] Thus Runco and Harbaugh spent nearly five hours outside *Endeavour* on January 17, 1993, testing their ability to climb into foot restraints, translate across the payload bay, and handle a bulky object called an Orbital Replacement Unit. Despite encountering some fatigue, the two men proved they had a solid grasp of the basics in advance of the most complex work ever done in space.[18]

Since different astronauts would undertake those feats, Runco and Harbaugh offered much advice for them related to training. This had been one of the objectives of their "back to the basics" EVA in the first place. Many of their recommendations stressed the need to avoid moving too quickly in the WETF, because this only reduced a spacewalkers' body control and efficiency in the pool or in space. Since EVAs lasted

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[17] Harland, 124.

[18] Ibid, 182.

several hours each, astronauts had to work in the daytime and nighttime of each orbit. Thus Runco and Harbaugh recommended training for the reduced visibility of nighttime tasks by placing WETF lights on the orbital day/night cycle. The two men also had a recommendation concerning fitness: future spacewalkers should undertake independent exercise to enhance hand, wrist, and forearm endurance, as this was more crucial than cardiovascular endurance. Some of their recommendations related to the divers who worked with astronauts, such as the idea that divers should impart very small disturbing forces to the water to counter its damping effect on the astronauts' motions. Divers could do too much, though. Runco and Harbaugh recommended not letting divers clear any tether snags, so the astronauts could learn to be aware of their tether and clear the snags by themselves.[19] The JSC training personnel could not implement every recommendation that astronauts like these two made, because NASA had a finite budget allocated for training crews. But several pieces of advice could be quickly implemented because they did not require any spending and information flowed freely among astronauts and instructors.

But throughout 1993, the *STS-61* crew assigned to make the first *Hubble* servicing mission had more than their predecessors' advice to help them train. They had an entirely new training method that drew upon a still young technology. When the *Mercury* astronauts reported for work in 1959, virtual reality was relegated to the pages of science fiction novels. In 1962, cinematographer Morton Hellig did succeed in building a prototype of a bulky machine called *Sensorama* that showed movies while

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[19] "EVA Lessons Learned," 2-46 to 2-55.

engaging the viewer's sense of sight, sound, smell, and touch. But not until the 1980s did entrepreneurs form virtual reality companies in large numbers for training of medical personnel, airline pilots, soldiers, and eventually for the enjoyment of video game players.[20] By 1990, JSC housed a Virtual Reality Laboratory (VRL) where astronauts could wear a headset and see images of the Earth, the orbiter payload bay, and tools they would work with in space. Software developers had written the lines of code for the Dynamic Onboard Ubiquitous Graphics (DOUG) that generated these images.[21] When Kathy Thornton, Tom Akers, Jeff Hoffman, and Story Musgrave began training for the *STS-61* mission, they met with the VRL manager David Homan and pioneered this facility as a crew training device. Astronauts who had trained for EVAs prior to this mission had only worked inside the orbiter payload bay, a mockup of which fit inside the WETF. But *Hubble* was 43.3 feet long, taller than the depth of the WETF, so the training personnel had to cut the telescope mockup in half for pool exercises. This meant the *STS-61* crew needed another method to train to work with *Hubble* in a geometrically correct form and found it in the VRL.[22]

The four spacewalkers and robotic arm operator Claude Niccolier all found several benefits to virtual reality training. First, training in a virtual environment rather than the physical environment of the pool meant there was no limitation on the size of

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[20] Grigore C. Burdea and Philippe Coiffet, *Virtual Reality Technology* (Hoboken, NJ: John Wiley & Sons, Inc., 2003), 3-9.

[21] Neel V. Patel, "Meet DOUG, the NASA Virtual Reality Tech Prepping Astronauts for Spacewalks," April 7, 2016, *Inverse*, https://www.inverse.com/article/13911-meet-doug-the-nasa-virtual-reality-tech-prepping-astronauts-for-spacewalks (accessed January 19, 2017).

[22] Jeffrey A. Hoffman, Interviewed by Jennifer Ross-Nazzal, November 17, 2010, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/HoffmanJA/HoffmanJA_11-17-10.htm (accessed January 19, 2017).

the equipment the astronauts worked with. Second, the virtual environment eliminated a problem associated with gravity while working in the pool. While astronauts were neutrally buoyant in the WETF, when they turned upside down they still felt the uncomfortable effect of gravity when they did so. This was not realistic to spaceflight and there were even issues of astronauts developing shoulder problems due to their hanging in their suits while inverted. In the virtual environment, they could see the same scene they would see in space and even receive haptic feedback to give them the same sense of touch without feeling these physical effects. Third, arm operators like Niccolier could rehearse taking the arm through its various angles while seeing it digitally generated through the headset. As noted in an earlier chapter, robotic arm operations in the WETF suffered from a lack of fidelity. Fourth, the *STS-61* crew found that because the VRL was still a novelty for astronaut training, Homan did not have to answer to the JSC training bureaucracy. He could implement astronaut's suggestions more easily as a result. Astronauts beginning with Hoffman have been quick to point out that virtual reality should not replace neutral buoyancy. The physical environment has remained the best place to rehearse translating from one worksite to another over the last two decades. But as a supplement, Hoffman remembers that the *STS-61* crew felt impressed about the virtues of virtual reality and "a lot of people who came and take a look at it obviously became convinced as well, because it's become a pretty widely used training tool."[23]

The technology has steadily progressed over the last two decades, as seen in the comments of Hoffman and Clay Anderson, an astronaut who flew in 2007 and 2010.

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[23] Ibid and Beauregard, E-Mail Correspondence with Author.

Hoffman remembered that when he trained in 1993, the computers in the VRL were slow enough that he experienced a one-second time lag in using the headset. If he suddenly turned his head to look in a different direction, it took a second for the visual scene to catch up with him. Only one person at a time could use the headset, another limitation in 1993.[24] Anderson comments that by the 21st century, the speed and visual representation of the experience had improved drastically while multiple people could participate. "For a long time in my early training, we did not have good visual models of the Earth, the clouds, the sunrise, and the sunset," he explains. "But if you were to see the VRL today, it would take your breath away how realistic it looks. Just look at the way technology has advanced in virtual reality games over the last ten years. People are puking when they ride a virtual reality roller coaster. That advancement in capability is hugely important because it doesn't take a lot of computer power and doesn't take a lot of money. The whole deal with NASA is to do stuff as cheaply as possible, because it's on the taxpayer dime."[25]

There was a plenty valid reason for the investment of money and time in *STS-61* EVA training, whether in the pool or the VRL. Scientists had found after the *STS-31* crew deployed *Hubble,* the telescope returned blurry images due to a slightly misshapen mirror. The telescope had become a national embarrassment, which only the *STS-61* crew could remedy by taking advantage of the fact that engineers had designed the telescope for human repair in orbit. Only one year earlier, Thornton and Akers had

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[24] Interview with Hoffman.

[25] Clay Anderson, Phone Interview by Author, January 18, 2017.

encountered difficulty in retrieving a communications satellite. It had taken them eight hours just to retrieve *Intelsat* and take it to the orbiter's payload bay. Now this crew would have to maneuver along the largest object any group of spacewalkers had ever confronted and do the delicate work of installing a massive device that would correct *Hubble*'s vision: the Corrective Optics Space Telescope Axial Replacement (COSTAR). If the *STS-61* spacewalkers could not do this, the recent agreement with Russia to build an International Space Station would be for naught. NASA Administrator Dan Goldin even visited them during their training and told them the future of American human spaceflight was in their hands. How could the crew make sure they would not let down the scientific community, the space agency, and taxpayers alike?[26]

The crew relied on three methods: virtual reality, the pool, and visits to Goddard Spaceflight Center. Hoffman remembered that the crew did most of their pool training at the Marshall Spaceflight Center, which featured a larger facility than the WETF. "We'd go down there for a week or so, and it was basically a routine which we'd get right back into the next time we went down," he explained. "You get up early in the morning. We'd all gather around the table. There'd be a model of the Shuttle, *Hubble*, the arm, and the little toy astronauts. We'd go through the entire 'This is what we're going to do,' because we were really trying to choreograph to try to eliminate any wasted motion." Between pool sessions and virtual reality sessions, the spacewalkers were able to rehearse techniques like Hoffman grabbing Musgrave by the boots and feeding him into the telescope. Musgrave then removed components to get access to the

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[26] Houston, 101-109.

rate gyroscopes. He replaced these old units, looked for the holes where the pins for the new units were supposed to go, and installed the new rate gyroscopes. This was only one example, as the crew needed to replace solar arrays, the drive electronics for the arrays, and the Wide Field Planetary Camera as well as install COSTAR. Nobody had ever done work of this complexity in orbit before. The fact that there so many variables at play for the spacewalkers, from what tools to use (there would be about 200 onboard), to how much force to exert, to the effect of daytime and nighttime on their visibility, to how they were restrained, to the coordination of their movements with the arm operated by Niccolier, meant the spacewalkers needed the training. The trips to Goddard also helped because the astronauts could see the real hardware there and could rehearse placing these components into a mechanical simulator of the telescope.[27]

The mission itself was one of the greatest testaments to training in the history of the shuttle program. From December 5-9, 1993 the *STS-61* crew performed an unprecedented five EVAs in as many days. As the *Gemini* program had shown, an astronaut who had not trained for this unforgiving environment outside a spacecraft would become quickly fatigued in translating from one place to another, let alone in doing significant work. Earlier in the shuttle program, the thought of two astronauts opening the doors of a giant telescope, loosening latches, removing electrical connectors, sliding out an old instrument, and installing the refrigerator sized COSTAR in its place had been wishful thinking. This also went well beyond the capability of any robotic mission, underscoring the importance of training astronauts. But since they had done so

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[27] Interview with Hoffman and Houston, 109-115.

time and time again in a realistic ground environment, Thornton and Akers had the confidence to do just that. The four spacewalkers accomplished every task set out for them. After *Endeavour* left the telescope behind, the mirrors in the new COSTAR could relay corrected beams of light to *Hubble*'s scientific instruments and the telescope could awe scientists with vivid photos of distant galaxies. "Of all the programs that I have been associated with, it's the one that was best planned and has been best executed," argued Dick Covey, the *STS-61* Commander.[28] It was the first of five *Hubble* servicing missions (*STS-61* in 1993, *STS-82* in 1997, *STS-103* in 1999, *STS-109* in 2002, and *STS-125* in 2009), each of which succeeded in upgrading the telescope and keeping it in operation.

While *STS-61* was probably the greatest landmark in the evolution of shuttle EVA training, *STS-64* provided another one the following year. Carl Meade and Mark Lee spent nine months training for the use of a backpack called Simplified Aid for EVA Rescue (SAFER). Ten years had passed since the last time astronauts had made an EVA in which they were untethered from an orbiter, using the MMU backpack. Now Meade and Lee trained to use a more lightweight backpack that could move them at up to 10 feet per second through bursts of nitrogen. The idea was that if astronauts became disconnected from their tethers during future *Hubble* or ISS missions, they could maneuver themselves back to their worksite using the SAFER controls secured to their suit torsos. They would have to use just the right amount of thrust and maintain just the

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[28] Houston, 109-115 and Ben Evans, "'You and the Rest': Twenty Years Since NASA's Dramatic *Hubble* Repair Mission (Part 2)," http://www.americaspace.com/?p=46010 (accessed January 20, 2017).

right attitude, which called for training. Doing this in a pool was not practical, so astronauts relied on virtual reality to become proficient. "It was the only way you could train for that," remembers Jim Voss, who became one of the many astronauts to use SAFER while working outside the ISS. The virtual reality training worked well for Meade and Lee when they climbed outside *Discovery* on September 16, 1994, as they performed demonstrations of an EVA self-rescue and precision flying by tracking the robotic arm. Their success helped to further legitimize the use of virtual reality as a training tool.[29]

While spectacular missions like the *Intelsat* repair, *Hubble* repairs, and the SAFER test broke new ground, the shuttle program settled into a routine of scientific research and spacecraft deployments by the early 1990s. Despite the repetition of crew tasks, Pete Beauregard remembers, "Each flight had postflight lessons learned that would also apply to training." He cites two examples of how these lessons learned resulted in updates to the training plan for subsequent missions. One was the need to find a balance between simulations filled with too many malfunctions and too few. "If the training included what might be reasonably expected malfunctions, the training sessions would be pretty boring, and even the crews would complain," he explains. "On the other hand, sometimes the training teams would get a little carried away, and over time multiple malfunction scenarios were scaled back." A second example was the testing of flight rules in simulations. "There were nearly unlimited ways to test these and the training teams were good at finding malfunction combinations that might

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[29] *STS-64* Space Shuttle Program Mission Report (Houston, TX: JSC-08293, 1995), 35.

uncover holes in the flight rules," Beauregard recalls. "Many flight rules were changed over the years. Often this was for very good lessons learned from training sessions, but also from too many unrealistic or smart malfunctions. So that scaled back over the years." Although the four orbiters were typically flying six to eight missions per year by this point, the Space Shuttle program was still experimental. Military aircraft, after all, are not declared operational until after hundreds of flights. Thus the training for and flying of this much more complex vehicle was still subject to revision.[30]

As the missions sent an increasing number of rookie astronauts into orbit, the first time flyers learned from the more experienced astronauts during training. "When you are in a simulator, often there was a group of people with a mix of experience and inexperience and you can learn by watching and talking to them," remembers Jim Voss, who flew his first mission in 1991.[31] This was especially true when Pilots trained for their first missions next to Commanders, who always had the experience of at least one previous mission. "Jim Wetherbee was a mentor to me, especially since it was my first flight and he had flown twice before," explains Eileen Collins of her time training to become the first woman to serve as Pilot in 1995. "To throw out one of the things he taught me, I learned about the value of memorizing certain emergency procedures. I memorized the procedures on my first flight so I could be faster in the simulator."[32] But in the 1990s, the learning from more experienced astronauts became formalized through the Instructor Astronaut (IA) program. "Individuals will be assigned as IAs based upon

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[30] Beauregard, E-Mail Correspondence with Author.

[31] Author Phone Interview with Voss.

[32] Author Phone Interview with Collins.

their experience level, past performance, duty assignment, and availability," read a document belonging to Rick Husband, who was one of them. IAs supported newly selected ASCANs by providing them with technical expertise in spacecraft systems, as well as supporting assigned crews by observing them in the SMS and providing "constructive feedback on the crew's ability to work through problems together and to exercise effective Spaceflight Resource Management." IAs received notice that "No skill is more important than your ability to analyze and appraise crew performance. Your critique to the crew may be either oral or written."[33]

Husband's personal collection contains several examples of the kind of critiques that IAs made. During one simulation, he observed the performances of Bjarni Tryggvason, Nick Patrick, and Clay Anderson. "Training consisted of a prebrief, three entry runs (the first from deorbit through landing, the last two from 200,000 feet), and debrief after each run," Husband wrote. "Bjarni, Nick, and Clay rotated through the MS 1, MS 2, and CDR seats." He then offered a positive evaluation of those he observed: "Clay fully participated in the prebrief and was good about asking questions on the various topics. He had a super attitude toward learning and improving his knowledge. During the sim, Clay did well and had a good feel for the entry profile and events." Husband found himself evaluated as well by IA Bob Curbeam, who made comments on the teamwork of the four crewmembers sitting in the SMS for an entry simulation: "Extremely good at backing each other up—only one instance where this was not done,

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[33] "Space Shuttle Instructor Astronaut Program Instructor's Guide," August 6, 1999, Box 23, Folder 45, Rick Husband Collection, Texas Tech University, Lubbock, TX.

and it cost them dearly. I bet it will never happen again![34] When asked today, Anderson remarks, "Not all astronauts were good instructor astronauts. This was because the competition level was so fierce, especially in the world of EVAs. When you are assigned to a crew, you're not competing anymore. The mission is your total focus and anything you can do to improve yourself or your crewmates to execute the mission is paramount. When you're not assigned, though, there is competition to become assigned. Some astronauts withheld information because they didn't want you to become more qualified than them for that assignment." He does admit, "The majority of astronauts were good people."[35]

Even if some astronauts were less receptive than others to helping less experienced colleagues, the IA program provided two valuable benefits that earlier astronauts did not have. First, the IAs could judge the progress of their colleagues and comment on strengths or weaknesses. Second, the IAs could point out to their colleagues the differences between simulations and flights. Though the JSC instructors were very well qualified, none had actually been in space themselves. Since the IAs did have this experience, they were a valuable resource for the astronauts still waiting for their first flights. "It goes beyond noting the differences, but also helps to highlight the most critical factors to focus on," explains Greg Chamitoff, selected with Clay Anderson in the 1998 class. "A good example might be coping with the glare from the Sun during critical robotics operations. This is not something easy to simulate and isn't typically

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[34] "Instructor Astronaut's Debrief Form," Box 11, Folder 9, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[35] Author Phone Interview with Anderson.

dealt with much in training, but can be critical during actual operations."[36] David Brown, from the 1996 class, had a list of notes containing practical advice along these lines. The advice covered diverse areas, from "Make sure you manifest heavy sweat pants and a heavy sweat shirt with a hood," to "No dry wipes or wet wipes should go in the Waste Containment System," to "The whole rendezvous day seems to go faster than the sims, even with no malfunctions."[37] In short, rookie astronauts could benefit from reading manuals and speaking to instructors but the IAs provided expertise that went beyond those methods.

One other related innovation during the 1990s was the Commander Upgrade Program. All astronauts on the pilot track flew at least one mission as a Pilot before being promoted to Commander for their next mission. Before being assigned as Commanders, these astronauts went through an upgrade program to test their leadership ability. This included SMS sessions with a generic crew that gave the prospective Commander the experience of leading all of these crewmembers. An IA was present to evaluate the Commander during these sessions, with Curbeam being the person who evaluated Husband on September 24, 2001. The idea here was that Commander was the position of greatest responsibility on a crew and prospective Commanders required special attention for this reason. The briefing guide belonging to Husband listed the leadership traits NASA wanted to cultivate through this program. They included, "Know when to be strict," "Admit your mistakes," and "Be disciplined at all times."

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[36] Greg Chamitoff, E-Mail Correspondence with Author, December 26, 2016.

[37] "Notes for Rookies (with an emphasis on PLTs)," Box 27, Folder 7, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA.

The guide also stated that Commanders "are responsible for your crew's training. Work with your training manager to ensure you are getting everything your crew needs and that your training is optimized."[38]

As the program continued through the 1990s, training for Commanders, Pilots, and Mission Specialists alike became more realistic due to simulator upgrades. Clay Anderson saw the progression of the SMS across thirty-two years: from his first experience as a JSC intern in 1981 through his departure from the Astronaut Office in 2013. "In the early 1980s, you were limited by computer size and graphics capability," he explains. "As the graphics capability improved, and computer technology improved, and we had funding to upgrade the simulator, we did. In addition to that, if we were doing projects to upgrade the shuttle avionics capability in the real vehicle, your simulator had to match that upgrade."[39] The upgrades included the simulation of out-the-window visuals, as Eileen Collins remembers from her time as Pilot and Commander. "It never reached what you can get in the real vehicle, as far as clarity and depth perception were concerned," she recalls. "But it did improve over time and I know the simulator personnel spent a lot of time upgrading the visuals."[40] When John Glenn trained for his *STS-95* mission, the same person who had once used a *Mercury* Procedures Trainer that could simulate only a small amount of switches and dials and only a crude representation of out-the-window visuals now used an SMS powered by

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[38] "Commander Upgrade Program Instructor Astronaut Briefing Guide," May 12, 2000, Box 21, Folder 19, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[39] Author Phone Interview with Anderson.

[40] Author Phone Interview with Collins.

computers that could simulate a vehicle several times more complex.

Another alteration to training during the 1990s was the transfer of Space Shuttle operations to a company called United Space Alliance (USA, a hybrid enterprise between the two large aerospace firms Rockwell International and Lockheed Martin). On October 1, 1996, NASA signed a six year, $7 billion contract with USA to turn over critical areas like orbiter processing at KSC and training of astronauts and flight controllers at JSC. NASA Administrator Goldin supported the idea as part of President Bill Clinton's goal of cutting the federal budget and increasing efficiency in government. Though the agreement to entrust a private company provoked worries that safety would be compromised, Space Shuttle Program Manager Tommy Holloway declared that this would not happen. He explained that the contract included incentives based on USA's ability to meet safety goals and that NASA employees would retain the final say in critical flight operations where safety was at risk. The first mission with the program under USA control was *STS-80* in November and December 1996. The all-veteran crew undertook the longest mission in shuttle history (17 days) and returned more data than expected from a Wake Shield Facility and ORFEUS-SPAS satellite, quieting worries about the contract.[41] The crew made minor criticisms about their training in their mission debriefing, such as "Poor headwork in scheduling SMS upgrades" but gave a positive impression overall. The astronauts even commented, "The WETF staff were stars," "David Shaw was a star" in scheduling training activities, and "Martha May was

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[41] Hale, et al., 26 and Warren E. Leary, "Private Contractor to Manage NASA Space Shuttle Program," *New York Times*, October 1, 1996.

a star" in training the crew for photo and TV operations.[42]

As these changes took place, one useful barometer of the quality of training concerns the mistakes astronauts made. Astronauts did make mistakes during simulator sessions, as had been the case since *Mercury*. "As Commander, if we did a simulator session and my crew did everything perfect, I would ask my instructors to make it harder," Eileen Collins explains. "I wanted to see how each crewmember would handle mistakes, how they would recover from them, and how their attitude would be about a mistake. You don't want to make mistakes on orbit, so our philosophy was to make training hard on the ground and force crews into mistakes there so they will be better prepared in space." The record shows that in the actual missions during the busy 1990s, this strategy succeeded very well in eliminating mistakes. Astronauts made silly errors from time to time, such as Collins pushing in a wrong circuit breaker for a ham radio and being unable to contact a school. But when asked today about major errors concerning a mission objective or the safety of an orbiter, she reflects, "Nothing really comes to mind." The record supports the lack of significant mistakes, with one notable exception.[43]

The one exception came during the *STS-87* mission on November 21, 1997. Kalpana Chawla was making her first flight aboard *Columbia*. As the robotic arm operator, she deployed a Spartan spacecraft to make solar observations. But two and a half minutes later, the crew noticed that Spartan had not performed the preprogrammed

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[42] "*STS-80* Office Debrief," January 6, 1997, Box 23, Folder 51, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[43] Author Phone Interview with Collins.

pirouette maneuver they expected. Chawla tried to grapple Spartan, but did not receive a firm capture signal and accidently gave the spacecraft a rotational spin of about two degrees per second. "That snowballed, because Commander Kevin Kregel ended up having to chase down *Spartan* with *Columbia*," recalls Eileen Collins of her colleagues' mission. "He was trying to match the rotation rate of the *Spartan*, which was an extremely difficult if not impossible flying job." Kregel did succeed in bringing *Columbia* close enough that Winston Scott and Takao Doi could perform a seven-hour, forty-three-minute EVA to capture Spartan by hand. But the spacecraft did not return any science data.[44]

An investigation board determined what had happened: Chawla had missed a step in the checklist to turn on Spartan, resulting in the failure of its Attitude Control System. The missed step and the imparting of the spin were the human errors, although the board also blamed the design of the orbiter software by which Chawla deployed Spartan. The software did not give the crew any warnings that they were going to deploy Spartan without completing the activation sequence. The board report recommended that programmers make the software more user friendly and that instructors emphasize similar malfunctions in training.[45] "Kalpana's robotic arm operation had to do with crew coordination," remembers Susan Helms. "I know what she was doing, because I did the same task of capturing a *Spartan* spacecraft (on her *STS-64* mission). I think crew coordination is a lot of what's involved in training and I

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[44] Houston, 208 and Author Phone Interview with Collins.

[45] Philip Chien, *Columbia, Final Voyage: The Last Flight of NASA's First Space Shuttle* (New York: Copernicus Books, 2006), 55-57.

think there was a continuous process of improvement by the training team to improve this. I think that was evident in the shuttle program throughout all the years I spent at NASA."[46] Thus on this extremely rare occasion when a crewmember made a serious mistake, JSC personnel did learn from it. Chawla admitted her mistake and received an assignment to *STS*-107.

The most significant milestone during the 1990s, though, came with the dawn of cooperation between two former Cold War enemies: the Shuttle-Mir program. Although plans for international missions had fallen dormant since *Apollo-Soyuz*, President George H.W. Bush and Vice President Dan Quayle succeeded in reaching out to the new Russian Federation in 1992, the year after the Soviet Union collapsed. The "Joint Statement on Cooperation in Space" that the two nations signed called for Russian cosmonauts to fly aboard the Space Shuttle by 1994 and for the shuttle to then dock with the space station *Mir*. Thus in November 1992, two veteran cosmonauts flew to Houston to undertake shuttle training: Sergei Krikalev and Vladimir Titov. These two knew very well the vehicles they had flown aboard in the past: *Mir* and the *Soyuz* vehicle they had ridden to reach the station. But Krikalev and Titov now had the task of proving they could adjust to the more complex shuttle training, overcome the language barrier, and prove the struggling new Russian government under Boris Yeltsin was right to pursue a cooperative space project.[47]

JSC instructors worked with Krikalev and Titov alone during their first three

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[46] Author Phone Interview with Helms.

[47] Morgan, 5-7.

months in Houston, which meant overcoming the language barrier to teach them shuttle systems and operations. "We, the instructors, spent eight hours a day with them," Lisa Reed explained. This included an exhaustive series of briefings and SST sessions made more difficult by the fact that the instructors spoke to the cosmonauts through translators. If a briefing took one hour to teach an astronaut, it took three hours to teach a cosmonaut. Reed called this "like drinking from a fire hose for them," but Krikalev and Titov "rose to the task and did very well."[48] In February 1993, Krikalev began simulations with the *STS-60* crew: Commander Charlie Bolden, Pilot Ken Reightler, and Mission Specialists Jan Davis, Ron Sega, and Franklin Chang-Diaz. Though these five and the instructors had spent almost all of their lives in a Cold War environment, including Bolden's combat missions in Vietnam, all adjusted to working with Krikalev. The social events the crew attended helped to integrate Krikalev into the American way of life. Krikalev also adjusted to training for a shuttle flight that was much more hectic than his *Mir* flights; the flight plan for every day was laid out in fifteen-minute segments, because the crew only had eight days to perform their scientific research as opposed to the months Krikalev had aboard *Mir*. When *Discovery* roared into orbit on February 3, 1994, he felt well trained to operate the robotic arm, the Space Acceleration Measurement System, and several joint experiments in *Spacehab*.[49]

The next step called for *Discovery* to rendezvous with *Mir*. For the first time in

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[48] Lisa M. Reed, Interviewed by Rebecca Wright, June 19, 1998, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/ Shuttle-Mir/ReedLM/ReedLM_6-19-98.htm (accessed January 22, 2017).

[49] Charles F. Bolden, Interviewed by Sandra Johnson, January 15, 2004, Houston, Texas, http://www.jsc.nasa.gov/history/oral _histories/BoldenCF/BoldenCF_1-15-04.htm (accessed January 22, 2017) and Morgan, 8.

the long history of the Space Shuttle, the vehicle finally had a chance to “shuttle” a crew to a space station. The *STS-63* crew featured Titov, so once again the JSC instructors worked with a Russian while the five Americans spent a couple of weeks in Russia. A group of Americans had begun training in Star City for long duration *Mir* missions by this point (see Chapter 15), so shuttle crews began much briefer training sessions there in anticipation of the day that they would climb aboard *Mir* as well.[50] But the most significant aspect of training for this mission was the rendezvous with *Mir*, the largest spacecraft an orbiter had ever confronted. The momentum and mass of these two vehicles—87 tons for *Discovery* and 103 tons for *Mir*—meant that a small human error could have hazardous consequences when the two were in proximity. Thus the crew spent numerous hours in the SMS and SES, made especially effective by the SFRM techniques that instructors had recently introduced. As Commander, Jim Wetherbee had to fly the vehicle toward *Mir*. Pilot Eileen Collins and MS 2 Mike Foale paid attention to orbiter systems and the ship’s trajectory. MS 1 Bernard Harris worked with a hand held laser that gave navigation data. On future docking missions, the MS 3 would have to prepare the docking system as well. In the course of training for these tasks, all the astronauts learned about SFRM techniques such as maintaining communication discipline with Mission Control, prioritizing failures and analyzing them for impact, and giving fellow crewmembers verbal or visual confirmation that they were cleared to take a critical action. To reduce the chances of the kind of mistake mentioned earlier, two

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[50] Houston, 143-144.

people observed each switch throw or hand controller input.[51]

When *Discovery* reached orbit on February 3, 1995, the training paid off. The crew and flight controllers handled some adversity by stopping a leak in one RCS thruster and shutting off fuel to another leaking thruster. On February 6, this allowed the crew to make a flawless approach to within 35 feet of *Mir,* stationkeep for 15 minutes, and then fly around the station at 400 feet away. The flight provided a strong indication of the effectiveness of the training regimen. Though Wetherbee primarily earned credit for the feat, he had trained as only one component of a team which was well honed by the time they reached orbit thanks to SFRM.[52]

Taking the last step and docking the orbiter to *Mir* during the *STS-71* mission in June called for new training methods. Like past missions, the *STS-71* training team consisted of one lead and four core discipline instructors. But given the complexity of rendezvous and docking, the team included additional instructors in those disciplines as well. Lisa Reed instructed the crew in the Orbiter Docking System, which engineers had just affixed to *Atlantis* and which would need to make hard contact with *Mir*'s docking system. She went to Rockwell International, watched the operation of the docking ring, and then wrote the programming requirements for the SMS to simulate this system. "I would teach them, once we had contact with the *Mir* docking mechanism and capture, how to bring the two together to create an airtight seal so that we could eventually open the hatches and see all those wonderful welcoming ceremonies," she explained. Along

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[51] Morgan, 14 and "Rendezvous Crew Resource Management Philosophy" in "Orbiter Crew Resource Management, 1998," Box 22, Folder 76, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[52] *STS-63* Space Shuttle Program Mission Report (Houston, TX: JSC-08296, 1995), 6-7.

with this came simulations to "teach them how to potentially get out of a hairy situation should it arise." By launch day, the crew understood how to recognize the sounds for fire, cabin depressurization, or cabin leak and when to make an emergency undocking. Other simulations in Star City taught them to transfer cargo through a mockup of *Mir*, in a preview of the ISS missions to come. Ellen Baker trained as a Payload Commander, meaning she was in charge of nearly three tons of science cargo aboard *Atlantis*. The training included 12 hour integrated simulations with flight controllers in Houston and Moscow, which added complexity.[53]

On June 29, Commander Robert "Hoot Gibson" and Pilot Charlie Precourt proved the value of having trained human operators at the controls aboard *Atlantis*. Their small engine firings brought the orbiter to a point about nine miles behind *Mir*. After beginning their terminal phase initiation burn, the crew benefited from a new procedure called an R-bar approach. This meant approaching *Mir* from directly below, which allowed gravitational forces to slow *Atlantis's* speed relative to *Mir* more than if the approach came from directly in front of *Mir*. This reduced the need for RCS thruster firings, but Gibson still needed the piloting skill to exert manual control when *Atlantis* was half a mile below *Mir*. He went to the aft flight deck that overlooked the payload bay, pulsed the hand controller in response to a camera fixed to the docking system, and centered this system with *Mir's* docking system. Having slowed his approach to 0.1 feet per second, he made a docking that was off by less than one inch and 0.5 degrees. Reed

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[53] Interview with Reed, June 19, 1998 and Lisa M. Reed, Interviewed by Jennifer Ross-Nazzal, July 24, 2015, Houston, Texas, http://www.jsc.nasa.gov/history/ oral_histories/ReedLM/ReedLM_7-24-15.htm (accessed January 23, 2017).

felt thrilled that the training had paid off. "The last time we actually docked during *Apollo-Soyuz,* it was a different time, it was a different place, and we weren't necessarily friendly," she reflected. "This time it just had an overwhelming impact on me…The rest of the day—the training team—we just walked around. We were all kind of in a daze because we had trained these people to do this, and they had gone up and done it perfectly." The cargo transfer and joint scientific investigations also succeeded, as did the first crew transfer in shuttle history. Laid out in custom seats, Gennady Strekalov, Vladimir Dezhurov, and Norm Thagard returned aboard *Atlantis* on July 7 after 115 days aboard *Mir*.[54]

The shuttle docked eight more times with *Mir* until *STS-91* in June 1998, with the training and execution becoming smoother with the passing missions. Shuttle crews followed a pattern of spending a few days each in Russia, allowing them to take classes on *Mir's* construction, components, life support, and communication systems, as well as going through docking and transfer procedures. As these trips and the actual missions progressed, one of the greatest benefits was that astronauts learned how to become more effective loadmasters when transferring thousands of pounds of cargo into *Mir*. Bonnie Dunbar remembered that past experience indicated how long this should take and this made training and execution smoother by the time of her *STS-89* mission. Crews needed to be loadmasters on every *Mir* mission and ISS mission to come, so this had particular value.[55]

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[54] Morgan, 32-34 and Houston, 147-150.

[55] Morgan, 67 and Bonnie J. Dunbar, Interviewed by Jennifer Ross-Nazzal, September 14, 2005, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/DunbarBJ/DunbarBJ_9-14-05.htm (accessed January 24, 2017).

Another benefit of training came in preparation for *STS-74*, a 1995 mission when *Atlantis* delivered a Russian-built docking module to *Mir*. This was the first time an orbiter carried a space station module in its payload bay that the crew then had to assemble to a station, which would become the primary function of the Space Shuttle program during the ISS era to come. Once again, teamwork became a guiding principle of training for this task. MS 1 Chris Hadfield had to use the robotic arm to grab the docking module, lift it out of the payload bay, rotate it into a vertical position, and place it just a few inches away from *Mir*. Then Commander Ken Cameron and Pilot Jim Halsell had to fire RCS thrusters to ram the module into a connection with *Mir*. Meanwhile, MS 2 Jerry Ross and MS 3 Bill McArthur trained for an emergency EVA to use a set of straps to ratchet the module into place. Thus all five *STS-74* crewmembers had roles to rehearse during this operation. Their actual mission went smoothly and demonstrated convincingly that ISS construction would be feasible.[56]

The rendezvous and docking training also became more sophisticated as the missions progressed, especially with the addition of a new training device. A machine called a Part-Task Trainer used Silicon Graphics technology to display a view of the approach to *Mir* while astronauts used a hand controller to rehearse making the kind of precision docking Gibson had made. The advantage of this device was that it was easier for astronauts to schedule time here than the SMS or SES. Astronauts could also begin simulating an approach at different points here and with different failures, such as the loss of RCS thrusters, mixed in. After *STS-91*, Pilot Dom Gorie wrote, “The training

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[56] Morgan, 36 and Houston, 151-152.

with several attitudes, ranges and station-keeping options builds a much deeper knowledge base of orbital mechanics and orbiter flying qualities." This proved especially useful due to the problems with *Mir* that will be discussed in the next chapter. Knowing that *Mir* lost attitude control in 1997, shuttle crews had to train for several variations of those options Gorie mentioned to make sure the orbiter would safely link with the station. But all of the crews successfully rendezvoused and docked on the strength of their training. On June 12, 1998, Charlie Precourt and Gorie brought *Discovery* to a landing and the Shuttle-Mir program to a close.[57]

Most of the shuttle flights from this point focused on the daunting task of ISS construction, although one additional milestone came in 1998 and demonstrated another way that shuttle training in this era had departed from the pre-*Challenger* era. Before the tragedy, Payload Specialists such as Jake Garn, Bill Nelson, and Christa McAuliffe had only meager training duties before their flights. At the time McAuliffe was in training, there were even plans to fly a journalist after her. The accident put a stop to these plans. During the post-*Challenger* era, the Payload Specialists had backgrounds more suited to making mission contributions than politician, high school teacher, or journalist. Usually they were either academics whose research prepared them for the experiments aboard a specific mission or foreign astronauts given a chance to fly on the shuttle. Each of them participated in the training and science research more thoroughly than Garn, Nelson, or McAuliffe. On January 16, 1998, Administrator Goldin made an

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[57] "*STS-91* Fly-Around Lessons Learned," in "Debriefing Notes and Forms, 1999," Box 14, Folder 62, Rick Husband Collection, Texas Tech University, Lubbock, TX.

announcement that provoked controversy even as it stirred the public imagination: Ohio Senator John Glenn would return to space aboard the *STS-95* mission that October. Critics claimed this was simply a matter of NASA seeking publicity and refusing to say no to a politician who wanted a flight. But Goldin made clear he would not have granted Glenn his wish without approval from the National Institutes of Health that his proposed experiments on the aging process had scientific merit, or without the training that accompanied them.[58]

True to Goldin's word, Glenn took on a significant responsibility during his training and flight that demonstrated how far PS training had come since the 1980s. He went through briefings on the shuttle cabin, equipment, and emergency procedures, just as his politician predecessors Garn and Nelson had. But he also had responsibility for more experiments than any of the other six *STS-95* crewmembers, which covered vital areas of biological research such as the immune system, muscle loss, bone loss, and sleep disorders. After meeting with each Principal Investigator for a familiarization session, he used computer based training to electronically interact with the equipment and payloads that would fly in the *Spacehab* module, located in *Discovery's* payload bay. Even the 77 year old who had become the first American to orbit Earth in an age of primitive computer technology embraced the use of laptop computers in 1998. Payload Commander Steve Robinson remembered, "I had the training people calling me up, saying, 'Would you get this guy to quit asking for more training?' He just went after it. By the time we flew, he knew more about laptop computers than I did." Then he

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[58] Houston, 83-84.

rehearsed his tasks alongside the other six crewmembers in two timeline simulations that were integrated with Mission Control and three simulations that were integrated with Mission Control and the Payload Operations Control Center. There were over eighty experiments onboard, which placed time pressure on the entire crew and especially Robinson as Payload Commander. A post-flight report called *STS-95* "one of the most challenging missions to train to date" due to late manifest changes, several payloads not being ready to train until a late date, and reduction of the crew time available for the payloads. But the astronauts proved their flight readiness in the simulations and went on to return useful data over just under nine days in orbit.[59]

While this mission proved the value of having trained humans overcoming challenges to return a myriad of scientific data, one mission the following year proved the value of having them to respond to malfunctions. As Commander of *STS-93*, Eileen Collins trained to become the first woman to command a shuttle mission. She reflects today that flying the aborts and manually flying the ascent to orbit, in case it was necessary to take over from the autopilot and place the vehicle in a very specific orbital inclination, were the most challenging flying she did in the SMS prior to the mission. *STS-93* presented a significant challenge in case an abort was needed, because *Columbia* carried the heavy *Chandra X-Ray Observatory* in the payload bay. "We used to go around saying we had the heaviest payload in the history of the shuttle program," she says. "We were very heavy and had a very aft center of gravity, which made an abort

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[59] Ibid, 84-85 and "*STS-95 Spacehab* Post-Flight Report," January 15, 1999, Box 77, Folder 10, John H. Glenn Archives, The Ohio State University, Columbus, Ohio.

very tricky. In fact, we had a lot of what we called black zones. If we had two or three engines out, you just had to accept the fact that you weren't going to make it. It was important that the engines were running. But by the time I flew, I had a high degree of confidence because I had the ability to ask for more training if I wasn't confident." As she sat in the SMS, she had no way of knowing that *STS-93* would become one of the troubled launches in shuttle history.[60]

On July 23, 1999, the trouble for *Columbia* began about five seconds after liftoff. An electrical bus called AC-1 failed, which resulted in the failure of a primary controller of one main engine and backup controller of another. That abort Collins had trained for would have come to fruition at this point, except the redundancy of the main engine controllers fortunately made this unnecessary. "We did train for this, and you're going to love this story," she remembers. "During the launch, the CapCom called back to us, '*Columbia*, AC bus sensors off.' This was an action that the Pilot did. He has to throw three switches and that protects us for the next failure. So Jeff Ashby did that. Then the CapCom told us what the failure was. The funny thing about that was that the very last simulator session that my crew did before launch had the same failure: the AC-1. That was extremely odd, you might want to call it a coincidence, but it was extremely unlikely that the SimSup would do this. We were all kind of joking about it because it was kind of unusual that this would happen. The training was just outstanding. I don't know how much more praise I can give the training, because I thought it really prepared us well." Thus as the world celebrated the 30th anniversary of *Apollo 11* that month, a

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[60] Author Phone Interview with Collins.

SimSup had unwittingly trained astronauts in a malfunction that was about to occur on a real mission, just as Dick Koos had in 1969. *Columbia* did have one other serious launch malfunction which the crew could not train for: a hydrogen leak in one of the main engines. The crew took no action and did not even know about it until told in orbit, but *Columbia* had an early main engine cutoff because it had run out of fuel. Still, the *STS-93* crew reached orbit after all.[61]

Later that day, Catherine Coleman used the robotic arm to deploy the 50,162 pound observatory. Two other crewmembers had trained to perform an EVA after the deployment, in case they were needed to solve a malfunction like Jerry Ross and Jay Apt with the *Compton Gamma Ray Observatory* on *STS-37*. The deployment went perfectly instead, but Collins cites this as a reason that having trained humans on the mission offered benefits that a completely automated mission would not have had. "*Chandra* could have been launched on an expendable rocket," she explains. "It was more expensive to launch it instead on the shuttle, but the advantage of having it on the shuttle was having a crew there. We were trained to deal with a whole list of things on *Chandra* that could fail. The mission had a higher probability of success because people were there." NASA now had three "Great Observatories" in orbit, surveying distant galaxies in light across the electromagnetic spectrum, and trained crewmembers had been responsible for deploying all of them (*Hubble*, *Compton*, and *Chandra*).[62]

By this point, the last and most daunting task in shuttle history had begun:

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[61] Ibid.

[62] Ibid and Houston, 91.

construction of the ISS. While astronauts had traveled much farther away from Earth during *Apollo*, never had they confronted a project as challenging from a standpoint of robotics and EVA operations as this one. The completed station would be 239 feet long by 356 feet wide, meaning it could not be launched in one piece and astronauts needed to assemble the components using the robotic arm and tools carried by hand during EVAs. Fortunately, the results from training and execution of these tasks during the 1990s had built confidence. The NBL had replaced the WETF in 1998, meaning astronauts had a pool large enough to house full-scale mockups of ISS modules for EVA training. If the astronauts wanted to remove the elements of training in the pool that did not match the real experience, they also had virtual reality simulations that were unrestricted by size limitations. Ross, one of the most experienced spacewalkers in the Astronaut Office, helped formulate the training requirements for these astronauts who would construct the ISS. His plan called for at least three runs in the NBL to evaluate every assembly or maintenance task that would be required. He and the neutral buoyancy instructors chose a cadre of astronauts to carry out these runs that varied widely in size, strength, and EVA experience. Those deemed suitable to build the ISS received the attention of Astronaut Office Chief Bob Cabana and Director of Flight Crew Operations Dave Leestma for assignment to crews. Whereas their *Apollo* predecessors had demonstrated the value of training by becoming field geologists, these people would train to become “orbital hard hats.”[63]

The task of beginning ISS construction fell to the *STS-88* crew: Commander Bob

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[63] Houston, 175.

Cabana, Pilot Frederick Sturckow, MS 1 Jerry Ross, MS 2 Nancy Currie, MS 3 James Newman, and MS 4 Sergei Krikalev. These astronauts had the assignment of carrying a node named *Unity* in *Endeavour's* payload bay and connecting it to a Russian module called *Zarya*, which would launch the previous month atop a *Proton* rocket. Training the crew to operate the orbiter and reach another spacecraft had reached a mature stage by the point, especially given the Shuttle-*Mir* experience. Cabana remembered traveling to Russia to learn about the docking system for the ISS from the person who designed it, Vladimir Syromyatnikov, and feeling confident about this aspect of training. But the crew quickly learned that simulating *Unity* and *Zarya* themselves was another matter. "At that point in the program, they did not have the simulator up in Houston, where things actually worked, and you could train on it reliably," Cabana explained. The astronauts had nothing like an SMS, which mimicked the operation of a vehicle using powerful computers. Training thus posed a new challenge that the crew of the 93rd shuttle mission would not have otherwise confronted. As per the tradition in American spaceflight dating back to *Mercury*, the crew relied heavily instead on learning the systems of *Unity* and *Zarya* as they were being built. They visited the Khrunichev plant in Russia to learn about *Zarya* and the Marshall Spaceflight Center in Huntsville to see *Unity* as it progressed from an empty aluminum shell to a finished product at the Cape. This allowed them to understand the essential resources that were routed through these two modules, such as fluids, the environmental system, and electrical system, and the electronics work they would have to do once inside the new ISS.[64]

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[64] Robert D. Cabana, Interviewed by Rebecca Wright, July 15, 2015, Houston, Texas, http://www.jsc.nasa.gov/oral_

When *Endeavour* soared into orbit to chase down *Zarya* on December 4, the mission provided a strong testament to training. More than previous missions, these construction flights had to be tightly choreographed with each crewmember knowing what task to accomplish in a specified amount of time. Ross reflected, "The assembly flights are not only time packed, but everything has to stack on top of each other. It's kind of like building a house of cards."[65] This flight provided a great indication of what he meant. As described earlier for the *Mir* missions, rendezvous required the Commander, Pilot, and Mission Specialists to assist each other. Once the orbiter had reached *Zarya*, Currie used the robotic arm to lift *Unity* out of the payload bay and carried it into place on *Endeavour's* docking port. Then she used the arm to capture *Zarya* and mate it to *Unity*. Ross and Newman proceeded to climb outside and do the delicate work that needed to be done by hand: the attachment of cables, connectors, and hand rails to the two docked modules. The rest of the crew had to assist them, with Currie operating the arm and another astronaut choreographing the spacewalkers' activities. Then the crew became the first to float through the tunnel from *Endeavour* to the ISS, where they installed the electronics that brought the *Unity-Zarya* combination to life. The need to become successful in these orbital construction duties placed a high premium on working together as a team and following a timeline in realistic simulations. But the crew of the long delayed *STS-88* mission had that training and proved successful, demonstrating in the process that human ability went beyond what an automaton could

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histories/ISS/CabanaRD/CabanaRD_ISS_7-15-15.htm (accessed January 25, 2017).

[65] Jerry L. Ross, Interviewed by Jennifer Ross-Nazzal, February 5, 2004, Houston, Texas, http://www.jsc.nasa.gov/history/oral_histories/RossJL/RossJL_2-5-04.htm (accessed January 25, 2017).

accomplish.[66]

Yet as Cabana implied, the training to operate ISS modules definitely required improvement. The seven astronauts of the next mission to visit the station, the *STS-96* crew, supported this point during their postflight debriefing. They commented that training for ascent and entry aboard *Discovery* “was great” and argued, “In general, when a crewmember completes the shuttle training flow they know everything they need to know to fly their mission.” But this contrasted with the training to learn ISS systems. The seven astronauts did work with a Station Training Lead as well as a Shuttle Training Lead for this mission, but found that JSC instructors did not have as extensive a depth of knowledge on ISS systems as on shuttle systems. The astronauts did compliment the instructors for “running down the answers to their questions,” but developing American expertise in a new international project presented a new challenge that had yet to be fully met. The training hardware also needed improvement, according to the *STS-96* crew. They did get a chance to train in mockups of the *Unity* and *Zarya* modules, but for every two hour session they would lose about 30 minutes due to simulator breakdowns.[67]

In addition to these problems, the crew faced a new problem in training for ISS flights: the sheer amount they needed to undergo. For instance, MS 4 Julie Payette had to become proficient in ISS systems during an early phase of that program while also training to make Earth observations, operate a camera, choreograph an EVA from inside *Discovery*, assist with the deployment of a satellite called *Starshine*, transfer supplies

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[66] Houston, 176.

[67] *STS-96*/2A.1 Postflight Training Debrief Minutes,” in “*STS-96* Space Shuttle Mission Report, July 1999,” Box 20, Folder 12, Rick Husband Collection, Texas Tech University, Lubbock, TX.

into the ISS, assist with the reentry on the flight deck, and serve as backup for a host of other chores. To add to the challenge, she was making her first flight. The crew ran the risk of becoming tired prior to their flight, a problem that other shuttle crews had faced. But these seven astronauts "did not feel tired when they launched," for which they credited longtime Training Manager Myron Fullmer. They believed that if they had a new Training Manager, "it would cause the crew to spend additional time coordinating scheduling details. In some cases, crews may even sign up to do things that are not essential, driving their workload even higher than necessary." But Fullmer helped the astronauts maintain a reasonable schedule prior to launch so that they could launch "physically and mentally in good shape." After the crew succeeded in performing the first ever docking with the ISS, restocking the facility and landing *Discovery* on June 6, 1999, Pilot Rick Husband scrawled two notes at the top of the *STS-96* postflight debrief outline: "Amazing job" and "Everyone happy." Even if the new program was a work in progress, this did not stop talented astronauts and instructors from accomplishing their jobs.[68]

In July 2000, the Russians finally achieved a much delayed milestone that transformed the station itself and the training process: the launch of the *Zvezda* module in which a crew of three could fly long duration missions. Thus the ISS now consisted of two Russian components and one American component. The Russian flight controllers were responsible for sending commands to *Zarya* and *Zvezda*, while

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[68] "*STS-96* Crew Assignments," "*STS-96*/2A.1 Postflight Training Debrief Minutes," and "*STS-96* Postflight Debrief Outline," in "*STS-96* Space Shuttle Mission Report, July 1999," Box 20, Folder 12, Rick Husband Collection, Texas Tech University, Lubbock, TX.

American flight controllers were responsible for sending commands to *Unity*. This resulted in the need for a high degree of synchronization between the two control centers and the crews of subsequent shuttle missions. Thus Station Training Lead Marc Reagan remembers the first joint integrated simulations between all three of these entities as taking place that year. Reagan worked with his instructor counterparts in Russia to make these simulations possible. "Figuring out how we were going to work together and how we were going to simulate together and figuring out what each of our priorities were and executing them was a ton of work," he remembers. "We broke new ground. We did not have to do that during Shuttle-*Mir*, because there was just one American astronaut showing up at a Russian space station that was completely under Russian control." But since America and Russia shared this new facility, "The work in terms of figuring out how we were going to train together was basically done by me and our *STS-92* team."[69]

According to Reagan, the *STS-92* crew met the new challenges presented to them. "*STS-92* was a very veteran crew," he reflects. "They were very solid veterans and you didn't have to train them over and over to get things right." These seven astronauts also had two and a half years to train, due to the long delay in the *Zvezda* launch. According to Pilot Pam Melroy, this time helped the crew meld their personalities into an effective unit, helped by the fact that Commander Brian Duffy did not have a dictator's mentality. He made all seven feel as if they made decisions together, which helped morale during challenging times. Thus the crew succeeded in learning how to coordinate their actions between two control centers during the

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[69] Marc Reagan, Phone Interview by Author, January 17, 2017.

rendezvous and docking, the four EVAs required to connect cables to the Z1 Truss Structure they would bring inside *Discovery's* payload bay (the first piece of the enormous metal backbone for the space station), and their actions inside the growing ISS. The training that Duffy did in making a rendezvous with the station came in especially handy when *Discovery* made its approach on October 13, 2000. The orbiter's KU band system failed, meaning he did not have radar for the rendezvous. But he relied on a laser system in the payload bay, a handheld laser in the flight deck, and his own "seat-of-the-pants" judgment honed from hours of training in the SES and SMS to dock with the ISS successfully. By the time *Discovery* left, the crew had left the ISS finally capable of housing a permanent crew.[70]

The construction tasks grew ever more daunting during the several shuttle missions that visited the station over the next two years. Yet every mission succeeded and this would not have been possible without the recent advances in EVA training. If astronauts had tried to build this unprecedentedly large outpost by training in the old WETF, or if a pool had been their only means of training, their chances of success would have been far lower. But when crews trained to install a truss segment that was over 40 feet long, for instance, a mockup could fit in the NBL and the astronauts could rehearse maneuvering around it just as they would in space. This allowed Andy Thomas to remark after his *STS-102* EVA in 2001: "You do it almost by memory, each step. You know where the handrails are, because you've trained on a very high fidelity mockup. In fact, that's what surprised me about it. It had this sense of, 'I've done this before. I've

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[70] Ibid and Houston, 177-181.

been here before.' It was all because the pool training is such high fidelity training."[71] When robotic arm operators wanted to rehearse carrying a spacewalker to a worksite via the arm, virtual reality training came in especially handy as well. "To do that in the water, the robotic arm that was in the water was typically not very helpful," says Clay Anderson. "It was big, cumbersome, and broke down a lot. It wasn't the same as flying the arm in space. Oftentimes, astronauts who tried to fly the arm in the pool got negative training."[72] But the combination of virtual reality to train for this task and the NBL to train for the delicate work done by hand resulted in a record where by the end of 2002, spacewalkers had accumulated over 300 hours working outside the station. During the long political debate concerning Space Station *Freedom* and then the ISS before it was built, one of the points of controversy was whether such an extreme amount of EVAs was feasible. Training allowed astronauts to dispel that worry.[73]

Training for robotic arm operators, whether via virtual reality or the MDF, also stands out as a critical element of what made the construction missions successful. When Marsha Ivins used the robotic arm to deploy the *Destiny* laboratory module in January 2001, for instance, the module was so large that she had remarkably little clearance on either side of *Atlantis's* payload bay when she lifted it out. She also had the task of removing a mating adapter from the *Unity* module, but had her view blocked by the module. She met the first challenge by acquiring the precision through training to lift the module out, rotate it 180 degrees, and position it within reach of two

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[71] Houston, 184-185.

[72] Author Phone Interview with Anderson.

[73] Harland, 351.

spacewalkers. She met the second challenge by training to use a Space Vision System that calculated the 3D position of an object for her even as her view was blocked. Having highly trained robotics operators resulted in a station that was over 40 feet long by the end of 2002, since all truss segments and habitable modules had been added with their work.[74]

Shuttle crews also had to coordinate their training with station crews who were conducting expeditions several months long by this point. For instance, Chris Hadfield operated *Endeavour's* robotic arm during the *STS-100* mission in 2001. But the objective of that mission was to assemble another robotic arm on the ISS for the Expedition 2 crew. Late in the mission, Expedition 2 crewmember Susan Helms used the newly delivered arm to hand over a pallet to *Endeavour's* arm under Hadfield's control. Later that year, another shuttle crew delivered an airlock and Helms had to work the arm again to assist visiting spacewalkers Jim Reilly and Mike Gernhardt. Reilly, Gernhardt, and Helms had trained together for this, but not for three months by the time the EVA happened. "It was an interesting experience, in that when it did come time to do the task, it was almost like we'd never been apart," Reilly explained. "It was just a joy to watch that whole system operate, in terms of our performance. I was intrigued by that, fascinated by the dynamics of how the team worked and how we gelled. All the shuttle and station crews worked pretty much the same way."[75]

While several crews succeeded in building the ISS and one more succeeded in

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[74] Ibid, 317.

[75] Houston, 187-189.

upgrading the *Hubble Space Telescope* by the end of 2002, another patiently awaited their turn. A largely inexperienced *STS-107* crew had begun training in 2000 for the last shuttle flight devoted solely to science research in a *Spacehab* module, rather than the ISS or *Hubble*: Commander Rick Husband, Pilot Willie McCool, MS 1 David Brown, MS 2 Kalpana Chawla, MS 3 Mike Anderson, MS 4 Laurel Clark, and PS 1 Ilan Ramon, the first Israeli in space. This remains the last mission of its kind, in that astronauts have performed science research on the ISS ever since rather than rushing through a 16-day research program. *STS-107* therefore deserves consideration as a means of understanding how sophisticated training had become to do as productive a job as possible for Principal Investigators in a small amount of time. Given that the crew needed to perform more than eighty experiments, 16 days aboard *Columbia* became a short time frame that challenged these seven astronauts to make the most of their training.[76]

The most striking aspect of training concerned how multitalented the seven needed to become. Husband and McCool needed to learn orbiter systems and abort procedures just like all Commanders and Pilots before them, but also know how to give injections and draw blood for life science experiments and make Earth observations studies. The other five each needed to know systems for the orbiter and *Spacehab* as well as attend briefings on each experiment, but their knowledge went well beyond even that. Chawla trained to assist Husband and McCool with dynamic events as the Flight Engineer. As the Payload Commander, Anderson needed to keep track of the Flight

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[76] See Chien, 1-10.

Data File that laid out the activity plans for everyone in *Spacehab*. Brown and Clark trained as crew medical officers, certified to administer procedures from first aid to surgery. Brown and Ramon trained to become inflight maintenance technicians on *Spacehab*, meaning they could make repairs to an experiment if necessary, and operate computers. Brown and Anderson trained to make an emergency EVA (investigators would later wonder if these two could have spotted the catastrophic damage to *Columbia*'s left wing and what they could have done about it). The preflight assignments even extended to taking care of the crew photo (McCool) and making a mission patch and shirts (Clark).[77] In the case of *STS-107*, having seven people onboard did not mean a leisurely training pace at all. The astronauts ran the risk of becoming fatigued before they left the ground. But their mission, slated to take place in the summer of 2001 when they were first assigned, experienced an amazing 18 delays before finally leaving the ground. Problems with *Columbia's* processing and the higher priority of ISS and *Hubble* missions pushed the launch to January 16, 2003, which gave the crew the benefit of much more training time than originally expected.[78]

Training until that time required a tremendous amount of travel. The crew met with Principal Investigators at a European Space Agency site in Noordwijk, Netherlands, while also visiting Bremen, Germany, the Glenn Research Center in Cleveland, Ohio, the University of Colorado at Boulder, and KSC. Susan Helms remembers traveling to Noordwijk prior to her similar *STS-78* mission aboard *Columbia*, remarking, "I think

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[77] "*STS-107* Crew Assignments," in "*STS-107* Training Plan, December 2000," Box 14, Folder 2, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[78] Chien, 127-135.

anytime you get a chance to talk face to face with the people whose experiments you're running, that's helpful." Attending these briefings allowed the astronauts to understand how each experiment functioned and the scientific goal behind them while also giving them hands-on experience with the hardware, but the level of training required to operate them varied. Some simply required flipping a switch and letting the experiment function by itself. Others required inspections and adjustments by crewmembers who needed to be trained in these tasks.[79]

Others required more complex knowledge of how to meet the Principal Investigators' needs. For instance, the European ARMS experiment required the astronauts to wear special sensors that monitored their heartbeat and respiration while they rode an ergometer. A Mediterranean Israeli Dust Experiment required them to use a laptop computer to command a camera that studied the physical properties of atmospheric dust over North Africa and the Mediterranean Sea. The crew thus had a degree of interactivity with experiments like these that required taking informed minds into space for the sake of the PIs who could not go themselves. For instance, Dr. Paul Ronney reflected that he had worked since 1984 on an experiment to study the structure of flame balls in microgravity. He felt pride in seeing it come to fruition and was pleased to see the astronauts feel the same way. Chawla was the only Ph.D. scientist on the crew, but he said all "worked very hard on the development of the crew procedures to minimize the chance of mistakes and extract every possible bit of data."[80]

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[79] "Training Sites," in "*STS-107* Training Plan, December 2000," Box 14, Folder 2, Rick Husband Collection, Texas Tech University, Lubbock, TX and Author Phone Interview with Helms.

[80] Chien, 138-139.

Though the seven astronauts had only three flights of experience between them, the SimSups could draw upon the experience of numerous simulations in preparing astronauts for around the clock research flights, dating back to *STS-9*. The most effective simulations were those integrated with Mission Control and the Payload Operations Control Center, so that the crew could work with these two entities to solve the problems the SimSups inserted as a team. Some of the problems required immediate action, but some were open ended that required the crew to plan ahead over 24 hours in the *Spacehab* simulator. For instance, a slow cabin leak meant they had to re-plan their activities to accomplish as much science as possible before returning home. The simulations even included physical issues, such as an injury to Ramon while the timeline called for him to ride an ergometer. The crew and controllers in Houston and Huntsville had to decide whether this activity needed to be rescheduled, throwing a wrench into a hectic schedule, and whether Ramon needed to be medically examined by Clark (these were two of the four astronauts who worked on the Red Team, while the Blue Team rotated with them).[81]

In August 2001, the crew had the chance to undertake a training method that was still fairly new. Experiment briefings and simulations helped them develop their knowledge and test their problem solving skills, but these training methods were sharply limited in duration and did not require the astronauts to confront actual physical hardship. At the end of a day in a simulator, the astronauts could feel comfortable in the knowledge that they could drive home and sleep in their own beds. JSC instructors

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[81] Ibid, 143-144.

wondered what would happen if they instead forced astronauts to live outside for several days to work as a team in “a prolonged stressful, isolated, and confined environment.” Thus an agreement with NASA and the National Outdoor Leadership School (NOLS) called for the astronauts to go on camping trips and work with NOLS instructors who would evaluate them on their leadership, teamwork, and self-management skills. This will be covered in more detail in the next chapter, because this expeditionary training applied more to ISS crews. Shuttle crews spent a much smaller amount of time together in training and flying, so their expeditionary skills were less important. But since the *STS-107* crew inadvertently ended up training together for about two and a half years, they had time to make this NOLS outing and the desire to bond as a crew during such a long process.[82]

The trip took them a mountain range in Wyoming from August 20-31. The astronauts walked among the mountains for an average of about four miles each day while carrying backpacks that weighed up to 70 pounds. They had to navigate the correct routes during their climbs of daunting mountains, including the 13,200 foot Wind River Peak (the 95th highest peak in the United States), with no help from instructors. Then they had to eat and camp at altitudes consistently above 9,000 feet, where the air pressure was significantly lower than at sea level. But according to NOLS instructors John Kanengieter and Andy Cline, the crew assisted each other rather than complain about the workload or the heat. Since Husband was the Commander, the goal of

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[82] Ibid, 144-145 and “NASA/NOLS Expedition Pre-Briefing,” in “NASA/NOLS Leadership Trip Materials, 2001,” Box 22, Folder 61, Rick Husband Collection, Texas Tech University, Lubbock, TX.

demonstrating leadership especially applied to him. "Rick is an exceptional leader, regardless of the environment he finds himself in," the instructors wrote. "He sees unfamiliar situations as learning opportunities and confronts them with optimism and excitement. He is self-effacing and humble in a way that draws people to him and exposes them to his competence and leadership abilities." They also evaluated him favorably on his safety awareness and outdoor skills. The two instructors thought so highly of his performance that they handwrote "Will follow you anywhere, Rick!" right above their signatures on the evaluation form.[83] Thus Husband demonstrated that NASA had the right person in command of the mission, while saying himself that the trip "was a great experience" for him from a leadership standpoint.[84]

Part of Husband's leadership capacity for this trip involved evaluating his six crewmates, and his glowing comments indicated how strong a crew NASA had assembled for *STS-107*. When asked if their performance traits were below standards, met standards, or greatly exceeded standards, he answered with the latter for all traits for all crewmembers. When asked to "please write observations of effective or ineffective behaviors," he complimented them on all accounts. When asked if he would like to fly with them on a long duration ISS mission, he answered yes for all of them. By all accounts, the talents that these astronauts brought into the corps upon their selection along with their training at JSC prepared them exceptionally well for spaceflight. Enduring the challenging work of this trip only allowed them to form an even stronger

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[83] "Evaluation of NASA Leadership Expedition: Rick D. Husband," in "NASA/NOLS Leadership Trip Materials, 2001," Box 22, Folder 61, Rick Husband Collection, Texas Tech University, Lubbock, TX.
[84] Chien, 144-145.

bond.[85]

The numbers support the idea that none of the previous 112 shuttle crews were better prepared than these seven. In June 2002, the crew completed their training requirements and continued the shuttle tradition of enjoying a cake cutting ceremony at JSC with their families to mark this milestone. But the delays meant they needed to maintain their proficiency and resulted in their training 74 weeks longer than a typical crew. Their most striking expenditure of time was the 3,506 hours they spent training with *Spacehab*. They also spent 15 weeks traveling to meet with Principal Investigators and learn about experiments. The simulations continued until January 2003, so there was no chance of the crew becoming rusty. The crew made their last ascent and entry simulations about a week before launch, while Husband and McCool performed their last STA landing at KSC the day before launch.[86]

For 16 days, it appeared that the training had paid off. The *STS-107* crew met the challenge of performing all the experiments on their agenda. The flight plan called for 468 hours of their time in performing these experiments and the astronauts went 23 hours even beyond that, giving up free time to make sure they did the best job possible for the Principal Investigators. They also performed a variety of repairs to the *Spacehab* cooling system and several payloads that demonstrated the value of having humans in space who had received in-flight maintenance training. NASA scientist Dr. John

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[85] "Expedition Candidate Training Observation Forms," in "NASA/NOLS Leadership Trip Materials, 2001," Box 22, Folder 61, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[86] Chien, 148-151 and "*STS-107* FCOD Flight Readiness Review, 2002," Box 18, Folder 1, Rick Husband Collection, Texas Tech University, Lubbock, Texas.

Charles felt enthused about the results.[87] Video that Laurel Clark filmed on the morning of February 1 showed the crew happy and confident as *Columbia* plunged back into the atmosphere. They had no way of knowing tragedy was about to strike.

A report released several years later made numerous insights into how the tragedy unfolded inside *Columbia's* cockpit and connected them to crew training. At 8:58 a.m., Husband and McCool received their first sign that something was amiss: a reading on a monitor indicating a loss of pressure on the left main landing gear tires. Their training in the SMS had included a circuit breaker trip that resulted in tire pressure sensors being disabled, so they were undoubtedly concerned but prepared to diagnose the problem based on their simulator experience. But the problems quickly stacked up: a left main landing gear indicator transitioned to an indeterminate state, a light illuminated as two RCS thrusters began firing continuously, and the master alarm sounded due to a fault in the flight control system. Again, training prepared them to examine these malfunctions and look for commonality in them. But the crew could not know what was really happening: as superheated air passed into a breach in *Columbia's* left wing, it melted the wing structure, which caused the vehicle to become aerodynamically unstable and break apart. Husband tried to call Mission Control, but was cut off after his words, "Roger, uh, buh." In the seconds right after this, the investigators concluded that the crew would have noticed *Columbia* yawing and rolling uncontrollably, as well as a master alarm indicating the loss of hydraulic pressure that powered the ship's control surfaces. The astronauts had to have known that something had gone catastrophically

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[87] Chien, 140 and 308-309.

wrong.[88]

Physical evidence from the debris indicated that like the crews of *Apollo 1* and *STS-51L Challenger* before them, the *STS-107* crew reacted in accordance with their training right until the end. A panel on McCool's side of the cockpit showed switches in off-nominal positions. Investigators realized that he had tried to recover hydraulic pressure by flipping these switches to begin a restart of *Columbia's* APUs and to turn on hydraulic circulation pumps. "While turning on the hydraulic circulation pump is not on the emergency checklist, it nonetheless can provide some limited hydraulic pressure and shows good systems knowledge by the crew members as they worked to attempt to restore orbiter control," read the report. Investigators did find that not all of the astronauts were fully prepared at this point, as one middeck crewmember was not wearing a helmet and was not fully strapped into his seat. But it was Husband and McCool on the flight deck who had the responsibility of responding to orbiter malfunctions, and even though their simulations had not exposed them to a catastrophic event like this, their training gave McCool the presence of mind to respond appropriately. Yet about 40 seconds after Husband's voice transmission had been cut off, the crew compartment broke free from the remainder of the orbiter and depressurized within 17 seconds at most. The astronauts lost consciousness and died due to blunt force trauma as the debris fell above Texas.[89]

The investigators praised the training of the fallen crew in their report, making

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[88] *Columbia Crew Survival Investigation Report* (Washington, D.C.: NASA SP-2008-565, 2008), 1-13 to 1-19.

[89] Ibid, 1-19 to 1-29.

clear that the astronauts did everything they could have done, but did include a few training related recommendations. "Throughout their training, the *STS-107* crewmembers displayed expert orbiter systems knowledge, correct and thorough procedure execution, and excellent SFRM techniques," the report read. During one simulation, the crew even demonstrated this by performing the entire session without verbal communication. The astronauts knew the procedures and each other's duties so well that they could function using only nonverbal communication. The investigators did make one unexpected finding from the tragedy: the debris indicated that the astronauts had not closed and locked their helmet visors prior to cabin depressurization. Their training had exposed them to several situations requiring closed visors, such as smoke and fire, cabin leaks, broken window panes, and contingency aborts requiring in-flight bailouts, so why did the crew apparently not close them during this catastrophe? According to the report, they were probably focused on solving problems such as the loss of hydraulic pressure during that 40 second period after Husband's last transmission rather than their own survival. This is what their training in the SMS had emphasized. Though all astronauts went through emergency egress training as well, this took place on different days as the SMS sessions, with little discussion of the transition from solving problems to bailing out of a vehicle. Thus the investigators recommended that future training instructors emphasize to astronauts "the transition from recoverable systems problems to impending survival situations." Though the *STS-107* crew had been in an impossible situation, this training might make a difference for a future crew in a different emergency situation.[90]

After the *Columbia* Accident Investigation Board (CAIB) released an August 2003 report detailing why the tragedy had happened and recommending the changes to minimize the threat of External Tank foam again impacting an orbiter, attention shifted more to the next mission: *STS-114*. The CAIB report did speed along the pending retirement of the Space Shuttle program, announced in 2004 by President George W. Bush. But the astronauts and instructors knew that NASA needed to honor its commitment to completing construction of the ISS and this could not happen if the remaining shuttles (*Discovery*, *Atlantis*, and *Endeavour*) stopped flying. Even more than that, ending the program would have failed to honor the memory of Rick Husband, Willie McCool, David Brown, Kalpana Chawla, Mike Anderson, Laurel Clark, and Ilan Ramon. Family escort Clay Anderson spoke for many of his colleagues when he wrote in a letter to his alma mater, Hastings College, "It will be better than before; it has to be, or my friends will have died in vain."[91] For the remaining eight years of the shuttle program, astronauts and instructors walking around JSC frequently saw photos of the crew and the *STS-107* mission patch to remind them of the legacy they sought to continue. The memory of Chawla's excited words, "We are training to fly in outer space!" inspired them to make training more productive than ever.[92] The task of carrying out the *STS-114* Return to Flight mission fell to Commander Eileen Collins,

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[90] Ibid, 3-64 to 3-68.

[91] Clayton C. Anderson, *The Ordinary Spaceman: From Boyhood Dreams to Astronaut* (Lincoln: The University of Nebraska Press, 2015), 109-110.

[92] Ibid, 169.

Pilot Jim Kelly, MS 1 Soichi Noguchi, MS 2 Steve Robinson, MS 3 Andy Thomas, MS 4 Wendy Lawrence, and MS 5 Charles Camarda.

The training of these seven and all subsequent shuttle crews changed in three ways, all of which concerned the need to examine an orbiter's Thermal Protection System (TPS) prior to reentry for the kind of damage that had doomed *Columbia*. First, crews needed to use a 50 foot robotic arm called the Orbiter Boom Sensing System (OBSS) that was equipped with cameras and lasers to scan the leading edges of the wings, the nose cap, and the crew compartment. "It added a lot of time to the first day or two of on-orbit activities," explains Pete Beauregard, the Chief of the Spaceflight Training Division when the accident and return to flight happened. "Inspection was slow and tedious, and then a special ground team had to analyze the data over the course of the flight."[93] Collins remembers the work that her crew performed to make sure they were ready to carry out this procedure. "My arm operators were Jim Kelly, Andy Thomas, and Charles Camarda," she explains. "They and the engineers and instructors worked together to develop all of these arm positions, and it was very challenging to get them right. My crew took so much time with this, working on it for a year and a half."[94]

Second, crews needed to perform a Rendezvous Pitch Maneuver (RPM) when approaching the ISS. This meant the Commander would take the hand controller and perform a back flip, or pirouette, 600 below the station to expose the tiles on the underside of the orbiter to an ISS expedition crew. The ISS crew could then take photos

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[93] Beauregard, E-Mail Correspondence with Author.

[94] Author Phone Interview with Collins.

and the Mission Management Team could decide if the ship was safe for reentry. In the worst case scenario, the shuttle crew could take up residence on the ISS until another orbiter could launch and rescue them. Training for this was where the SES dome came in especially handy. The operation required the orbiter to flip at three-fourths of a degree per second and hit six different parameters on the hand controller with a corresponding rate (up and down, right and left, and fore and aft), but Commanders could rehearse this using a training device Eileen Collins calls "very helpful." "We started developing the RPM maneuver using the SES in 2003 and then we trained for it during the first half of 2005," she explains. "It was developed by engineers in their offices, but we used the SES to test their calculations on the operational side. We worked very well together as a team, including my *STS-114* crew, several other astronauts who were working on the RPM maneuver, and the rendezvous engineers. Then we flew this maneuver on *STS-114* and it worked almost exactly the same as it was simulated on the SES. When I flew the maneuver on the actual mission, I was calm, confident, and very pleased that it went as well as it did."[95]

Third, Mission Specialists needed to repair damage to the TPS by EVA if necessary. This procedure called for an astronaut to ride the robotic arm to potential damage sites, including to the underside of the shuttle where no spacewalker had ever ventured before and where this person would be out of view of the rest of the crew. Neutral buoyancy instructors therefore had to teach astronauts about the hazards associated with this, so they could rehearse their movements in the pool or with a virtual

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[95] Author Phone Interview with Collins and Houston, 252-253.

reality headset. A spacewalker ran the risk of suit damage due to sharp edges, protrusions, thermal extremes, molten metal, or impact with the orbiter. He or she could suffer a laser injury, electric shock, or inadvertently be released from the robotic arm. The TPS could also suffer damage from a loose tool, the robotic arm, or an astronaut's movement. As for the work of actually repairing tiles, the astronauts trained for several methods. One involved using a caulking gun to fill a damaged tile with an ablative substance called Shuttle Tire Ablator (STA)-54. Another involved using a handheld device called the Emittance Wash Applicator to squeeze a foam mesh onto a damaged tile. Another involved affixing an overlay panel made of carbon silicon carbide over a damaged tile with screws. In case of a damaged RCC panel on the leading edge of a wing, the specific cause of the *Columbia* tragedy, the astronauts trained to use a caulking gun to fill it with a substance called Non-Oxide Adhesive Experimental (NOAX). "Tile and panel repair is difficult because the tiles are fragile," explained Stephen Robinson after one neutral buoyancy session for *STS-114*. "And if they're damaged, they are more fragile." This called for training, both in the NBL and KC-135 aircraft, to master the delicate techniques required to repair damage rather than create more damage.[96]

Juan Garriga, who had been a JSC instructor since 1991, still has vivid memories of his job as the Training Team Lead for *STS-114*. Speaking of this job in general, he reflects, "The crews were outstanding in making difficult tasks seem easy. Astronauts

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[96] Christine E. Stewart, "EVA Hazards Due to TPS Inspection and Repair," (Presentation, the 2nd IAASS Conference, May 14-16, 2007): 1-29 and Tariq Malik, "Shuttle Will Carry High-Tech Repair Kits," March 2, 2005, *NBC News*, http://www. nbc.news.com/id/7068622/ns/technology_and_science-space/t/shuttle-will-carry-high-tech-repair-kits/#.WIw_RvkrLIU (accessed January 28, 2017).

are the crème de la crème, like athletes making amazing performances that you or I could never do…The training team spends a considerable amount of time working with the crew. Ultimately we develop a bond. They become not just our friends but our family. It's no different than if your spouse or sibling were sitting in the cockpit." He especially remembers *STS-114* in this regard, saying, "This was a highly visible mission and we added the means to inspect the shuttle tiles for damage the vehicle may have experienced during the ascent phase. That posed a new task we had never performed before. To prepare we spent a significant time simulating the activity. The world's eyes were upon us and that alone made it challenging. As usual, everything had to go right. More so now than ever."[97]

Discovery finally took the *STS-114* crew aloft on July 26, 2005, to place the new training techniques to the ultimate test. The simulations succeeded in building the crew's confidence to make inspections with the OBSS, make the RPM maneuver for a further inspection, and perform an EVA on July 30 to experiment with RCC repair. This EVA lasted several hours, but the NBL in Houston had the capability to simulate sessions this long. The inspections revealed several pieces of gap filler protruding from the underside of the orbiter. Since gap fillers had the potential to create turbulence and an increase in temperature during the reentry, flight controllers had a decision to make: should they allow Stephen Robinson to make an unprecedented EVA onto the underside of *Discovery*, with the aforementioned hazards that this posed, or accept the risk of leaving the gap fillers in place? The flight controllers decided on the former, despite the

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[97] Juan Garriga, E-Mail Correspondence with Author, January 26, 2017.

fact that Robinson had not trained for gap filler removal. As it turned out, he simply needed to make a gentle pull with his spacesuited fingers when he went outside on August 3 to remove them. His movements honed via the pool and virtual reality headset succeeded in avoiding damage to himself or the orbiter. He explained, "We hadn't trained specifically for that, but it's sort of like when you learn to fly an airplane. You can land at an airport you've never even seen before, and it's because you've got all the skills you need." Thanks to their actions, the astronauts knew the health of their vehicle and did not have to fear a repeat of the *Columbia* accident when they reentered and landed at Edwards Air Force Base on August 9.[98]

Discovery, *Atlantis*, and *Endeavour* went on to fly 22 times after the accident, with the state of training arguably at its highest point yet. Beginning with *STS-115* in September 2006, ISS construction finally resumed after a gap of nearly four years. Astronauts succeeded in utilizing their robotics and EVA skills to install the enormous truss segments for the port and starboard sides of the ISS, the U.S. *Harmony* and *Tranquility* nodes, the Cupola, the European laboratory *Columbus*, the Japanese laboratory *Kibo*, and an Alpha Magnetic Spectrometer that searched for evidence of dark matter. Training reached such a high point for these activities for multiple reasons. First, the missions were spread farther out than earlier in program history as engineers and managers worked through technical issues such as External Tank foam liberation, the effects of Hurricane Katrina on the facility in New Orleans, Louisiana where the tanks were manufactured, the effects of a hail storm on one tank at the launch pad, and a

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[98] Houston, 254-262.

hydrogen leak at the launch pad. This allowed crews to prepare more thoroughly than some of their predecessors. As one example, the *STS-124* crew spent six hours in training for every hour of flight. This worked out to about 1,940 hours per crewmember, or nearly a year of 8 hour workdays (compared to the less than 500 hours that the *STS-51L* crewmembers received over twenty years earlier). Commander Mark Kelly even had time to take this crew and a flight director on a 10 day expedition training trip to Alaska, following in Husband's footsteps.[99]

Second, as the number of shuttle missions to the ISS increased, more astronauts could offer feedback to subsequent crews on how to train for their flights. Stephanie Wilson remembered one example as the robotic arm operator for *STS-121*, the second post-*Columbia* mission. She received feedback from the *STS-114* crew on the operation of the OBSS arm, especially concerning the clearances of the arm as it came close to the orbiter.[100] Jim Reilly described another example as an *STS-117* spacewalker who learned from the truss installation performed by the *STS-115* crew. "Joe Tanner, Steve MacLean, Dan Burbank, and Heidemarie Stefanyshyn-Piper all kind of ran across a problem with some of the bolts and connectors on (the truss they installed)," he explained. "We've taken those lessons and applied them to what we're doing so that we can work around some of the limitations in the hardware that they experienced. We'll be taking a torque multiplier up with us that will allow us to take bolts off should they bind

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[99] Ibid, 237-340 and Hale, et al., 100-101.

[100] "Preflight Interview: Stephanie Wilson," February 23, 2006, *NASA*, https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/sts121/interview_wilson_2006.html (accessed January 28, 2017).

up."[101] As the experience level in the Astronaut Office went up and the number of first time flyers assigned to crews generally went down during the last years of the shuttle era, the instructors understood the impressive array of knowledge they had on hand. "At face value, having previously experienced astronauts may seem like a gift from above," Garriga says. "In numerous ways, it was. But the pressure was on! Imagine if you were the driving instructor that was teaching a handful of NASCAR drivers to drive a new car. The bar was seriously raised! I and the other members of training teams were very excited because it was going to drive us to work even harder to teach a crew of experienced astronauts."[102]

Third, the size of ISS expedition crews increased to six in 2009, which meant more people were available to assist with tasks as the station underwent construction. This eased the task of training even as the level of work went to unprecedented levels of complexity. In July of that year, *Endeavour* soared to the ISS on the *STS-127* mission to complete installation of the Japanese Experiment Module *Kibo*. The shuttle crew plus the station crew equaled 13 people on the station. But Pilot Doug Hurley still recalled that all of them had robotics and EVA work to perform and benefited from having a larger station crew onboard as well as the training that came with them. "Everybody had to do their jobs," he said. It wasn't a case where it was just a couple of people that were key to this mission. Everybody who was up there greatly influenced the success and/or possible failure, if you didn't do your job. We had multiple robotic operations with three

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[101] "Preflight Interview: Jim Reilly," November 3, 2006, *NASA*, https://www.nasa.gov/mission_pages/shuttle/shuttlemissions/ sts117/interview_reilly.html (accessed January 28, 2017).
[102] Garriga, E-Mail Correspondence with Author.

different robotic arms (*Endeavour,* the ISS, and *Kibo* all had arms in use), and it was all operational type uses. I know everybody says they do a complicated mission, but I'm going to let the facts speak for themselves. I'd argue that you'd have to dig pretty deep into the books to find a more complicated mission."[103]

But the most spectacular demonstration of the skills that trained astronauts brought to the final Space Shuttle missions came on *STS-120* in October and November 2007. Scott Parazynski had been the lead astronaut for shuttle repair techniques via EVA, meaning he spent two and a half years in the NBL and KC-135 aircraft perfecting this new concept. He wrapped up his career with his fifth shuttle mission, which he called "the ultimate space station assembly flight, because it was a big module coming up (the *Harmony* node) plus a very, very challenging combination of EVA and robotics to (relocate and) install the P6 (truss) segment and arrays. It was really, in my mind, the most exciting assembly mission of the entire sequence." The EVAs fell to him and Doug Wheelock. Their training exemplified the value of having experienced spacewalkers work with rookie spacewalkers, because Wheelock called Parazynski "just a terrific mentor for me. I don't know how I could learn from anyone any better. He's just a wealth of knowledge for me." He also had vivid memories of how the virtual reality simulations helped him, especially in terms of malfunctions. "They've been nice enough to throw in for us attitude errors, translation errors, and maybe some unexpected arm motion that we would normally not see…They've also thrown things at us that we've practiced that have caused us to very, very finely tune our cadence." At the end

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[103] Houston, 304.

of the process, he commented, "I can close my eyes and walk through the timeline." Wheelock thus went into his first flight with superb knowledge of his *STS-120* objectives and well-honed spacewalking skill, but as it turned out the most worthwhile piece of advice came from Parazynski: "You're going to get out there and find that something doesn't work."[104]

On October 30, the shuttle and station crews encountered one of the most frustrating days of ISS construction and the onus fell to Parazynski and Wheelock to solve a major problem. A steel guide wire intended to keep the solar array panels for the P6 truss aligned jammed and tore a gash through one of the arrays. If the astronauts could not repair the damage, the station might not have had the power to support the European and Japanese modules scheduled to launch the following year. All who eagerly awaited the completion of this massive international project looked to Parazynski and Wheelock to repair the array on an EVA. In a dramatic moment reminiscent of the *Skylab* era, flight controllers had to re-plan a spacewalk and trust that their new instructions as well as the skills these two astronauts had acquired in training would be enough to save an expensive facility. In addition to that, a group went to the NBL and simulated the procedure: cut out the damaged guide wire and sew the rip together with five wire "cuff links." "A bunch of brilliant, unsung heroes spent seventy-two hours working around the clock, looking at different ways to get an astronaut out there to repair," Parazynski reflected.[105]

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[104] Ibid, 284-286 and "Preflight Interview: Doug Wheelock," September 27, 2007, *NASA*, https://www.nasa.gov/mission_ pages/ shuttle/shuttlemissions/sts120/sts120_interview_wheelock.html (accessed January 29, 2017).

[105] Houston, 287.

Why did the seemingly simple task of sewing cuff links require the training that Parazynski and Wheelock had done before the flight and that their colleagues were doing now? The unforgiving variables of spaceflight transformed that simple task into a dramatic one. No spacewalkers had ever maneuvered to a workspace this distant, far removed from a protective spacecraft. Stephanie Wilson and Dan Tani needed to couple the OBSS robotic arm onto *Discovery*'s robotic arm so that they could move Parazynski and Wheelock 165 feet across the truss, then move Parazynski 90 more feet up to the damage site. This required trained arm operators, because Wilson and Tani would be maneuvering this unprecedentedly long structure to within a foot of a highly charged solar array and needed to avoid a collision. Parazynski also needed trained judgment in working next to an array that could have electrocuted him. If he did not work fast enough, he also ran the risk of using up his oxygen supply before his 45 minute trip back to *Discovery's* airlock. Meanwhile, Wheelock was in a shadow and experiencing a temperature of minus 300 degrees. Despite the presence of his suit, he reached the point where he could not feel his hands. The success of this seven hour, 19 minute EVA in repairing the array epitomized Stephen Robinson's point about training giving astronauts a general skill set that allowed them to adjust to new demands. The two men literally grabbed onto one another and climbed across each other's bodies to reach their difficult worksite, then accomplished their job because the pool and virtual reality simulations had given them experience in choreographing their movements and working with their tools. These astronauts had made the difficult look easy and they could not simply do this overnight; only training for years made this possible.[106]

Similar comments apply to the last *Hubble* servicing mission, *STS-125*. On May 11, 2009, a crew of seven rode *Atlantis* into orbit knowing nobody would ever visit *Hubble* again and that the pressure was therefore on them to accomplish all the tasks on their agenda: removing and replacing a camera, installing a Cosmic Origins Spectrograph, and repairing a Space Telescope Imaging Spectrograph (STIS). MS 4 Mike Massimino remembered that training for this took on an urgency reflecting the end of the shuttle program. The funding for new tools the astronauts would have to use in the NBL and in space, as well as helmet cameras that worked in the NBL, quickly arrived for them. Even apart from the trips to the NBL and the *Hubble* mockup at Goddard, spacewalkers Massimino and Michael Good could train to repair the STIS on a model of this device located down the hall from their office. There was a good reason *Hubble* engineers gave the crew this model: repairing the STIS is still today the hardest task any person has ever done during an EVA. Massimino and Good needed to remove a metal clamp, a handrail, six screws, 111 tiny screws (with the bulky gloves they were wearing), a rubber gasket, a grounding wire, and channel locks just to access this instrument. Then they needed to remove the power board to the STIS and slide in a new board, perfectly straight so that all 120 tiny metal pins could slide in flush. "We must have done it hundreds of times," Massimino recalled of training at the STIS model. He remembered the training giving him not only confidence in working with the hardware, but in coordinating with his crewmates to the point that "It was like we had one

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[106] Ibid, 288-295.

brain."[107]

One other aspect of training for *STS-125* covered a grimmer scenario: what if *Atlantis* suffered *Columbia*-like damage to its Thermal Protection System? This was the last shuttle flight not going to the ISS, so this crew could not use the station as a safe haven. Thus the crew prepared for a potential rescue launch of *Endeavour*, after which this vehicle would rendezvous with *Atlantis* and the crew would translate across a robotic arm into *Endeavour*. The crew felt prepared to wait up to 21 days for a rescue, while turning off systems to conserve electricity and subsisting on a diet of protein bars and water. "It was morbid and not at all pleasant, but it served to bond us closer as a crew," Massimino explained.[108]

The mission succeeded, again because a group of astronauts had the skill set honed from training to overcome adversity. The adversity in this case was that Massimino found he could not remove one of the screws holding a handrail in place that blocked access to the STIS. Flight Director Tony Ceccacci decided that, based in part on the results of a test done at Goddard, Massimino should apply sixty pounds of linear force to simply yank the handrail loose. He did this successfully without puncturing his suit.[109] No person could have felt confident in his or her ability to improvise on the spot without training and certainly no person could have felt confident about the delicate task of working with such tiny equipment without it. Once again, training had empowered astronauts to perform tasks that an automated machine could not have performed on its

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[107] Massimino, 268-279.

[108] Ibid, 260-261 and 276.

[109] Ibid, 280-299.

own. Massimino recalled a proposal from 2004 to launch a robotic mission to rescue *Hubble*. But "with all the different contingencies you'd have to plan and design for, it would have cost a bazillion dollars and you still wouldn't get the same quality of repair. Ultimately, what the robot mission ended up proving was the value of astronauts. Astronauts can think on the spot, improvise solutions, communicate abstract thoughts…If you have a person with a human brain operating hands with opposable thumbs, you can shift gears on the fly, work the problem, devise a solution." A robot could not be trained to accomplish those feats.[110]

The shuttle program reached a grand finale two years later with *Atlantis's STS-135* mission. Commander Chris Ferguson, Pilot Doug Hurley, MS 1 Sandy Magnus, and MS 2 Rex Walheim became the last crew to use the training facilities that had served astronauts so well for thirty years. Juan Garriga remembers this as one of his most challenging missions as a Training Team Lead. "Again, all the crewmembers were experienced," he reflects. "What made it challenging was that this was the last mission and everything had to go right. There was a lot of press presence."[111] The crew and instructors indeed had the familiar challenge of working around the intense media interest in the flight, including a *Houston Chronicle* photographer who followed them. Training contained two other challenges beyond what Garriga mentions, though. The crew consisted of only four people, because this was the last mission and no rescue shuttle could be launched in case of irreparable Thermal Protection System damage.

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[110] Ibid, 250.

[111] Garriga, E-Mail Correspondence with Author.

This marked the smallest shuttle crew since *STS-6* in 1983. Magnus remembered that she and her colleagues had to do more cross training so that such a small crew could accomplish the combination of tasks from orbiter inspection, to rendezvous, to docking, to robotics, to cargo transfer, to photography, to landing. The astronauts did not have the luxury of specializing on just one or a few areas. Their need to become multitalented more reflected the ISS crews discussed in the next chapter than shuttle crews.[112]

Another challenge concerned the attitude of the crew and instructors. Given that all four crewmembers had flown before and the program was coming to an end, would their dedication level remain high? All accounts confirmed that this did happen. "Nobody showed up at any sim or training event and said, 'We're not going to do this…I'm just going to phone it in," Hurley remembered. "That just never happened." He also hailed the "unbelievably incredible professionalism" of the United Space Alliance instructors with whom he worked.[113] The instructors maintained their professionalism despite the fact that they knew the retirement of the shuttle would spell the loss of many jobs. ISS crewmembers still required training and eventually astronauts would ride the *Orion* spacecraft still under development. But the capability of launching astronauts from American soil would be gone for several years to come, meaning the retirement of the shuttle was a devastating event for the astronaut training profession. "We come in and certify and serve just like the civil servants and often stay here for an entire career," explains longtime USA instructor Mike Sterling of his organization.

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[112] Houston, 314.

[113] Ibid, 313-314.

"However, like at the end of the shuttle program, we can be laid off easier when staffing needs decrease significantly."[114] The day finally came in July 2011 when the last shuttle mission simulation took place. Lisa Martignetti maintained, "Nobody's performance level or dedication has changed. All these people who know it's going to be their last sim are excited about it…I'm just so proud of everyone I work with."[115] On July 21, 2011, Chris Ferguson landed *Atlantis* after one last successful mission with the words, "After serving the world for over thirty years, the Space Shuttle found its place in history, and it's come to a final stop."[116]

The Space Shuttle program ended carrying a considerable legacy, in that the process of training astronauts differed from previous programs in several ways. Flying the first reusable spacecraft thus broke new ground that future astronauts and instructors will have to consider. The most significant legacy concerns the fact that five orbiters took 355 people into orbit over thirty years. The number of people and length of the program dwarfed the *Mercury*, *Gemini*, *Apollo*, and *Skylab* programs. This meant that the training flow could become more standardized, from the briefings that ASCANs received upon their selection, to the grades they received upon their first sessions in the NBL or MDF, to the number of hours called for in using the various simulation facilities once astronauts were assigned to crews. This also meant that instructors could make more standardized suggestions to help new flyers, with some of the most valuable

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[114] Michael Sterling, E-Mail Correspondence with Author, January 24, 2017.

[115] Traci Watson, "Unsung Heroes Kept Shuttle Flying," July 7, 2011, *USA Today*, http://www.usatoday30.usatoday.com/tech/ science/space/2011-07-06-space-shuttle-unsung-workers_n.htm (accessed January 30, 2017).

[116] Houston, 336.

instructors being astronauts themselves who had previously flown. The Space Shuttle program was the antithesis of *Mercury* in this respect. The notion of Training Team Leads staying with shuttle crews throughout their training is another legacy that benefited astronauts and marked a departure from previous programs. Another legacy that differed from the earlier programs concerns the progression of technology. Computers increasingly shaped the teaching profession throughout the last decades of the 20th century, in that they provided a tool that was often more convenient and provided more thorough information than a person could. The Space Shuttle program was no exception to this rule, in that computers aided astronauts' understanding of the many systems they had to learn. Virtual reality proved to be the ultimate manifestation of advanced technology shaping teaching and the astronauts would have had more difficulty working on *Hubble* or the ISS without it.

Yet another legacy concerned the wealth of tasks astronauts needed to perform. Astronauts had traveled much farther from Earth during *Apollo*, but this did not mean astronaut tasks during the shuttle era were less complex. The work in constructing and repairing large structures with a combination of robotic and EVA operations, the sheer number of experiments requiring operation, and the need to pilot the vehicle to a landing back on Earth stand out as clear steps beyond *Apollo*. But in each case, the instructors answered the need for briefings and high-fidelity simulations of these tasks with aplomb. The training division at JSC weathered changes over the course of the 30 years that ranged from an expansion in the number of instructors to hire, to an expansion in the number of astronauts to train, to the gender and race diversity of instructors and astronauts, to the transition to the United Space Alliance for employment, to the new technologies that affected training, to the *Challenger* and *Columbia* tragedies that spurred new training methods. But the evidence could not be clearer that astronauts from 1981 to 2011 went to space prepared despite these changes and the challenge of assigning a wealth of tasks to each crewmember. The comments of the instructors and astronauts, and more importantly the quality of work astronauts performed during 135 missions, supports this with very few exceptions. No person died due to inadequate training and, except for the *STS-87* accident, historians will search in vain for crew mistakes that seriously affected a mission. As the 21st century brings new programs, whether operated by a government or a company, instructors and astronauts will have the knowledge that that it is possible to confront adversity or change and still accomplish an objective. They will have a model to emulate, given that these people have adequate funding and the sense to look to history as a guide.

Space Shuttle training did not mark a complete departure from *Mercury*, *Gemini*, *Apollo*, or *Skylab*, however. Several practices stood the test of time from the 1960s to the 2010s, from the use of electronic simulators that were often integrated with Mission Control, to debriefings involving astronauts, flight controllers, and SimSups after sessions in those simulators, to pools to rehearse for EVAs, to direct astronaut contact with the hardware they would be operating, to briefings from experiment Principal Investigators. After Chris Ferguson, Doug Hurley, Sandy Magnus, and Rex Walheim landed aboard *Atlantis*, they took part in a mission debriefing where instructors and engineers valued their suggestions as users of technology, just as Alan Shepard had exactly fifty years before. Thus even as this new program broke new ground, astronaut training remained an evolutionary process. The thread running from *Mercury-Redstone 3* through *STS-135*, that training empowered humans to accomplish tasks automatons could not, also remained as strong as ever. The astronauts who did construction work on *Hubble* and the ISS, deployed satellites, made adjustments to experiments, and solved glitches with the orbiters themselves left no doubt that their abilities went beyond robots. Only robust training that developed the minds and bodies of the 355 people who flew aboard the shuttle could ever have made this statement possible. When future generations of tourists flock to the Smithsonian National Air and Space Museum to see *Discovery*, the Kennedy Space Center to see *Atlantis*, and the California Science Center to see *Endeavour*, they would do well to understand that these vehicles did not make history by themselves. The people who flew aboard them had to develop the skills to perform the tasks that made these vehicles worthwhile.

CHAPTER XV

MIR AND ISS: "A MARATHON, NOT A SPRINT"

Lucia McCullough remembers the phrase. Ever since Jerry Carr, Ed Gibson, and Bill Pogue had splashed down on February 8, 1974, American human space missions had not lasted any longer than about two weeks. Astronauts needed to train for specific tasks laid out for them in high detail throughout every day of those many shuttle flights, reflecting a "sprint" of activity. The idea of sending astronauts to train for a space station flight of several months remained frustratingly out of reach. Though the Space Station *Freedom* proposed by President Ronald Reagan in 1984 produced hardware mockups that astronauts trained with in the neutral buoyancy pool, the proposal remained dormant until a breakthrough from the new administration of President Bill Clinton in 1993. As described in the last chapter, the Bush administration had succeeded in reaching an agreement with the new Russian Federation in 1992 for cosmonauts to fly aboard the Space Shuttle and the shuttle to dock with Russia's space station *Mir*. But the Clinton administration pushed the cooperation into a higher gear with an agreement for several Americans to live aboard *Mir* for missions several months in duration, followed by the construction of an International Space Station that the U.S., Russia, and 14 other nations would have a hand in assembling and staffing with crewmembers. Though the Space Shuttle would continue flying to facilitate the construction and make a few additional missions, for the most part astronauts would undertake scientific research on the ISS instead. They would fly for several months, not one or two weeks. As an ISS instructor who joined NASA in 1999, McCullough knew that training these astronauts would have to reflect the fact that missions several months long were "a marathon, not a sprint."[1]

Thus ever since 1993, the training of astronauts has had to reconcile two issues: how to adjust to missions several months long and how to adjust to joint missions with Russia. The previous chapter only described the brief interactions of shuttle crewmembers with Russians. The long duration missions required an entirely different level of interaction with a former Cold War enemy now struggling as an independent nation. Many astronauts did not want to undertake a long duration mission that required extensive training in Russia, wanting instead to stick to the shuttle. Norm Thagard received word that he would become the first American to live aboard *Mir*. The task of becoming the guinea pigs in terms of adjusting to life in Russia and the training procedures favored by the Russians fell to him and his backup Bonnie Dunbar, who traveled there in February 1994. Thagard would then launch aboard a *Soyuz* spacecraft one year later, which would deliver him to a 115 day stint aboard *Mir* with cosmonauts Vladimir Dezhurov and Gennady Strekalov. Though the *Apollo-Soyuz* crew had traveled to Russia two decades earlier, so much had changed since then. Not only had the Soviet Union ceased to exist, but Thagard would be inaugurating the process of learning how to operate another country's space station and working with people from that foreign nation for several months both on the ground and in orbit. Joint American-Russian training had reached a state of permanency that the brief *Apollo-Soyuz* mission

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[1] Launius, 152-153 and Lucia McCullough, E-Mail Correspondence with Author, January 27, 2017.

had not brought about.[2]

His training over the one year after he arrived at the Gagarin Cosmonaut Training Center (GCTC) in Star City differed dramatically from his four shuttle flights. As the *Apollo-Soyuz* crew had learned, becoming proficient in the Russian language was one of the most difficult and time consuming differences. The briefings that Thagard and Dunbar went through were all in Russian, prompting Dunbar to compare the experience to a first grader going to graduate school. Thagard remembered thinking that sending Dunbar to Russia without previous Russian language training had been a mistake. One of the later Americans to train for a *Mir* mission, John Blaha, also remembered thinking that NASA had inadequately prepared him for language study. Thagard, on the other hand, had gone through several months of language training at the Defense Language Institute in Monterey, California just before his trip to Russia. The Shuttle-*Mir* astronauts thus took to Russia varying levels of fluency in the language and experienced varying degrees of difficulty in learning and speaking the Cyrillic alphabet. The hundreds of hours the astronauts had to spend on this task bogged down the training process in a way that shuttle astronauts did not have to deal with, and this was one of the reasons for the reluctance to volunteer for the Shuttle-*Mir* project. But all who did volunteer eventually surmounted the challenge.[3]

Survival training was another difference from the shuttle program that harkened back to the *Mercury*, *Gemini*, and *Apollo* days. Though all Shuttle-*Mir* astronauts went

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[2] Norman E. Thagard, Interviewed by Rebecca Wright, Paul Rollins, and Carol Butler, September 16, 1998, Houston, Texas, http://www. history.nasa.gov/SP-4225/oral-histories/thagard.pdf (accessed January 31, 2017).

[3] Morgan, 44 and Interview with Thagard.

home on the shuttle, they had to train for the possibility of an emergency necessitating their reentry and landing aboard *Soyuz*. As ISS instructor Marc Reagan points out today, when all Americans do have to land aboard *Soyuz*, “Astronauts may end up bobbing around in a lake upon their touchdown at the end of a mission, or in a desert, or in an ocean, or in a jungle, depending on what caused them to evacuate and make an emergency landing. It could be days before a search and rescue force finds you.” One of the early Soviet space crews, Pavel Belayayev and Alexei Leonov, had to undergo an emergency landing and recovery in a cold and inhospitable forest in 1965. Thagard therefore underwent a survival simulation in the woods. He, Dunbar, and Dezhurov sat in a *Soyuz* that had been plopped there, changed from their suits into their winter clothes, and spent forty-eight hours in the woods trying to keep warm in the subfreezing temperatures of a Russian winter. Instructors were nearby to ensure the astronauts’ safety if necessary. Astronauts also went to the Black Sea to simulate climbing out of a *Soyuz* immersed in water that might be very cold. This required donning four layers of Arctic clothing and life jackets, launching signal flares, and finally climbing out for a rescue.[4]

Another difference concerned learning the Russian spacecraft themselves. The Russians were still using the *Soyuz* that Tom Stafford, Vance Brand, and Deke Slayton had once learned. But Thagard was going to become the first American to ride the *Soyuz* into space and to a docking with *Mir*. Reagan remembers the requirements for Americans training to operate the *Soyuz* during ascent and docking, which began with

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[4] Morgan, 41 and Interview with Thagard.

Thagard and continue to this day. "If you're going to be a left seater, which is the flight engineer, you will spend a significant amount of time in Russia because the flight engineer has some significant duties," he says. "The flight engineer is really the copilot of the spacecraft. If you're going to be a right seater, you have far fewer duties and far fewer systems you are responsible for. You can cut down the training quite a bit."[5] Thagard was a right seater, but went through simulations with Dezhurov and Strekalov to make sure he was comfortable operating the *Soyuz*. He also went through briefings on *Mir* systems. Though less complex than the Space Shuttle he had already flown on, *Mir* featured a living quarters as well as modules for scientific research called *Kvant*, *Kvant-2*, and *Kristall*. The classroom briefings prepared him to operate *Mir's* scientific equipment such as telescopes, cameras, and spectrometers, the life support equipment that would keep him alive, the attitude control equipment that kept the station in the right orbit, and his means of everyday tasks such as sleeping, eating, bathing, and urinating.[6]

The astronauts needed to learn not only about different spacecraft than the Space Shuttle while sitting in Russian classrooms, but also adjust to a different method of evaluating their learning. As indicated in an earlier chapter, NASA instructors succeeded in constructing workbooks for newly selected shuttle astronauts to study. But as Blaha explained, "In Russia, they do it the old-fashioned way. A person takes a piece of chalk and he goes to a chalkboard, and you're sitting as one or two students, no more. That piece of chalk goes to the chalkboard, and the man starts teaching you a particular

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[5] Author Phone Interview with Reagan.

[6] Morgan, 38.

system in a *Soyuz* or on *Mir*. And you take notes and you ask questions. When the course is complete, the Russians have another team administer an oral exam to the student." The Russian method of training therefore relied less on written material and less on sessions in expensive, high-fidelity simulators than American shuttle training. Though there were simulators for *Soyuz* and *Mir*, the emphasis on simulation sessions declined as astronauts went to Russia. The focus was more on oral material presented in a classroom than simulation sessions, partly because the Russian program was less well funded but partly because this approach had worked well for them throughout the more than two decades that cosmonauts had now been living on space stations. The notion of placing an astronaut on the spot for an oral exam, with a group of experts frighteningly staring right at them and noticing any weaknesses in their knowledge, also differed from the shuttle experience.[7]

Susan Helms also remembers a different philosophy of instruction when she made her first training trip to Russia in the 1990s. "The Russian philosophy is very much starting with the basics," she explains. "For example, when the Russians talked to crewmembers about the life support system, the instructors started at the level of 'how much water does a human need to drink every day?' There is a reason that they did that. It's because they did not at that time have the kind of continuous communication links with *Mir* that the Americans were used to having with the Space Shuttle. The American philosophy of training made some assumptions about reliance on Mission Control, whereas the Russian philosophy of training goes back and trains the Russian

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[7] Ibid, 39.

crewmembers on the basics during the many times they cannot talk to Mission Control."[8] This strong emphasis on teaching crewmembers the ins and outs of space station systems also reflected the Russian concept of system maintenance, as Greg Chamitoff learned in the 2000s. "For those who are trained as system experts on Russian systems, we know the details of each system down to low level components, sensors, flow diagrams, expected internal signals, and all the parts that could be replaced," he explains. "The U.S. hardware redundancy philosophy is based on the notion of replacing a box when it fails instead of fixing it. We don't plan to open things up and tinker with them on a large scale. As such, our training and knowledge of the internal workings of many systems is much less detailed."[9]

Not all of the Russian classroom instruction was unfamiliar territory to Americans, as Chamitoff remembers today. "In many ways, given the barriers due to the Cold War, it is amazing to see the similar approaches to many of the technologies used and the operational techniques for utilizing them," he explains of the American and Russian approaches to human spaceflight. "These similarities go down as deep as the mathematics to describe trajectories and control systems to fly them, the various sensors used, and the use and management of data to control the vehicle overall. System by system, there are parallel methods for accomplishing similar functionality."[10] Besides the systems they would have to learn themselves, the astronauts could see similarities in the training process. The Russian instructors asked the astronauts to make a progression

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[8] Author Phone Interview with Helms.

[9] Chamitoff, E-Mail Correspondence with Author.

[10] Ibid.

from learning single systems to operating them in a full-scale simulation of an entire vehicle, just as in the United States. Shortly before the launch, crews went to the launch site in Baikonur for a countdown demonstration test before beginning a quarantine period in a crew quarters, just as in the U.S.[11] The first American astronauts who trained in Russia therefore did have a head start in their learning because they already understood American spaceflight operations. But differences continued to abound, as Thagard learned when he moved past classroom instruction and into sessions aboard the *Mir* simulator.

The relationship of the crew with flight controllers was one of the biggest differences. In the United States, astronauts and flight controllers trained to work as a part of team that worked together on a fairly equal footing. Ever since the *Mercury* program, the controllers encouraged astronauts to share their opinions about issues concerning training or operations, and valued those opinions. But Chamitoff makes clear that, "The Russian approach is that the crew is there to do what they are told. There is an opportunity for crew feedback, but the debriefs are more a process of telling the crew what they did right and what they did wrong, and therefore how much pay they will receive…One of the stressful things for Russian cosmonauts is wondering how their pay or career will suffer as a result of infractions or unsuccessful activities." Thagard became the first American to experience this during simulations in advance of his March 1995 liftoff. Not only did he have to apply his knowledge earned in the classroom of how *Mir* functioned and carry out his tasks accordingly, he had to adjust to a new

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[11] Morgan, 18-19.

environment where his voice had less clout than in the United States. The power belonged with flight controllers ordering him what to do, whether in training or flight.[12]

But above all else, Thagard's training differed from his previous shuttle training because he had to prepare to spend 115 days in space instead of a week or two. "Shuttle flights are short, so you can intensively train for virtually every aspect of them, and that's not true for a three-month flight," he remembered. "In fact, you're going to have to wind up having things happen over the course of a flight that you never anticipated at all." When the *STS-107* crew had prepared for their sixteen day research flight, as described in the last chapter, each crewmember had a responsibility in performing over 80 experiments that he or she knew would have to be fulfilled at a certain time on a certain day. Training reflected the need to prepare astronauts for this highly structured environment. But this was not realistic in Thagard's case, because he simply had too many days in space ahead of him to train in this way. By 1995, the Russian instructors felt confident in him not because he had prepared for every single day in miniscule detail, but because he had passed the oral exams in *Soyuz* and *Mir* systems while standing in front of a group of experts in Star City, placed his knowledge of systems together in the *Soyuz* and *Mir* simulators where he had worked well with his Russian colleagues and flight controllers, undergone survival training, and stayed proficient in Space Shuttle systems on top of that since he would have to land aboard *Atlantis*. Though he had to go through the whole process with a higher workload and less time than cosmonauts in the past, he maintained, "I don't remember feeling very daunted by

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[12] Ibid.

that, because…I knew they had a fairly structured program in Russia. So my attitude was whatever we need to know or do, they'll take us through it, and, indeed, that was the case."[13]

By the day he became the first American to launch from the Baikonur Cosmodrome in Kazakhstan, Thagard totaled 1,728 training hours. 883 of the hours came in training with a generic group of cosmonauts, while 845 came in training with a specific crew. His *Soyuz* training took up the most amount of his time, at 169 hours of classroom instruction and 263 hours in a simulator. This prepared him to fulfill his tasks during the upcoming rendezvous and docking with *Mir*, as well as execute an emergency evacuation to *Soyuz* and safe landing. His *Mir* training amounted to 248 hours of classroom instruction and 118 hours in a simulator. The simulator time allowed him to rehearse his actions during a standard flight day, which was a challenge because several systems and science hardware operated simultaneously, flight controllers participated via radio communications, and video showed the crew at work to the controllers who were ready to make note of any mistake. The nature of a mission several months long was that an astronaut might have to reschedule a task and refresh his or her knowledge about how to perform a task. The sessions in the *Mir* simulator gave Thagard and his successors experience in planning and organizing so they could do this effectively. The syllabus also called for six hours of training in responding to a fire and eight hours in responding to a cabin depressurization, which would unfortunately come in handy later in the program. Studying the Russian language took up another 174 hours of Thagard's

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[13] Interview with Thagard and Morgan, 18.

time. Thus he had an extremely busy schedule even without taking into account his training to conduct science experiments.[14]

He spent another 311 hours training for this aspect of his flight, thanks to the teamwork of instructors in Houston and Star City. JSC instructors gave him a basic familiarization with the goals of the experiments and hardware associated with them over three weeks. GCTC instructors then had their turn in training him. Six months before launch, he went through another three week session at JSC, this time meeting with experiment suppliers. Then he underwent his final training back in Star City, this time with the flight data file for his specific mission. Medical experiments called for over 200 more hours of training to prepare him in drawing blood, taking biological materials samples, and processing the samples. Tasks such as drawing blood with a catheter were acquired skills, which made these sessions invaluable. A report on the Shuttle-*Mir* program written jointly by Americans and Russians made a telling statement about the importance of experiment training: "Experience acquired in implementation of long-term crewed flight testifies that effective execution of the science program is possible only when the crewmembers are active participants in the scientific investigations and experiments. This in turn is achieved when in the training process the cosmonauts are not restricted to forming the skills of experiment algorithm execution, but acquire some fundamental knowledge about the studied phenomenon in the necessary scope, and become acquainted with the design principles of the science

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[14] George C. Nield and Pavel Mikhailovich Vorobiev, eds., *Phase 1 Program Joint Report* (Washington, D.C.: NASA SP-1999-6108, 1999), 143-161.

hardware, its design, and functioning." The report therefore made clear that Shuttle-*Mir* crewmembers were not automatons sent to blindly carry out research, but humans who should utilize the knowledge that training gave them.[15]

Thagard rewarded the instructors' faith in him with a productive 115 days aboard *Mir*, although his experience did call for more training attention in a couple of areas. His training aboard *Soyuz* prepared him well for the launch experience on March 15, 1995 and the docking with *Mir* on March 16, when he controlled the radios and television cameras and monitored spacecraft systems for any anomaly. He then benefited from speaking with the crewmembers who were leaving *Mir* concerning the state of the space station; they could help him prepare for his stay by giving him details on inventory control that nobody relegated to the ground could. He still said he had trouble finding equipment and getting started on his science research and passed this along as a message for future crewmembers to train in the *Mir* simulator for those initial operations. He performed his 28 experiments well along with performing maintenance tasks, supporting an EVA by his two Russian crewmates, and helping to activate the new *Spektr* module. The maintenance tasks on an outpost over ten years old were especially crucial, because *Mir* crewmembers spent over half their time on this chore. The flight did pose psychological challenges for him that shuttle crewmembers had not faced. As a U.S. Marine who had flown combat missions in the Vietnam War, he had to coexist for 115 days with two Russians just a few years after the end of the Cold War. Though he considered Vladimir Dezhurov a more autocratic Commander than the Commanders of

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[15] Ibid, 164-173.

his shuttle flights, and had to deal with a much more autocratic group of flight controllers as well, he did maintain a positive relationship with his colleagues. The psychological problem he did struggle with concerned underwork. He felt he did not have enough meaningful work to keep him busy, while the flight controllers overworked the cosmonauts to keep *Mir* in operation. Future Shuttle-*Mir* crewmembers now had this firsthand experience to consider as they went through their training process.[16]

Thagard did have additional training resources to assist him in orbit, as a way to counteract a problem an astronaut had to deal with for the first time since *Skylab*: the time lag between training for a task on the ground and performing it in orbit. He had one technology that his *Skylab* predecessors did not: a laptop personal computer with a CD-ROM drive that could play discs containing training material. If he needed a refresher on the characteristics of a system or on operating an experiment, he could watch the videos on the discs. The instructors often videotaped the astronauts' last training sessions before leaving Earth so that when it came time to perform a critical operation during a mission, the astronauts could see themselves asking questions and operating the same equipment. Though shuttle Commanders had used simulation software in orbit to train for landings beginning in 1993, this Crew On-Orbit Support System aboard *Mir* went well beyond any training resources astronauts had ever used in space before. It marked a step toward the future of spaceflight training, as journeys to Mars will be so long that crews who go there will especially benefit from in-flight training. Thagard also benefited from speaking with an instructor he had worked with for the past year in Star

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[16] Morgan, 23-29.

City during his 115 days in space. In the Space Shuttle program, instructors did not continue working with crews once their missions began. But Thagard felt his communication with the ground benefited from the chance to continue speaking with this Russian Air Force Captain who had instructed him.[17]

After Norm Thagard, Shannon Lucid, and John Blaha completed their increments, Jerry Linenger began a more troubling mission. In the history of Americans living aboard space stations, 1997 was easily the most difficult year from a crew perspective and highlighted the necessity of the emergency training that continues today for ISS missions. On February 24, Aleksandr Lazutkin was in the *Kvant-1* module when he saw an oxygen-generating canister erupt into flame. The crew had trained for emergency evacuation prior to the flight and handled themselves in this fire crisis well, even as they encountered trouble with their equipment. Their response required quick teamwork, which they implemented by ordering a *Soyuz* readied for evacuation from *Mir* (Commander Valery Korzun), printing out reentry information for the two *Soyuz* vehicles currently docked to the station (Lazutkin), passing out fire extinguishers and oxygen masks (Linenger), and fighting the fire with the extinguishers (an effort led by Korzun). One problem concerning the response was that when the crew heard the master alarm go off, they were accustomed to hearing four or five such alarms per day. The frequency of the alarms resulted in them feeling less urgency in responding to them by the time this one life threatening issue emerged. Linenger found that his first oxygen mask did not work, which caused him to fear for his life. The crew also found the fire

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[17] Ibid, 40 and 22.

extinguishers ineffective, as the oxygen canister needed to burn itself out for the crisis to end. But from a training standpoint, the three felt satisfied with their personal responses. Linenger's training as a doctor also came in handy right after the incident when he did medical exams on his crewmates and found that none of them suffered from serious smoke inhalation. If they had not responded as quickly as they did in finding oxygen masks, their health may have been in serious danger.[18]

Linenger also became the first American to train for and perform an EVA in a Russian *Orlan* suit. After briefings covering the design of the suit, he climbed into the Hydrolab, Russia's equivalent of the NBL, for 46 hours of EVA training. This facility was similar to Houston's version in several ways, from the depth of the pool, to the length of the runs, to the team of scuba divers ready to offer assistance. It did contain one system unique to Russia: a suspension system connected to the spacesuits that offset their weight, which simulated the weightlessness of space and let spacewalkers understand how to maneuver within their suits while in this condition.[19] When he actually went outside *Mir* on April 29 with Vasily Tsibliev, he did encounter one surprise: the sensation of falling. He believed that astronauts who performed EVAs on shuttle missions felt more contained due to the presence of the massive payload bay. But his training prepared him well to install an optical properties monitor and radiation dosimeter as well as retrieve several materials exposure panels.[20]

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[18] Ibid, 67 and 91-93 and "Jerry Linenger Debrief, June 16, 1997," in "Debriefing Notes and Forms," Box 14, Folder 62, Rick Husband Collection, Texas Tech University, Lubbock, TX.

[19] Anderson, 154.

[20] "Jerry Linenger Debrief" and Morgan, 96.

As it turned out, the fire was not even the most severe crisis of the year. On June 25, England native Mike Foale was onboard when a *Progress* resupply ship remotely controlled by Tsibliev collided with the *Spektr* module and caused a pressure leak. The crew heard a hissing sound as *Mir's* life sustaining air escaped into the vacuum of space. When Tsibliev saw a pressure meter drop toward 600 millibars, with 540 millibars needed to maintain consciousness, the three men knew their lives were in jeopardy and time was quickly running out to isolate the leak. Their training had taught them to avoid panic in situations like this one and had given them the knowledge to seal off *Spektr* from the rest of the station. This required disconnecting cables that ran through the hatch between *Spektr* and an adjoining node, then popping a hatch cover into place. The crew avoided losing consciousness just in time, but the disconnection of those cables and the tumbling of the station after the collision resulted in a power loss. How were they supposed to stop the tumble and point the solar arrays toward the Sun while their computer was knocked out by the power outage? Foale answered by holding his fingers up to a field of stars to estimate *Mir's* spin rate, evoking memories of sailors from centuries past. When he radioed his estimate to Mission Control in Moscow, the flight controllers fired an engine to stop the spin. He also kept a star watch while Tsibliev sat inside a *Soyuz* spacecraft, so that he could shout instructions to his Commander in firing *Soyuz* jets as a way to orient *Mir's* solar arrays toward the Sun.[21] The crew therefore succeeded in saving their lives and restoring power to *Mir* thanks in part to Foale's skill.

Despite his safe return aboard *Atlantis* on October 6, Foale's mission stirred

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[21] Morgan, 105-111.

controversy about the wisdom of continuing Shuttle-*Mir* that reached the highest level of the U.S. government. Blaine Hammond, the Chief of the Astronaut Office Safety Branch, sent letters to NASA Inspector General Roberta Gross arguing "that politics of cooperation had come to overshadow NASA's judgments on safety and technical integrity." He also argued that the Russians were being too secretive by withholding training information from the five Americans who had now flown on *Mir*. He even wrote about the crises thus far, "We may not be so lucky next time and, in my personal opinion, there will be a next time, it's just a matter of when and how bad."[22] Although Shuttle-*Mir* Program Manager Frank Culbertson had to assuage criticism of the project by testifying before Congress, several review boards determined that the effort should continue and NASA Administrator Dan Goldin gave the green light. The review of the program did lead to some changes from a training standpoint. Tsibliev had not rehearsed the remote controlled docking of a *Progress* vehicle in more than four months when the collision happened, resulting in the Star City instructors admitting a mistake in training him and vowing not to repeat it. Foale had not been briefed about the test of the manual docking system, another mistake that needed correction.[23] In the future, the Americans on *Mir* would have the chance to offer "safety and mission assurance" inputs for critical mission events.

But Foale's actions after the crisis happened bore the mark of a well-trained

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[22] William J. Broad, "Top Safety Official for Astronauts Says NASA Ignored Warnings about *Mir's* Dangers," *New York Times*, May 28, 1998.

[23] "System Failure Case Studies: *Spektr* of Failure," *Space Safety Magazine* Vol. 4, Issue 11 (November 2010): 1-4 and Morgan, 114-116.

crewmember. Not only did he nearly lose consciousness after the collision, he lost access to the *Spektr* that had been his bedroom and housed many of his experiments. He could not even reach his own toothbrush, needing to borrow Tsibliev's until another *Progress* arrived on July 7. He needed to spend many hours mopping up water and ethylene glycol. In a mission that still had several months to go while trapped inside this confined space, a person without his training might have lost patience or willingness to perform assigned tasks. Yet he displayed his professionalism and determination by saying just before his return that his successor David Wolf should continue the program. In explaining why, he said, "Really, I think it comes down to the fact that, even though this flight has been one of the hardest things I have ever attempted in my life, I have to remember what John F. Kennedy said when I was about four years old…He said, 'We do not attempt things because they are easy, but because they are hard, and in that way we achieve greatness.'" His mission epitomized better than any other why expedition training later became such a valuable resource for space station crews. ISS instructor Marc Reagan remembers that Foale was one of the Shuttle-*Mir* crewmembers who recommended the training expeditions to distant landforms and the ocean floor that would give crews experience in working together in a hostile environment.[24]

The last two missions for Americans on *Mir* went more smoothly, although not without the challenges that reminded both astronauts and instructors that international long-duration spaceflight was still in its infancy. When Wendy Lawrence was disqualified from long-duration flight because she did not fit within the size limits of the

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[24] Morgan, 111-114 and Author Phone Interview with Reagan.

Orlan suit, David Wolf had to test whether a backup crewmember could step in and be trained adequately. "The training accelerated in the last month because suddenly I was going flying in a month or so instead of five or six months," he recalled. "I was a backup, and that was invoked very late in the game, and I felt full of energy and ready to tackle that."[25] Compressing his EVA training from six months to about three weeks especially posed a challenge, because he had to spend mornings through evenings every day in the Hydrolab or in classroom instruction. But despite this and his knowledge that people ranging from journalists, to politicians, to former astronauts did not want Americans to continue going to *Mir*, Wolf did not feel worried. He explained that training helped him to push worry out of his mindset: "I had studied the systems for quite a long time. I had discussed all of the failures with the people that experienced them and knew the most about them. I had a good plan of action should such similar problems occur again or any other such problems that were anticipated, and I was extremely comfortable with the mission as a result of the training and the closeness to the issues." He had to perform a four-hour EVA, improvise manual procedures to command a solar array to deploy, recover from a temporary power loss, weather the loss of Russian E-mail communication, and complete 36 experiments during his four months aboard *Mir*, but he persevered. Andy Thomas then wrapped up the Shuttle-*Mir* program with a four and a half month mission in 1998 that was the smoothest yet.[26]

After Thomas returned aboard shuttle *Discovery* in June, Aleksandr Aleksandrov

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[25] David A. Wolf, Interviewed by Rebecca Wright, June 23, 1998, Houston, Texas, http://www.jsc.nasa.gov/history/oral_ histories/Shuttle-Mir/WolfDA/WolfDA_6-23-98.htm (accessed February 4, 2017).

[26] Morgan, 122-148.

and Yuri Kargopolov collaborated with William Brown and Tommy Capps on the chapter of a joint report that evaluated training. The authors generally praised the training process, citing the crewmembers' ability to perform scientific research and maintenance on the aging *Mir* as strong points. But they also made three primary suggestions in looking forward to the ISS. First, astronauts should be proficient in the Russian language before beginning training on the *Soyuz* vehicle. Training for this task in the Shuttle-*Mir* program "was hampered by the poor knowledge that some of them had" of the language. Second, all members of a crew should train together as often as possible. During Shuttle-*Mir*, the replacement of cosmonauts did not coincide with the replacement of astronauts. For instance, Andy Thomas had to spend time with Anatoly Solovyov and Pavel Vinogradov for just over a month and Talgat Musabayev and Nikolai Budarin for just under four months. Thomas did not have the chance to train adequately with all four of these people before launch. On some flights, a Russian Commander did not even trust an astronaut to perform operations because the two had not trained together. Training for ISS missions thus needed improvement in preparing astronauts for staggered increments. Third, the authors cited the argument of all astronauts and cosmonauts involved in Shuttle-*Mir* that ISS training should focus more heavily on psychological preparation. In addition to dealing with the stress of the aforementioned crises, astronauts had experienced sensory and social deprivation while spending several months aboard *Mir*. The authors thus suggested a longer training period for ISS crewmembers, including training under extreme conditions.[27]

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[27] Nield and Vorobiev, eds., 143-177.

By the time Andy Thomas returned, the first ISS crews who hoped to benefit from the implementation of these suggestions were already in training. Bill Shepherd, Sergei Krikalev, and Yuri Gidzenko were selected in 1996 as the crew of Expedition 1. By 1997, the crews of Expeditions Two, Three, and Four had been formed (with the U.S. and Russia alternating Commanders).[28] Whereas their predecessors prepared for their stay on *Mir* solely in Russia, NASA had the responsibility of creating a training infrastructure for forthcoming ISS components that the U.S. would contribute such as the *Unity* node and the *Destiny* science laboratory. When training to operate individual systems in these components, crews could use a laptop interface to study them. "There's a lot to learn about how the systems work, how you can monitor them, and respond to anomalies—all from the laptop interface," Greg Chamitoff explains. Engineers also constructed mockups of the planned modules to size at JSC's Space Vehicle Mockup Facility so crewmembers could rehearse physical procedures in them. Finally, engineers constructed yet another facility for electronic simulations. This facility featured communications, data, and live displays for the crewmembers as they worked with Mission Control to solve simulated malfunctions (although, as discussed later, the astronauts did not believe this facility offered sufficiently high fidelity at the outset). Thus crews had several methods of training for a mission that drew on the technological advances of the 1990s.[29]

By all accounts, training for these first ISS crews drew upon past spaceflight

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[28] Morgan, 134.

[29] Chamitoff, E-Mail Correspondence with Author.

programs as a guide. "The early ISS instructors talked with experienced shuttle instructors to find out what they knew, and we also read lessons learned from *Skylab* and *Mir*," confirms Lucia McCullough.[30] Greg Chamitoff elaborates on this point, explaining, "Countless aspects of training were very similar to that for the Shuttle, because in many cases things were just an evolution of a previous approach. For example, things like photo operations, meals, housekeeping, communication style, and procedure format began in a similar fashion to Space Shuttle operations." In addition, the first ISS crews worked with a Station Training Lead who followed them throughout the training process just as Training Leads had done with shuttle crews. As had been the case for many years already, these Training Leads worked with crews as they progressed from studying individual systems, to electronic simulations that were integrated with Mission Control, to large scale simulations that took days and involved all the personnel assigned to the mission solving malfunctions inserted by SimSups.[31] Thus although Shepherd was the Commander of a groundbreaking Expedition 1 mission, he could feel comfortable that training for this was an iterative process that drew on what had worked during the Space Shuttle program he had represented on three earlier missions.

Similar comments apply to an even greater extent to his training in Russia, where instructors drew on what had worked in training crews for *Mir* missions (the old space station deorbited and burned up in March 2001, with no funding left to support it). Shepherd, Krikalev, and Gidzenko trained in a mockup of the *Zvezda* living quarters

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[30] McCullough, E-Mail Correspondence with Author.

[31] Chamitoff, E-Mail Correspondence with Author.

while in Star City, which Chamitoff remembers as “essentially the core of the *Mir* base block with a few upgrades.” After spending a lot of time training in the *Zvezda* mockup, crews found that their operations were almost exactly the same as onboard *Mir*. Moreover, the Russian training for the ISS was given by the same senior instructors who trained all previous crews for *Mir*. Different from the U.S., where JSC contained hundreds of people working in different aspects of operations and who were quite fluid with respect to job changes, the Russian hierarchy typically consisted of a senior person with one apprentice. Those people knew everything about a system and there was little to no mobility between groups. Even when Chamitoff went through training in Star City several years later, the senior instructors could say that they had trained every single person who had ever sat in a *Soyuz* capsule or flown on *Mir*. These instructors taught largely the same syllabus, with any evolution of the training simply due to additional hardware or software. “While I can’t say that nothing has changed, it is not apparent that training has changed much over the past 20-30 years on the Russian side,” Chamitoff concludes. Thus Krikalev and Gidzenko could each feel comfortable as *Mir* veterans that training for the new ISS was an iterative process that reflected what they had already done as well.[32]

Even so, Shepard, Krikalev, and Gidzenko were pioneers who went through a more demanding training process than the shuttle crews who had come before them and the ISS crews who have come after them. The three men trained from 1996 until their

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[32] Ibid.

launch on October 31, 2000 due to delays in launching their *Zvezda* living quarters.[33] Besides the daunting duration of the training flow, the process challenged them due to the sheer number of details the three of them needed to know. The crew needed to become experts in each of the major ISS systems: Command and Data Handling, Communications and Tracking, Operations Local Area Network, the Inventory Management System, Guidance, Navigation, and Control, the Electrical Power System, the Thermal Control System, the Environmental Control and Life Support System, Structures and Mechanisms, and Robotics. Shepherd, Krikalev, and Gidzenko learned all of these systems in high detail by working with one instructor for each system, each of whom worked for a Station Training Lead (STL) who oversaw all of them. Thus STL Marc Reagan had his hands full trying to coordinate the activity of all the instructors who worked with the crew and the crew had their hands full learning about this complex station.[34]

Though the experience Shepherd, Krikalev, and Gidzenko had from previous programs certainly helped them understand those systems, Chamitoff notes that differences quickly emerged in learning ISS systems. “Much of that is a transformation due to the use of computers for everything from procedure following to command execution,” he explains. “The ISS systems were monitored and controlled via thousands of displays on a laptop. The procedures were both hard copy and electronic, but

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[33] Rex Hall, David Shayler, and Bert Vis, *Russia’s Cosmonauts: Inside the Yuri Gagarin Training Center* (Chichester, UK: Springer-Praxis, 2005), 294-299.

[34] “Space Station Systems Training,” *NASA Human Spaceflight*, https://www.spaceflight.nasa.gov/shuttle/support/training/iss training/systems.html (accessed February 6, 2017).

typically executed from a computer display as well. So the mechanisms of operation and the training to go with it changed to adapt to this new paradigm."[35] Software skills thus became more important than ever if crewmembers hoped to succeed in 21st century spaceflight, as in so many tasks throughout the world.

Besides the intensive training with Reagan and the systems instructors who he oversaw, Shepherd also encountered a challenge with the amount of time he had to spend away from home. He made four or five one-month visits to Star City per year beginning in 1997 with Krikalev and Gidzenko. He went through classroom lectures on the *Soyuz* spacecraft, *Zarya* module, *Zvezda* living quarters, EVA, the *Orlan* suits, and the Russian language in sessions which took place every day from 9 a.m. to 6 p.m. Though most of the instruction was theoretical and based in a classroom, he did receive several hours of practical instruction inside the simulators for the *Zarya* and *Zvezda* modules. He also underwent physical training in a personal gym located in the American Houses basement, which contained weight machines and aerobic equipment. For outdoors exercise, he ran a track around Star City and in nearby woods that covered over 3 miles round trip. He also received two days of survival training, a holdover from the Shuttle-*Mir* era. The instruction progressed until Shepherd was ready for his oral exams, some of which took place in a classroom and some in the simulators. The day before the exams, he took part in a review session during which he could ask any question he liked as a way to prepare. Then the instructors administered the exams, which lasted about one hour each, before giving Shepherd a grade from 1 (fail) to 5

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[35] Chamitoff, E-Mail Correspondence with Author.

(excellent pass). Clay Anderson remembered 5 as the standard grade that astronauts received.[36] As Shepherd went through all of this, he learned about the family separation that made ISS training less glamorous than shuttle training. His commutes to Star City were frequent enough that he described the process as very hard on him and his wife Beth.[37]

As Shepherd commuted between Houston and Star City, Marc Reagan developed his own memories as the STL coordinating training for the Expedition 1 crew. He describes the process of negotiating between the U.S. and Russia on training requirements as contentious. "The Russians had a model of Shuttle-*Mir*, where the American astronauts came to Russia, learned Russian, and received all of their training from Russian instructors," he recalls. "But now there were agreements that the language to be used on the ISS would be English and Expedition 1 would have an American Commander. This was a significant departure from the Shuttle-*Mir* days." The departure from that Russian-centric model resulted in clashes concerning how much time each crewmember would have to spend in which country and what language each would have to speak in training. The Russians did win the argument that Americans would have to speak Russian while training in Russia. They also won the argument that Americans would have to spend one year in Russia to train on the *Soyuz* spacecraft, even though this seemed excessive to the Americans. The two sides even had to decide on which holidays to recognize. Russians celebrated Christmas in the first week of January,

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[36] Hall, Shayler, and Vis, 300-303.

[37] Warren E. Leary, "Men in the News: The Crew of the International Space Station," *New York Times*, November 3, 2000.

not on December 25, so the sides had to make a decision on whether Shepherd should train on Russia's Christmas Day. Reagan remembers Shepherd as having strong opinions in sorting out these issues, as the ISS Deputy Program Manager before being assigned to the crew and a strong willed former Navy SEAL. "It was very contentious, yet it also led to very close friendships, some of which endure to this day," Reagan reflects. "This was because we worked so hard in trying to meet a common goal."[38]

As if learning a new language and commuting between two nations to learn systems and operate simulators on an expert level was not enough, Shepherd had still more tasks to fulfill during those years from selection in 1996 to flight in 2000. A NASA official even created a pie chart to explain how training time was divided back in those early years of the ISS. Shepherd, Krikalev, and Gidzenko trained to make an EVA should it become necessary. This was the largest part of the chart. Next came robotics operations, although this crew was scheduled to return before the delivery of the station robotic arm so they would not have to worry about operating an arm of their own. They did have to train to work with the *STS-97* and *STS-98* shuttle crews that would visit them, making sure the ISS systems reacted properly to the addition of new components as the shuttle robotic arm installed them. Next came payloads, which meant training to operate the equipment that would arrive on the shuttles and *Progress* resupply vehicles. Though the primary purpose of the mission was to activate station systems and participate in the construction of the outpost, the payloads did include a few scientific experiments. Next came medical operations, as the crew needed to know how to care for

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[38] Reagan, Phone Interview with Author.

one another during the 140 days they would be in space. Next came ISS simulations, meaning the time honored process of working with flight controllers and SimSups before flight. Next came learning each of the ISS systems mentioned earlier. Finally, the crew needed to learn how to respond to three life threatening potential emergencies—fire, depressurization, and toxic spills—and learn photo/TV operations. There was no wonder that Shepherd, Krikalev, and Gidzenko needed such a lengthy training process given the number of demanding tasks they needed to pioneer for a new program. The three men needed to take on a "jack of all trades" mentality.[39]

The three men had to confront yet another challenge during these first years of the ISS program: those simulations that took up a significant portion of that pie chart were not yet as high fidelity as they were later in the program. Their colleague Jim Voss, then training for the second mission that followed theirs, quickly answers "No" when asked if the electronic ISS simulator in Houston accurately represented the real station during the late 1990s and early 2000s. "We did have computers that could issue commands, but even the screens for the computers were not fully developed when we were training," he says. "We learned a lot instead by looking at real hardware before it launched and then we looked at it when we got on orbit." He praises the training in Star City as far superior to the training in Houston at this time. "The Russians had modules up there that were like *Mir* modules," he remembers, echoing Chamitoff's comments. "They had very high fidelity mockups on the ground, which contained functional

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[39] "How Training Time is Divided," *NASA Human Spaceflight*, https://www.spaceflight.nasa.gov/shuttle/support/training/iss training/piechart.html (accessed February 6, 2017).

systems that looked exactly the same as the real modules." Thus the first American residents of the ISS—Bill Shepherd, Jim Voss, Susan Helms, Frank Culbertson, Dan Bursch, and Carl Walz—could rehearse realistic operations in Star City but not so much in Houston. Like the astronauts who had successfully inaugurated new programs before them in *Mercury*, *Gemini*, *Apollo*, *Skylab*, and the Space Shuttle, these astronauts would have to christen the ISS despite having a simulator in a primitive state.[40]

Mark Sonoda gives a technical explanation for the discouraging state of the ISS simulator in Houston from his experience as a Station Training Lead. The real ISS featured a computer called the Multiplexer/Demultiplexer (MDM). The simulator had to emulate the MDM, but "when we started training for ISS we only had Functionally Equivalent Unit MDMs," Sonoda explains. "The FEU is basically a test unit that the avionics and software folks use for testing the flight software. It was high fidelity on the normal operation of the MDM, but not good at training malfunctions." Sonoda remembers having to compensate for this by using an alternative method of presenting a malfunction that was not supported by the simulator. "For example, if the simulator could not accurately simulate a computer failure, we as instructors would find out all the signatures the crew and flight controllers would expect to see and we would either mock that up on a paper copy of the display or tell the astronauts something like, 'on display XXX you see YYYY message,'" he recalls. When told of Voss's comments, he says, "I agree, the facilities we had when he was training were very primitive and limited in

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[40] Author Phone Interview with Voss.

capability."[41] A 2014 document on lessons learned from the International Space Station supports the comments of both Voss and Sonoda, stating, "For the first ISS crew, the training facilities and crew procedures were not fully ready. As crews for increments 1-4 were going through training, we provided information on everything we thought they needed to know based on our best estimate of the operational concepts both for individual systems and the integrated system. It was a painful startup experience."[42]

But all of these challenges thrust upon them in training were still not enough to derail them from a successful mission. On October 31, 2000, the three men launched from Baikonur aboard a *Soyuz*. For the 136 days from November 2, 2000 to March 18, 2001, they went through an Expedition 1 mission in which they benefited from training that was more skill based than task based. Space Shuttle Mission Specialists who performed dozens of experiments during a brief mission needed heavily task based training to prepare them for what they knew they would have to do every day. But these three made greater use of skill based training, because their days in orbit were not filled with those predetermined tasks. There were tasks they knew they would have to perform and did, such as activating the station's life support systems, computers, and the Crew Health Care System in the initial weeks, performing a small number of experiments, and helping the *STS-97* and *STS-98* crews in their construction missions. But in general, their work aboard the ISS was different than the shuttle experience because it was more spontaneous. Every afternoon, they communicated with flight controllers in planning

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[41] Mark Sonoda, E-Mail Correspondence with Author, January 24, 2017.

[42] David M. Lengyel and J. Steven Newman, eds., "International Space Station Lessons Learned for Space Exploration" (Houston: JSC, 2014), 46.

sessions concerning what they would have to do the next day.[43] Then the crew would have to make use of the skills acquired during training to fulfill the flight controllers' requests. They had to deal with issues like the stationary bicycle and treadmill breaking down, or malfunctions in the oxygen generation and carbon dioxide scrubbing systems. In short, Shepherd, Krikalev, and Gidzenko had to become maintenance technicians. They had learned how to troubleshoot during four years of training and, despite the lack of simulation fidelity, still managed to overcome all malfunctions on the strength of their systems knowledge.[44]

Yury Usachev, Jim Voss, and Susan Helms were up next as the Expedition 2 crew, reaching orbit aboard *Discovery* in February 2001 and entering the station for the first handover ceremony from one crew to another. Voss offers yet another perspective on the difference between American training and Russian training based on his experience as a backup during the Shuttle-*Mir* program and nearly four years training for Expedition 2. He remembers the "very detailed level" of systems knowledge the Russian instructors drilled into him. "When things went wrong, you're expected to use your brain to figure out what happened," he explains. "It's a lot less simulator procedural based than in the United States. It's like, hey, our carbon dioxide removal system broke. What do we think is wrong with it? It's not a matter of following a flow chart through, it's a matter of using your brain a bit more." He remembers the

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[43] "Expedition 1 Press Kit," *NASA Human Spaceflight*, October 25, 2000, https://www.spaceflight.nasa.gov/station/crew/exp1/exp1_presskit.pdf (accessed February 7, 2017)

[44] "Bill Shepherd Interview," *NASA*, October 27, 2010, https://www.nasa.gov/mission_pages/station/expeditions/shepherd_interview.html (accessed February 7, 2017).

cosmonauts he worked with as helpful during these challenging times, including Commander Usachev. "They were all helpful and taught me to overcome the language difficulties," he says. "There were a lot of things that Usachev helped us with since he had made two six-month flights on *Mir*. He was very experienced and taught us some very practical things that you don't get in training." Though Voss and Helms were both U.S. military officers who had served during the Cold War and understood the irony of now working under a Russian Commander, they knew Usachev's knowledge was an asset they could draw upon in training and flight.[45]

This crew had to christen another critical aspect of training, because the *STS-100* crew sent the robotic arm to the ISS during their stay. Operating the arm required training even for veteran shuttle crewmembers because this arm was much larger than the shuttle arm and able to reach distant workstations on the ISS that the shuttle arm could not. "For three years we've been training some with the Canadians and some with our own people," Helms recalled before the flight. "And having flown the shuttle arm before, I would say that the station arm is about ten times more complex; there's a lot more to it. It's got a lot more flexibility; it also has a lot more redundancy." Her training took her to the Canadian Space Agency headquarters in Saint-Hubert, Quebec, which housed a virtual reality system in which she could watch a simulated arm move in three dimensions. She praised the virtual reality simulations as crucial in making her task of installing the *Quest* airlock that a shuttle crew had delivered onto the ISS as simply as possible. By making a large rotational movement around the elbow, Helms

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[45] Author Phone Interview with Voss.

installed the airlock that astronauts use to make EVAs outside the ISS to this day.[46]

This crew dealt with an increasing emphasis on science experiments from Expedition 1 to their stay, as they performed 18 experiments over their 163 days on the ISS. Still, the comments of Voss and Helms suggest that training for and operating the experiments was in a primitive state as well. Helms remembers asking several questions about the life science experiments "where we were the guinea pigs," but most of the experiments were autonomous. In most cases, "we just had to set up the experiment, put it in place, turn it on, do a few steps to activate it, and periodically monitor it and extract data to send to the ground," Voss recalls. The two do not remember doing much training for these experiments, because this was not necessary in those early years of the program for experiments far less complex than those that crews carry out today.[47] The ISS was still far away from reaching its full scientific potential at this point.

One way in which this crew did have to call on their training concerned their response to the frequent caution and warning alarms that marred their stay. While in Star City, Usachev, Voss, and Helms used fire extinguishers and emergency masks in case a situation like the one Jerry Linenger had faced repeated itself. On their first night alone on the ISS after the departure of shuttle *Discovery*, a smoke alarm went off. "That was because some dust had been picked up," Helms remembers. "We did not have a fire. But we went through the emergency procedure because this alarm went off. I felt like the training we had for that was sufficient. What we had to accomplish in real

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[46] "Preflight Interview: Susan Helms," *NASA Human Spaceflight*, http://www.spaceflight.nasa.gov/station/crew/exp2/inthelms. html (accessed February 7, 2017).

[47] Author Phone Interview with Helms and Author Phone Interview with Voss.

time, though, was to discern the difference between a false alarm and a real alarm. We did not smell smoke or see flames, so we had to ask, 'What could be the issue here?' We also had a lot of issues with over annunciation of problems on the space station. We were up there 163 days and we had something like 900 plus caution and warning alarms." Despite the alarms and a computer crash in the *Destiny* laboratory, Usachev, Voss, and Helms left the ISS in a larger and better state than they had found it when they returned in August 2001.[48]

As the missions progressed, the training burden on crewmembers decreased. Instead of four years, crews began training for 24-30 months. Meanwhile, the fidelity of simulations that were electronically integrated with flight controllers and SimSups increased. This removed another burden by allowing crewmembers to train more effectively for malfunctions. When asked about the fidelity of simulations, Greg Chamitoff's answer is very different from Jim Voss's because their missions were seven years apart. By the time Chamitoff trained for his Expedition 17/18 mission in 2008, he found that fidelity had grown high enough to give him a strong degree of confidence about working in orbit. Some of the system racks in the *Destiny* laboratory simulator might have been missing, for instance, but he explains that "it is a game of diminishing returns once you've matched things well enough for the specific training at hand."[49] Mark Sonoda again has a more technical answer on how fidelity improved. "We went from FEUs to simulate the MDMs aboard the space station to emulated MDMs on

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[48] Author Phone Interview with Helms.

[49] Chamitoff, E-Mail Correspondence with Author.

Single Board Computers to virtualized MDMs within the simulator itself," he remembers. As with all simulators dating back to the *Mercury* program, computer improvements made the most critical difference in increasing fidelity. The added fidelity allowed crews to develop more experience in solving complex failure scenarios that had always been so critical in preparing astronauts.[50]

The training for life threatening emergencies grew more complex and realistic over time as well. Jim Voss recalls when asked about emergency training for Expedition 2, "We couldn't prepare for much because, like I said, the fidelity of our simulations was very low. We really did our emergency training after we got on orbit." But this changed as the years passed. Instructors understood that the safest course of action was to give crews training on the ground. The station grew so radically in the years after Voss's mission that instructors also understood the need to teach crews how to respond to an emergency that might arise in a new location. Though the emergency training focused on just the three main scenarios of fire, depressurization, and toxic spills, "the books to handle them are very thick with countless variations and issues depending on location for these problems," Chamitoff remembers. "So the procedures are involved and so is the training." He recalls the realism as frighteningly accurate as well: "When you see smoke coming from behind a panel, even if you know it is a simulation, you are psychologically 100 percent engaged in the situation as if it was real." When asked if the preparation was sufficient for an actual emergency in space, he answers yes. "That doesn't mean you feel 100 percent ready for anything," he admits. "There's a lot to

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[50] Sonoda, E-Mail Correspondence with Author.

know, but with the help of written procedures and Mission Control, we have done pretty well handling the anomalies that have occurred.[51]

As more and more astronauts reported to Russia for training, the Americans benefited from the written guidance they received concerned their overseas trips. Some of the guidance concerned proper social etiquette, as seen in a manual prepared for NASA by Steven D. Jones of the East-West Business Strategies organization. The astronauts learned, "Alcohol is part of any Russian meal with the faintest trace of 'special' overtones, so as a foreign visitor, you are likely to see a lot of it…Refusing alcohol is a bit dicey socially; it's like rejecting part of the hospitality." They learned the Russian standard of treating women with deference, from holding doors, to helping them in and out of cars and on and off buses, to lighting cigarettes. They learned about the inconvenience of air travel in Russia and the warnings to not take rubles into and out of the country or certain valuable items out of the country without special export permits. They learned that in the midst of all of this, "The key difference is that with our comparatively expensive and colorful dress, Westerners stand out as dramatically wealthy in Russian society." Astronaut David Brown even filled out a "Cultural Awareness Questionnaire for Russian Training" in which he answered questions such as, "An acquaintance surprises you with a present. Do you accept it politely and open it later at home, or accept it with effusive thanks and open it on the spot?"[52] Thus for about the last 20 years, astronauts have benefited from

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[51] Author Phone Interview with Voss and Chamitoff, E-Mail Correspondence with Author.

[52] Steven D. Jones, "Manual for Russian Cross-Cultural Training," December 2-4, 1997, Box 14, Folder 7, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA.

resources designed to help them avoid any embarrassing situations in a foreign nation.

JSC instructors also heeded the advice from the report on the Shuttle-*Mir* program by focusing on giving astronauts psychological preparation for long duration flight and the training that came with it. Astronauts received a Family Support and Separation Guide advising them about how to handle the changes in their families' routines prior to embarking for Star City and then several months in space.[53] They also received a document called "Preparing for Long Duration Space Missions: Discussion & Resource Guide for Astronauts." This document defined the situation in which ISS astronauts found themselves, stating "Long duration flight is qualitatively, as well as quantitatively different from short flight," and elaborated on why with examples from history. Astronauts learned about the effects of personal confinement that emerged at 3-5 months for people at Antarctic field sites or astronauts aboard *Mir*, such as boredom, irritability, reduced motivation, fatigue, reduced short term memory, and disturbed sleep. Explorers at early Antarctic field sites had to deal with depression and suicide due to their unawareness of these issues, while John Blaha reportedly suffered from depression aboard *Mir* and prompted JSC instructors to give this psychological guidance to ISS crewmembers.[54]

The document contained examples of positive and negative cases concerning the psychological effects of long duration flight and helpful suggestions that ISS

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[53] "Family Support and Separation Guide," September 14, 1999, Box 29, Folder 4, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA.

[54] "Preparation for Long Duration Space Missions: Discussion & Resource Guide for Astronauts," April 2000, Box 29, Folder 7, David M. Brown Collection, Smithsonian National Air and Space Museum, Chantilly, VA.

crewmembers read during their training to avoid repeating the negative cases. The suggestions included finding enough engaging work to fill up the day, exercising, communicating with one's family, taking part in personally relaxing activities such as journal writing, letter writing, reading, drawing, and use of a ham radio, and physically removing oneself from the stress of an interpersonal conflict when necessary. Another portion of the document detailed the challenge of maintaining a strong relationship with Mission Control. "Significant stress can be unintentionally placed on crewmembers by the ground organization," the document stated. The document cited incidents from the *Skylab* and *Mir* programs as examples. During *Skylab,* the flight controllers did not adequately understand the real situation that crews faced onboard and overtaxed Jerry Carr, Bill Pogue, and Ed Gibson as a result. The Russians who had flown aboard *Mir* also encountered conflicts, because cosmonauts were often blamed for any problems onboard by flight controllers in Moscow that were more autocratic than those in Houston. The document detailed strategies to overcome these conflicts, such as looking at flight controllers "as part of your team and not another organization" and developing personal relationships with flight controllers during training.[55]

Extreme environment training became another of the best measures of how ISS training psychologically prepared crewmembers. On the recommendation of *Mir* veterans such as Foale, astronauts from the late 1990s to the present have made training trips designed to develop "expeditionary behavior." Greg Chamitoff defines this as "experiences that create personal, inter-personal, and team stresses that must be managed

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[55] Ibid.

and overcome."[56] This began with one's selection as an ASCAN. Clay Anderson remembers traveling to the Brunswick Naval Air Station in Maine with his astronaut class of 1998, one of the first activities the ASCANs undertook together. For two and a half days, the astronauts had to read and follow maps, construct personal and group shelters, search for food using traps and fishing lines, and build fires. A rainstorm on the second day prompted one astronaut to declare in frustration, "This is bullshit!" But after persevering through this experience, ASCANs felt more comfortable in undergoing expeditionary training as mission crewmembers. As described in the last chapter, the *STS-107* and other shuttle crews partnered with NOLS to make productive trips to sites in the western United States. But expeditionary training applied most to ISS crewmembers preparing to spend several months together, because those stresses that Chamitoff mentions were more likely to disrupt missions that lasted for several months. After being assigned to a mission, crewmembers spent one or two days in a classroom learning about expeditionary skills before making trips to extreme locations ranging from mountainous terrain in the heat of summer to lakes in the coldest part of winter.[57]

Chamitoff remembers how his trip to Cold Lakes, Canada in 2000 was applicable to preparing him for a long expedition in space. He explains, "We took turns being leader for the day, while pulling around our supplies and equipment on sleds in temperatures that were often below -4 degrees Fahrenheit and reaching -40 degrees at times. We were rarely allowed time to sleep, and we were continually given tasks that

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[56] Chamitoff, E-Mail Correspondence with Author.

[57] Anderson, 159-179.

stressed the team. For example, we would be told by radio to move our camp to a new location in the middle of the night. Then just after we arrived and got everything set up again, we were told to move again immediately. Managing tasks with thick gloves was a continuous frustration, being cold was a continuous challenge, being tired was a continual stressor, and there were other obstacles, such as cracked skin on fingers that eventually made every task difficult. This brings out emotions and, of course, pushes people to their limits. A situation could certainly arise on a mission in which you need the mental toughness, perseverance, and confidence to get through it. This was certainly practice for such a scenario. Ultimately, this exercise is also a filter, because it is impossible to hide any issues that an individual has. If someone cannot work well as a member of a team during good times and bad, then we probably don't want to be stuck with that person on a small crew on a long duration space mission."[58] Thus Chamitoff and his colleagues had a way of preparing for the psychological aspect of a mission that *Skylab* or Shuttle-*Mir* crewmembers did not have. The training process had become more sophisticated to meet the challenges of the ISS era.

But the most useful expeditionary training came aboard an undersea habitat called *Aquarius*. Bill Todd, who had trained shuttle crews since the 1980s, hit upon the idea of giving ISS crews a chance to live and work underwater off the coast of Florida as an analog for living and working in space. From October 21-27, 2001, he commanded three astronauts (Mike Gernhardt, Michael López-Alegria, and Dafydd Williams) on the first mission of NASA Extreme Environment Mission Operations (NEEMO). The crew

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[58] Chamitoff, E-Mail Correspondence with Author.

spent six days underwater aboard *Aquarius*, living in tight quarters and surrounded by an environment inhospitable to unprotected human life just as the astronauts hoped to encounter aboard the ISS. Again, crewmembers during the *Skylab* and Shuttle-*Mir* programs, or even the initial ISS expeditions, did not have this analog to prepare them for long duration spaceflight. The NEEMO program proved so successful that 21 missions have now taken place. Marc Reagan, a veteran of the second mission and now the Project Manager of NEEMO, points out that the assignment of an astronaut to an ISS mission often closely follows their serving on a NEEMO mission. This underscores just how closely the two operations mirror each other.[59]

Chamitoff calls his 2002 NEEMO expedition one of the best training tools for his ISS mission. "There were mission objectives, and these evolved over time," he explains. "For ours, they were mostly related to science aimed at studying the health of the coral reef. This involved detailed measurements and required careful work outside the habitat to observe, count, and measure coral heads and their relative health. Other exercises outside the habitat attempted to simulate EVA operations, while inside the habitat we had a daily schedule and many tasks that paralleled ISS operations. We even had a live link-up with the ISS and did several PR events with schools and news channel interviews. We also worked with Mission Control as they managed our schedule and activities in a similar fashion to how we operate ISS every day. So NEEMO was a real mission, even if it served as a practice mission for the ISS. It was a fantastic training tool in terms of schedule, life support criticality, procedure following, communications,

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[59] Anderson, 114 and Author Phone Interview with Reagan.

PR events, photo processing, command structure, daily operations, EVA operations, and so on. In short, there was no single training exercise that more closely resembled spaceflight operations or psychologically prepared us more for the real thing."[60]

JSC instructors thus addressed the issues of training fidelity and the psychological aspect of training after the first few expeditions, but life aboard the ISS has not been completely smooth sailing ever since. Like all previous programs dating back to *Mercury*, challenging and unexpected situations arose that demonstrated why crews needed training. Valery Korzun, Sergei Treschev, and Peggy Whitson found this out during their Expedition 5 mission from June to December 2002. The crew had to manually steer the solar panels for hours in order to avoid a total power failure due to a combination of failures. Situations like these are why Greg Chamitoff argues, "The training for off-nominal or emergency response is the most important training we do. In many ways, this is why the human is so useful and effective in space. We have the tools and the training to work around obstacles as they arise."[61]

The Expedition 6 crew faced unique challenges of their own. Ken Bowersox, Don Pettit, and Nikolai Budarin were aboard the ISS on February 1, 2003 when JSC Director Jefferson Howell passed along the news that seven of their colleagues had died in the *Columbia* tragedy. Like sailors on an oceangoing vessel, the crew needed to cope with the psychological burden of a change in their plans. Bowersox and Pettit said they were prepared to spend up to a year on the station if this proved necessary, since now the

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[60] Chamitoff, E-Mail Correspondence with Author.

[61] Ibid.

remaining shuttles would be grounded. "Right away, it wasn't clear if the Russians were going to let them come home on a *Soyuz*," recalls Marc Reagan. "That had not been negotiated, that if the shuttle should end up being lost, a crew would have to come home on a *Soyuz*. Whether the crew had the food and clothing to make it through to the next resupply mission was also unknown."[62] This situation epitomized why JSC instructors had recently emphasized training crewmembers on the psychological burdens they might face during a mission. Pettit reflected of ISS history in general, "Crews have been gone during every holiday, anniversaries, birthdays, recitals, graduations, weddings, family breakups, stock market crashes, wars, terrorist attacks (Expedition 3 Commander Frank Culbertson had received word of the September 11, 2001 attacks and taken photos from orbit of the smoke emanating from the World Trade Center towers), voting, jury duty, death in the family, funerals, and taxes. Death of fellow crewmembers occurred for us when *Columbia* disintegrated on entry…After a short time of reflection, I returned to the ever present work of the mission." The grief and uncertainty following the tragedy did not prevent the Expedition 6 crew from achieving what Petit called "a full pallet of tasks including space station construction, maintenance, and scientific investigations in human physiology."[63]

On May 3, 2003, Bowersox and Pettit became the first American astronauts to return to Earth in a *Soyuz* spacecraft. But their reentry and landing with Budarin produced further drama. A malfunction caused their *Soyuz* to lose its reaction control

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[62] Author Phone Interview with Reagan.

[63] Don Pettit, "Mars Landing on Earth: An Astronaut's Perspective," *Journal of Cosmology* Vol. 12 (October-November 2010): 3529-3536.

system and take the ship onto a ballistic reentry that exposed them to 8 Gs. When the *Soyuz* rolled to a stop, the three were almost 300 miles away from their planned landing spot and the ground support team did not know their location. Making the transition from 161 days in the zero G of orbit, to a sudden and unplanned 8 Gs, to the 1 G of a Kazakhstan field posed a physical challenge for Bowersox, Pettit, and Budarin. But they had withstood high G loads in a Russian centrifuge, like all ISS crews before them, and had undergone medical exams to make sure they were in peak condition prior to launch. Their training helped assure everybody supporting the mission that the three would be physically capable of taking care of themselves, even if they did have to crawl due to their weakened state. Due to their *Soyuz* training, the three could read procedures in Russian to power down the spacecraft. On the strength of their survival training, they then deployed survival gear including woolen clothes, food, water, a medical kit, a portable radio, and a signaling kit containing a shotgun pistol. When a helicopter arrived about three hours later, they fired the pistol to signal their location and were recovered.[64]

The loss of the Space Shuttle for the next two years proved disruptive, because ISS crews that had been training were split up and asked to take on new responsibilities. Because fewer consumables could reach the station without the shuttle flying, the crew size was reduced to two. Ed Lu had planned to fly as a right seater aboard *Soyuz* with Yuri Malenchenko and Alexander Kaleri for the Expedition 7 mission. But since he actually undertook the mission with Malenchenko only, Lu had to train to become a flight engineer aboard *Soyuz* and take on additional duties in ISS maintenance and

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[64] Ibid.

research. "We only had nine and a half weeks from that point until launch," he recalled of the time that the *Columbia* tragedy happened and he received these responsibilities. "So, we're running at about five to ten times normal pace, which means I'm in class with a simulator seven days a week, morning until night, and hit the books after that."[65] Marc Reagan describes crew changes such as this one as the most disruptive aspect of ISS training. But Malenchenko and Lu overcame the adversity of the training sequence over an ambitious 184 day mission filled with equipment repairs and research in technology development, physical science, biological science, countermeasures to the physiological effects of microgravity, and Earth observations.[66]

The challenging and unexpected situations continued during the era of two person crews and continued proving the value of having adequately trained crewmembers. On New Year's Day 2004, Mike Foale and Alexander Kaleri received word from flight controllers that the ISS was suffering a slow pressure leak. The onus fell on the crew to identify the leak and solve the problem, which Foale did on January 11. He used an ultrasonic probe to find that a cable called a vacuum jumper used to equalize pressure between the panes in the *Destiny* laboratory main window was causing a leak. If he did not have the skill to solve this problem, he and Kaleri would have had to take part in a lockdown of the ISS, which would have disrupted their scientific research. The Commander of the next crew, Gennady Padalka, summarized the

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[65] "Preflight Interview: Ed Lu," *NASA Human Spaceflight*, https://www.spaceflight.nasa.gov/station/crew/exp7/intlu.html (accessed February 9, 2017).

[66] Author Phone Interview with Reagan and John Catchpole, *The International Space Station: Building for the Future* (Chichester, UK: Springer-Praxis, 2008), 126-147.

significance of the episode when he said, “the last malfunction—I mean the situation with the leakage—showed us that if we had not had crew on board, we could have lost the space station.” The Expedition 8 crewmembers had the mental and physical flexibility to respond to the surprising development.[67]

The resumption of shuttle flights and the addition of new modules brought up by the orbiters brought new challenges in training ISS crews. Beginning with the Expedition 13 crew of Pavel Vinogradov, Jeff Williams, and Thomas Reiter in 2006, missions consisted of three crewmembers each again. The German native Reiter was the first astronaut not from the United States or Russia to serve as an ISS crewmember, which presented the challenge to astronauts of adjusting to training with people who represented still more cultures. From this point, astronauts rotated onto the ISS in staggered increments. For instance, Suni Williams flew with Michael Lopez-Alegria and Mikhail Tyurin for about four months during Expedition 14 and Fyodor Yurchikhin and Oleg Kotov for about two months during Expedition 15. Then Clay Anderson replaced her to fly with Yurchikhin and Kotov. The Station Training Lead and team of instructors had to account for the need to train all the crewmembers who would be living together, which Williams and Anderson remember as adding expense and complexity. Anderson did not train much with his two Russian colleagues, but became good friends with them and learned he could trust them as an astronaut training for his first flight. “Oleg was extremely capable technically,” he remembers. “Fyodor was good too. He was the Commander, so he was more the fatherly figure for the three of us. When I went

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[67] Catchpole, 153-154.

to Russia, we worked well together. They seemed to enjoy their trips to Houston, for the most part." Just as rookies could draw on the advice of Instructor Astronauts in the United States, they could draw on the advice of Russian and eventually European and Japanese crewmembers for long duration flight.[68]

The addition of new modules also meant new training requirements in Europe and Japan. In 2008, the shuttle added the European laboratory *Columbus* and Japanese Experiment Module (JEM) *Kibo*. This meant astronauts had to travel to the European Astronaut Center in Cologne, Germany and the Tsukuba Space Center in Tsukuba, Japan for training with the new components. Greg Chamitoff remembers receiving extensive training on *Columbus* and *Kibo* systems and science facilities in advance of his Expedition 17/18 mission that year. He was the one who had to set up tons of hardware and configure these modules to begin their science programs, so the trips especially benefited him. "The fidelity of the hardware available in a simulation varies significantly from country to country," he explains. "In Japan we can do high fidelity training in the JEM simulator, and the same for *Columbus* in Cologne." Thus NASA took the expense of sending him overseas to receive training from the instructors who were responsible for these modules and the most accurate simulators of them. Chamitoff remembered being trained to an expert level on these foreign modules.[69] The requirement to learn this new hardware and the experiments that came with it posed new training challenges, but once again instructors adapted to meet them.

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[68] "Preflight Interview: Suni Williams," *NASA*, https://www.nasa.gov/mission_pages/station/expeditions/expedition14/exp14 _interview_williams.html (accessed February 10, 2017) and Author Phone Interview with Anderson.

[69] Author Phone Interview with Chamitoff.

First, a change after Chamitoff's expedition removed the need for everybody needing to train for every single system. Instructors instead required only U.S. astronauts to handle U.S. systems and only Russian cosmonauts to handle Russian systems. Crewmembers did not have to know every system at an expert level, either. NASA introduced the categories of operator, specialist, and user to describe the level of expertise each crewmember would train to develop on a system. An operator needed to know the nominal operation of a certain system. A specialist needed to receive additional training for off-nominal operation. A user received only a brief familiarization session on a system.[70] This cut the training time for the six person crews who occupied the ISS beginning with Expedition 20 in May 2009. Chamitoff recalls the United States was well ahead of Russia on this idea of streamlining training down to what a crew really needed to know. "Russia had the old school idea of one instructor per subject wanting each student to study the entire subject," he explains. "NASA spearheaded the effort to streamline training, which has worked well because there's no reason for a Japanese astronaut to fix a Russian oxygen generator if there are three Russians onboard."[71]

Training also evolved to meet the crewmembers' needs in operating scientific experiments. With American, Russian, European, and Japanese laboratories now part of the ISS, each crew needed to operate an increasing number of experiments (by 2016, one expedition included 275 of them) and in some cases had not trained to operate them for a

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[70] Lengyel and Newman, eds., 46.

[71] Chamitoff, E-Mail Correspondence with Author.

year or more. Chamitoff explains that training for the research suffered due to the many other training needs each crew had. “Of course, we were briefed on the purpose and the science behind each investigation,” he remembers. “We did get hands on training with most experiments at some point in our training flow. However, it typically amounts to single digit hours or less for any given experiment. On the bright side, this has forced investigators to concentrate their training efforts on exactly what they think the crew needs to know.”[72] But the time lag between these meetings with investigators and the actual operation of the experiments posed a challenge for crews. Meeting the challenge called for a technique called “Just in Time Training.” When an astronaut needed a refresher on a certain experiment, he or she could watch a brief video on the ISS and thus train “on the fly” for the benefit of Principal Investigators. “To use an analogy, if I need to work on my refrigerator, I can go to Google and replace my refrigerator filter on a General Electric X598,” explains Clay Anderson. “And oftentimes I can find a video done by an expert who can show me how to do it. That is the principle that led us to change the way we train astronauts, such that they can do it in space for the first time without needing a two or three hour class on the ground. And if that class was three years before they flew, they have probably forgotten it all anyway.” Thus technology enabled this paradigm shift from the training of astronauts in previous programs.[73]

When astronauts have to conduct an especially groundbreaking experiment during an expedition, one technique is to assign an astronaut with a background in that

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[72] Ibid.

[73] Anderson, E-Mail Correspondence with Author.

field of research to that expedition. Kate Rubins earned her Ph.D. in cancer biology before running a laboratory at the Whitehead Institute for Biomedical Research in Cambridge, Massachusetts. NASA selected her as part of the 2009 class of astronauts. She then found herself utilizing her experience in life science during the Expedition 48/49 mission in 2016. She sequenced over 2 billion base pairs of DNA, becoming the first astronaut ever to do so, while performing numerous microbiome experiments. Her presence on the ISS benefited the Principal Investigators who sought new knowledge about the space environment, because she had been a PI herself in Massachusetts and had published and presented her research around the world. Her background provided a way to make sure that the first person to sequence DNA in space would be knowledgeable about the activity, despite the lack of time for detailed science training.[74]

If one were to go back in time and speak to the *Mercury* astronauts, they would undoubtedly express surprise about how the job of astronaut has changed since the 1960s. These astronauts had backgrounds as pilots and spent most of their time preparing for the dynamic events of spaceflight, rather than scientific research. Their successors continued to spend much time preparing for these events until the *STS-135* flight in July 2011, but then the Space Shuttle program ended. The only way for Americans to reach space over the last several years has been aboard a *Soyuz* spacecraft commanded by a Russian. Thus pilot training has given way to training designed to help astronauts understand how space station systems work, how to maintain a space station,

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[74] "Kathleen Rubins Astronaut Biography," *NASA*, https://www.jsc.nasa.gov/Bios/htmlbios/rubins-k.pdf (accessed February 10, 2017).

and how to operate experiments on a space station. “On a given day, the team at Mission Control sends about 3,000 commands to the American segment of the ISS,” Marc Reagan explains.[75] This means that flight controllers now have responsibility for those dynamic events that used to be the responsibility of astronauts, such as controlling a spacecraft’s attitude. Even the robotic arms are now partially controlled by flight controllers.[76] Thus the value of having trained astronauts in space in the 2010s concerns troubleshooting technical issues and making the adjustments or insights required to make the most out of experiments.

With astronauts now having spent over 16 years continuously occupying the ISS through fifty expeditions, the list of scientific investigations has now reached into the thousands and continues to grow. In some cases, the database of knowledge has benefited the future astronauts who will make long duration flights beyond low Earth orbit. ISS residents have returned data on how every component of the human body from ears, to eyes, to bones, to muscles respond to weightlessness over six months in orbit or one year in the case of Scott Kelly and Mikhail Kornienko in 2015-2016. Over the last few years, the breakthroughs that will benefit future astronauts include 3D printing, the growth of lettuce harvested on the station, and the aforementioned DNA sampling. A NASA guide explains in thorough detail how the database of knowledge benefits lives on Earth as well, whether in the form of data on human biology, materials processing, or even a humanoid machine called Robonaut that will have applications in

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[75] Author Phone Interview with Reagan.

[76] Beauregard, E-Mail Correspondence with Author.

medicine and industry. Ever since Expedition 1, crews have also observed Earth and made insights on coral reefs, deltas, glaciers, urban systems, and natural disasters. But the one constant with these experiments is that crewmembers have the training to adjust them, observe them, and speak words about them both in space and on the ground afterwards to Principal Investigators. As the astronauts perform hundreds of experiments per expedition, the PIs continue to benefit from the fact that astronauts are not automatons; they have trained minds to utilize in carrying out new research.[77]

The 2010s have also brought occasional reminders of the flexibility that trained humans can bring in maintaining the ISS. On July 31, 2010, the Expedition 24 crew heard an alarm alerting them of a power loss. Tracy Caldwell Dyson and Doug Wheelock had to work with flight controllers to repower components and ascertain that a module that pumped ammonia coolant throughout the station had failed. Their three EVAs in August to remove and replace the ammonia pump module posed danger because they were working with a hazardous gas, but on the strength of their extensive EVA training the two astronauts solved the problem. In 2012, the failure of a Main Bus Switching Unit reduced ISS power to just five of eight solar arrays, a highly unusual situation. But Expedition 32 crewmembers Suni Williams and Akihiko Hoshide were prepared to make an EVA on September 5 to replace the unit and restore the facility to full power. On May 9, 2013, the Expedition 35 crew reported seeing small white flakes emanate from their outpost and realized with the help of flight controllers that ammonia coolant was leaking. Chris Cassidy and Tom Marshburn made an EVA to inspect and

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[77] *International Space Station: Benefits for Humanity*.

replace a pump controller box suspected of leaking. None of these astronauts could have known during training on the ground that these issues would arise and prompt them to perform these jobs. But the emphasis on skill based training nonetheless gave them the flexibility to maintain the facility. This is another reason why Principal Investigators should feel thankful for the training that astronauts receive; when technical issues arise that threaten the continued flow of scientific data, astronauts have the training to solve the problems.[78]

The psychological training has generally proven effective as well. In addition to the extreme environment training, ISS crewmembers have met with a Behavioral Health and Performance Group during their training at JSC. Five people from this group have been assigned to each crewmember, with one hour meetings taking place at one year, six months, and 30-60 days prior to launch. These meetings cover issues such as training workload and fatigue levels, crew training interactions, NASA management concerns, personal relationships, mood and anxiety, mission challenges and risks, and the crewmember's preferred method of emergency notification in orbit. The person designated as the Crew Medical Officer for each expedition also undergoes training in treating worst case scenarios concerning mood and anxiety disorders, in addition to the training for treating physical ailments. The attention to this matter continues through Private Psychological Conferences (PPCs) that crewmembers take part in every two weeks during ISS expeditions. After going through years of these conferences, Gary

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[78] Robert Z. Pearlman, "Unplanned Spacewalk a 'Precedent-Setting' Move for Space Station Crew," *Space.com*, http://www.space.com/21098-unplanned-spacewalks-space-station-history.html (accessed February 11, 2017).

Beven reported in 2012 that no astronaut had ever reported issues such as physical aggression, major depression, suicidality, or panic attacks during a flight. He also reported that the standard mission featured good morale, friendly relations between American, Russian, European, and Japanese crewmembers, friendly relations with the Mission Control teams throughout the world, personal enjoyment of the mission, optimistic mood, and only occasional frustration concerning high workload, fatigue, lack of sleep, food, and items that broke aboard the station. Thus he concludes that the psychological preparation has proven successful.[79]

The current agreement among the participating nations is to keep the International Space Station operational until 2024, meaning astronauts and instructors are still looking for ways to improve training. The crews of every expedition have taken part in a debriefing covering the training process. Several astronauts have complained that they would be better served by having less training on how the core ISS systems work, which are largely controlled by flight controllers anyway, and having training more focused on the tasks they know they will have to perform. Marc Reagan explains that he and his colleagues have proven reluctant to accept this comment. “If you do have a significant systems failure and you don’t have communications with Mission Control to bail you out, you must have training to safe the situation and not make it worse,” he argues. He calls this the “dynamic tension” between the astronauts and instructors. But the instructors have won the argument by requiring crews to undergo system training,

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[79] Gary Beven, “NASA’s Behavioral Health Support for International Space Station Missions,” (Presentation, Cleveland Clinic Department of Psychiatry and Psychology Grand Rounds, September 13, 2012).

which means crews still train for 24-30 months. The process may not be glamorous or easy on families, but it prepares astronauts so well for their flights that they generally have few noteworthy criticisms. Reagan supports this by stating, “My experience is that in recent years, crews that have come back have not given any groundbreaking training input. The feedback that I’ve seen has tended to be nickel and dime improvements, not radical changes.”[80]

With the Space Shuttle program over, having delivered all of the U.S. components to orbit, much focus has turned to the efficiency of training and operations. “We made numerous changes to procedure execution, planning, stowage, and communications to minimize errors and improve onboard efficiency,” Greg Chamitoff recalls of his last years at NASA prior to leaving the Astronaut Office in 2013.[81] Lucia McCullough, who began her job as the Chief of the Training Branch in December 2016, confirms that space station instructors pride themselves on teaching efficiency to astronauts. “We learned the importance of practicing with tools and finding those tools in the ISS stowage locations so that an end to end task could be done efficiently,” she recalls. “We started building training timelines to incorporate a full task that included coordination with experienced CapComs roleplaying the ground. We used timelines and hardware such as cameras for photo documentation of a task so that crews learned what a ‘day in the life’ was really like.”[82] The initial ISS crews found that it could take two or three times as long to complete a task as was budgeted in a mission timeline, but training

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[80] Author Phone Interview with Reagan.

[81] Chamitoff, E-Mail Correspondence with Author.

[82] McCullough, E-Mail Correspondence with Author.

has helped subsequent crews develop more exactitude in their operations.[83]

What should historians conclude about the legacy of ISS training? The most accurate statement is that instructors have confronted no shortage of new challenges but have met them in virtually every case and have sent well prepared astronauts to the station. This was less true at the beginning of the program. “My general feeling is that the training needs to be prepared early so that the simulators parallel the real hardware,” comments Jim Voss today. This lesson from his experience as an Expedition 2 crewmember should guide future astronauts, instructors, and engineers in charge of developing training hardware. It will not be desirable to repeat the training experience that he and the other early ISS crewmembers had.[84] But future astronauts and instructors will also have an outstanding model to follow from the more recent years of ISS training. Two components of that model are probably most important. First, prior to sending astronauts on a long duration flight, instructors should subject these people to stressors that reveal which astronauts are able to get along in all kinds of situations with all kinds of people. Second, astronauts should receive skill based training that prepares them for unexpected contingencies that are more likely to arise during a long duration mission than a short duration mission like those the Space Shuttle undertook. These astronauts will not need to carry out the incredibly scripted timelines of tasks that Space Shuttle crews did, but will need to know how to remedy failures that could happen at any point during a several month mission.[85] McCullough comments, “The smart person

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[83] Lengyel and Newman, eds., “International Space Station Lessons Learned for Space Exploration,” 48.

[84] Author Phone Interview with Voss.

[85] Author Phone Interview with Reagan.

talks to and gathers as much of the history and lessons learned as they possibly can, from several perspectives."[86] The lessons learned from ISS training are not universally positive, but far more successful than unsuccessful based on the first 50 expeditions.

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[86] McCullough, E-Mail Correspondence with Author.

CHAPTER XVI

CONCLUSION

"We stand at the birth of a new millennium, ready to unlock the mysteries of space," declared President Donald Trump on January 20, 2017.[1] When the 45th President of the United States gave his inaugural address, his nation had indeed moved close to two landmark developments in human spaceflight. The first concerns commercial spaceflight, as the *Boeing* and *SpaceX* companies each hope to launch astronauts to the ISS aboard their own vehicles (named *Starliner* and *Dragon*, respectively) in 2018. This will return the ability to send Americans into space aboard an American spacecraft for the first time since 2011 and will mark a paradigm shift in that astronauts will be riding aboard commercially operated vehicles for the first time.[2] The second development concerns a cone shaped spacecraft called *Orion*. This vehicle made its first unmanned test flight in December 2014, orbiting the Earth for four hours. *Orion* remains on track toward a fall 2018 launch atop the new Space Launch System (SLS) booster, which will take it around the Moon. By 2023, the plan is for a crew of four astronauts to voyage to lunar orbit and perform a flyby of a captured asteroid. Just over half a century after *Apollo 17*, astronauts will finally voyage beyond low Earth orbit

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[1] Donald Trump, "Inaugural Address," January 20, 2017, *The American Presidency Project*, http://www.presidency.ucsb.edu (accessed February 13, 2017).

[2] Loren Grush, "SpaceX Officially Delays First Crewed Flight of its Dragon Capsule for NASA," December 12, 2016, *The Verge*, http://www.theverge.com/2016/12/12/13928844/spacex-crew-dragon-delay-nasa-commercial-crew-program-2018 (accessed February 13, 2017).

again. The current NASA goal is to then send humans to Mars as early as the 2030s.[3] The next twenty years have a chance to be one of the most exciting eras in the history of spaceflight, but to take such revolutionary steps astronauts and instructors will have to evaluate the lessons learned over the nearly sixty years that astronauts have now trained and adapt them to meet new circumstances.

This process is already underway for both of these two developments. Four astronauts are currently training for the first commercial flights aboard the *Dragon* and *Starliner*: Bob Behnken, Eric Boe, Doug Hurley, and Suni Williams. Two of them will make the first flight, a 14 day test mission. As of 2017, they are in the process of rehearsing mission phases aboard part-task simulators that allow one person to sit in front of an instrument panel. “Think of the part-task trainers as our training wheels,” Boe explains. “As we get more familiar with the systems, the training wheels will come off and we will start advancing to the next systems. Eventually, we will work with another crewmember, then with the whole flight control team.”[4] Astronauts are also currently rehearsing for *Orion* flights though water recovery exercises, sessions aboard a mockup at the JSC Space Vehicle Mockup Facility, and sessions aboard an electronic simulator. Since 2013, they have developed experience in the latter by responding to malfunctions during an *Orion*-SLS launch. Engineers have valued the questions and comments the astronauts have made during the simulations as they look to fine tune the

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[3] Mike Wall, “NASA’s *Orion* Space Capsule on Course for 2018 Trip Around the Moon,” September 10, 2016, *Space.com*, http//www.space.com/34021-nasa-orion-crew-capsule-photos.html (accessed February 13, 2017).

[4] Stephanie Martin and Steven Siceloff, “Simulators Give Astronauts Glimpse of Future Flights,” April 26, 2016, *NASA*, https:// www.nasa.gov/feature/simulators-give-astronauts-glimpse-of-future-flights (accessed February 13, 2017).

spacecraft design.[5] But integrated simulations involving an entire crew working with flight controllers are still in the future. Thus the question remains: how will *Starliner*, *Dragon*, and *Orion* training differ from the past and how will it draw on the past?

The flights aboard commercially operated vehicles will necessarily differ from the past because all people who have flown in space to date have done so aboard government operated vehicles. The first *Dragon* and *Starliner* flights to carry crews will take place with heavy NASA oversight and carry the aforementioned veteran astronauts who belong to NASA. But eventually, the companies should develop independence from NASA. Commercial space advocates believe that the notion of companies competing against each other to send people into Earth orbit will result in flights that happen much more frequently and at a lower cost than present, just as airline companies revolutionized aviation in this way. People do not book flights with a government airliner; with a few clicks of a mouse they do so with a commercial airliner and fly to their destinations aboard planes operated by pilots who have received training from the company that employs them. This training reflects the fact that airline companies are profit oriented. If transportation to Earth orbit takes the same form, this will be true for space pilots as well. "I fear that because these companies are profit motivated, astronauts asking for extra training will be discouraged because this will delay a launch," Eileen Collins says. "A company might not have the resources or the time, or a culture might develop where somebody asks, 'What, you need more training? What's wrong

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[5] Michael Harper, "Simulating the new *Orion* Spacecraft," September 27, 2013, *Red Orbit*, https://www.redorbit.com/news/space/1112960299/nasa-orion-spacecraft-astronaut-training-simulator-092713/ (accessed February 13, 2017).

with you? You're not good enough?' That attitude did not develop at NASA, because everybody respected what other people said. Somebody would say, 'Hey, I want another session,' and they would hear back, 'Great!'" But when companies strive to meet high launch rates and collect the profits that come with them, Collins believes that this will place a strain on training. She correctly believes that these companies should emulate the NASA training culture instead.[6]

Collins also cites one lesson learned from the shuttle era that companies should heed to improve upon past NASA training, however: do not overwork astronauts in training. She remembers meeting with one astronaut in the hallway, getting ready for his quarantine a couple of weeks before his mission: "I said, 'How are you doing?' And he said, 'I have never been this exhausted in my entire life!" Astronauts will run the risk of seeing their skills diminish and even getting sick "if you're working 20 hour days and sleeping two hours at night," as she relates. "Some people don't want to admit that they have limits or don't want to delay a launch, so these crewmembers need to be taken care of."[7] Mike Sterling adds based on his experience as a shuttle instructor, "It really is possible to train too much. If your training curriculum is too long, you burden the student and cause issues with proficiency and currency in the tasks and skills that you trained early in the curriculum."[8] Companies will have to resist the temptation of "go fever" that will push them toward training as many astronauts and launching them on as many missions as possible within a short time frame to collect profits. A more measured

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[6] Author Phone Interview with Collins.

[7] Ibid.

[8] Sterling, E-Mail Correspondence with Author.

pace will help astronauts develop their skills and avoid fatigue, not to mention help engineers resolve the kind of technical issues that have caused the *Challenger* and *Columbia* tragedies in the past.

As future crews train for spaceflights, Susan Helms believes another lesson from the past should guide them. “You have to have a sense of mission,” she argues. “I think that’s one of the things that’s very important for the people involved if they’re doing something that’s difficult. That is incredibly important psychologically. I’m not talking about a technical lesson here, I’m talking about a human lesson.” During the long training flows for her five shuttle missions and especially her ISS Expedition 2 mission, then during her time aboard the ISS as well, she felt a psychological boost by knowing she had something beneficial to do every single day. As crews spent long days in training studying detailed procedures, they should keep in mind the “big picture” concerning the importance of their mission. Astronauts in the past have always been motivated to spend long training hours and then fly in space to advance American national interests, and this will continue. Crewmembers of future commercial missions will not be U.S. government employees, however. They must find the motivation of advancing their company’s interests and advancing human spaceflight just as airline pilots advanced aviation when the era of commercial flights began.[9]

Meanwhile, NASA’s *Orion* flights will send astronauts to destinations beyond what commercial vehicles will initially be able to reach. Technological advances will alter the training of *Orion* crews from crews in the Space Shuttle era. The Space Shuttle

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[9] Author Phone Interview with Helms.

orbiters had as many as 10 display screens and 1,200 dials, gauges, and switches. *Orion* will contain just three screens, each the size of a sheet of paper. The spacecraft will even bring up the relevant display page for a procedure the crew needs automatically. Most of the switches will be electronic rather than physical, another critical change from past vehicles. The *Dragon* and *Starliner* vehicles feature similar cockpits in this respect. The improvements in information technology that have made this possible should ease the task of training astronauts. Lee Morin, the astronaut who has worked on the *Orion* cockpit for the past several years, says these changes from the shuttle era will reduce workload and improve coordination between crewmembers. This way the astronauts sitting in the cockpit will need to undergo less training in spacecraft operation and have more time to train for a mission objective like exploring an asteroid, the Moon, or Mars.[10]

Another critical difference that will separate an exploration mission from Space Shuttle or ISS missions concerns the time delay in communications between the crew and Mission Control. When humans voyage to Mars, it will take up to about 20 minutes for the crew to communicate with Mission Control. "Presently, all onboard procedures assume the ability to discuss or ask the ground for assistance or clarification," Greg Chamitoff explains of ISS missions. "Even when communication gaps may exist, they are temporary. Crew autonomy for task execution and for daily planning will have to change dramatically for future operations beyond low Earth orbit. Skill-based training

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[10] Tom Vanderbilt, "America's Next Spaceship," *Air and Space Magazine*, http://www.airspacemag.com/space/americas-next-spaceship-180952126/?page=1 (accessed February 13, 2017).

will have to evolve to a higher level in which the crew is not tied so closely to line-by-line procedures." Chamitoff's words suggest that astronauts on an exploration mission will be trained more like ISS crews than shuttle crews, in that they will need skill based training to remedy unexpected failures that may arise over several months in space. But even ISS crews have the luxury of knowing that help from flight controllers is almost instantaneous. If a crew encounters a dust storm while trying to land a spacecraft on Mars, for instance, help will be 20 minutes away in a dynamic situation. The astronauts will need the skills to determine if they can proceed or not and the skills to make a gentle touchdown on another planet without consulting Mission Control.[11]

Developing those skills in situations where Mission Control is not immediately available is an ongoing process, as former astronaut Steve Robinson explains. As a Professor at the University of California-Davis, he is working with NASA funding to try to quantify human performance in spaceflight skills. "Once you know how to measure how well somebody is doing, then you have a way of comparing different training approaches, different customization, and different environmental effects such as time on orbit, health, G-loads, vibration, and sound," he says. "We have to know how to measure something before we can start changing those variables. We have had success in that. We think all of that is really important in the future, especially for long duration missions far out in space because at some point carrying out tasks will have to be much more self-directed by the crew onboard."[12]

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[11] Chamitoff, E-Mail Correspondence with Author.

[12] Steve Robinson, Phone Interview by Author, February 1, 2017.

Marc Reagan adds that quantifying performance for exploration missions will be different than what instructors are used to teaching from the Space Shuttle and ISS programs. The job for astronauts exploring a near-Earth asteroid, the Moon, or Mars will be about "collecting the most interesting and valuable rocks, and keeping them in a pristine state as you collect them so when they're analyzed, you know they have not been contaminated," he says. "I think that is going to be a big challenge we have not wrapped our heads around so much. For the ISS, the measurement is minutes or hours spent on doing a certain amount of work. But there is a much more qualitative measurement for long term planetary exploration that is a whole different thing from what we are doing now."[13] Reagan's comments suggest that instructors read about the lessons learned from the *Apollo* exploration of the Moon discussed at the end of an earlier chapter. But future exploration missions will differ dramatically from *Apollo* due to the longer amount of time that crews spend on the surface, the much more advanced technology, and the tasks that will go well beyond what the *Apollo* astronauts accomplished in complexity. The famous Mars exploration advocate Robert Zubrin has written at length about what astronauts will need to do to determine if life once existed on the Red Planet. They will have to set up drilling rigs capable of penetrating over half a mile below the Martian surface to reach liquid ground water and the biosphere it might host.[14] This will require work by instructors in determining how to quantify tasks like these, along the lines of the comments made by Robinson and Reagan, and how to train

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[13] Author Phone Interview with Reagan.

[14] Robert Zubrin with Richard Wagner, *The Case for Mars: The Plan to Settle the Red Planet and Why We Must* (New York: Free Press, 2011), 349.

astronauts in them. It will mark a new departure in astronaut training.

Thus there are several obvious differences between the past training of astronauts and future plans, but many chances to draw upon lessons learned from the past as well. Crews of Mars missions will spend several months traveling to the Red Planet (as long as current propulsion technology is used), so their training in classrooms and simulators on Earth will not be fresh in their minds. This relates to the importance of training in space, which is not a new phenomenon and will need to increase for voyages to Mars. Chamitoff cites the importance of Just in Time Training aboard the ISS as one of the critical lessons learned from the past that will benefit the crews of Mars missions.[15] Just in Time Training for Mars missions will probably entail the spacecraft containing video demonstrations of spacecraft systems to aid astronauts in troubleshooting them. Other videos will probably cover the science experiments and drilling operations they will have to conduct on the Martian surface. The pilot will probably have a simulator onboard with which to rehearse landing on Mars, just as Space Shuttle Commanders did for landing on Earth. Another of the lessons learned from the shuttle era, the effectiveness of virtual reality in preparing astronauts to maneuver in space, should also come into play during the long outbound voyage to Mars. Clay Anderson points out that current astronauts would benefit from using cutting edge Oculus Rift virtual reality technology in preparing for EVAs aboard the ISS. “Unfortunately, we do not have an Oculus Rift capability aboard the ISS to refresh astronauts,” he says.[16] But if this issue

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[15] Chamitoff, E-Mail Correspondence with Author.

[16] Author Phone Interview with Anderson.

can be resolved, astronauts would have a way of minimizing the gap in rehearsing their actions which would be especially useful in training to explore the surface of another planet.

Future astronauts and instructors will have to grapple with several other issues that will be familiar to veterans of the ISS experience as well. Greg Chamitoff argues that training for future exploration missions must focus on what the crew needs to know, as a way of streamlining the process to a more reasonable load than what the first ISS crews experienced. He argues, “As vehicles and missions get more complex, it’s important to divide and conquer expertise among the crew. Early ISS crews had to know everything at the expert level, similar to the Shuttle and previous missions. As soon as crew size permits specialization, it should be used to reduce training overload.”[17] In the case of a Mars mission, as Zubrin describes, this specialization will probably take the form of crewmembers who are flight engineers and those who are scientists. The flight engineers will have to know how to troubleshoot the spacecraft that will take them to Mars and the rover they will ride on the surface. The scientists will have to know how to collect the most intriguing samples and analyze them, which will require skills in geology and biology because the most intriguing question of all concerns whether life has ever graced the Red Planet. Part of the crew will specialize on technical issues and part will specialize on scientific issues, which will allow for a streamlined process during the long months on Earth. The crew will then work as a team to integrate their

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[17] Chamitoff, E-Mail Correspondence with Author.

individual knowledge during a Mars mission that will last up to 2.5 years.[18]

Instructors will have a clearer idea of how to prepare crews for those long prelaunch months from experience. They will know about the importance of synchronizing simulations with onboard configurations. “It’s easy for things to get out of sync between training and operations,” Chamitoff states from ISS experience. “There is re-training that happens onboard because of the way things are done by the crew. It’s very important to have feedback from onboard back to the training personnel to assure relevance and currency.” Instructors will know about the importance of training methods that have benefited crews dating back to Alan Shepard’s *Freedom 7* flight: hands-on experiences with hardware before launch and end to end integrated simulations where the crew and flight controllers develop their skills in nominal and off-nominal operations. They will know about the benefit of the Instructor Astronaut program, which Chamitoff calls “an extremely valuable practice.” If exploration missions feature international crews, the instructors who train them will also have to decide whether or not the astronauts need to learn foreign languages. The ISS experience makes clear that language training is a life enriching experience for American astronauts, but places a time consuming burden on training requirements and introduces opportunities for miscommunication and mistakes. Finally, instructors will know about the importance of asking timely debriefing questions concerning training to a crew. “Current ISS crewmembers go through weeks of debriefing sessions that are very useful, but too often the questions come too long after the actual situation,” Chamitoff argues. “Timely

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[18] Zubrin with Wagner, 97-99.

debrief questions and answers should happen on a weekly basis for topics that will be hard to recapture months later." Instructors are easily more prepared to send well trained crews to Mars now than their predecessors were in 1961 to send well trained crews to the Moon, based on this experience of what has worked best in the past.[19]

The lesson that training empowers humans to develop the mental and physical flexibility to contribute to the success of a spaceflight should also drive future exploration. The entire history of spaceflight demonstrates over and over again that vehicles as complex as spacecraft do not function correctly 100 percent of the time, no matter how sophisticated the technology. Humans have increased the reliability of missions with their mental skills in diagnosing problems and physical skills in solving them that they have honed during training, and they will do so again while exploring a near earth asteroid, the Moon, or Mars. The exploration of Mars will especially demonstrate that this flexibility extends to gathering data about another body in this solar system. Mars landers from *Viking* in 1976 to *Curiosity* in 2012 have returned a wealth of data on the geological history of the planet, most notably that it has contained oceans of water potentially capable of supporting life. But the data concerning that search for life has not been conclusive, in part because robots lack the ability to bring trained minds and bodies to the scene of investigation. The mobility to drive a rover around the surface of a planet containing a land mass about the size of Earth's, the drilling operations, the ability to find intriguing rocks, and the ability to take the rocks back into

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[19] Chamitoff, E-Mail Correspondence with Author.

a habitat and subject them to scientific tests, will go beyond the ability of robots.[20] If human explorers ever find life on another planet, they will reach the discovery on the basis of their knowledge about how to perform these tasks and about the principles of life science. Even if this does not happen, human explorers will be able to extract resources from the space environment on the basis of their knowledge. This is why those explorers need to understand the history of astronaut training and what has made it successful.

The training of astronauts from the *Mercury* era through the ISS contains lessons for those explorers who will follow them as well as people in workplaces on Earth. Astronauts have trained under exceptionally unique circumstances, because workers in a typical U.S. workplace do not have the multimillion dollar training devices, or the national prestige associated with their jobs, that astronauts have had for nearly sixty years. But some of the factors that have contributed to their success would also contribute to the success of a workplace in any discipline. The selection committees have picked the most qualified candidates for the job over the years, so as to minimize the amount of training required. Instructors have taken into account the evaluations of the trainees, knowing the training is designed for their benefit. They have placed a strong value on integrated training that has tested the teamwork of all personnel responsible for a task. They have also adjusted the training program when necessary, in light of knowledge from new developments.[21] Astronauts have demonstrated the value

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[20] See Zubrin with Wagner.

[21] Voas, “Astronaut Training,” 171-197.

of successfully cross-training employees time and time again, whether through their work in learning geology during the *Apollo* program or in learning to become doctors during long duration space station missions. Effective responses to emergencies throughout the world also require gifted people willing to cross traditional professional boundaries.[22] The *Apollo*-Soyuz, Shuttle-*Mir*, and ISS programs have involved giving astronauts cross-cultural training, which again has proven successful and which people in business, education, and health services also require.[23]

Two scholars have argued that change is a useful way of understanding the importance of training. "In this environment where change is frequent, the training function cannot allow itself to become the 'dinosaur' of the organization," they write. "It too must explore and introduce new strategies and methods of learning to meet the changing needs of the organization and of its learners."[24] Instructors have met the changing needs of astronauts time and time again, whether through simulator advances to rehearse for changing mission tasks, cultural training to rehearse for changing international objectives, or extreme environment training to rehearse for changing mission duration. The record is clear that though technical failures have plagued numerous spaceflights from *Mercury* to the ISS, the skill of crewmembers on those flights has by and large been an asset and not a liability. All workplaces that involve people performing complex tasks which require training must strive for this record.

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[22] Gregory Bennett, *Cross-Training for First Responders* (Boca Raton: Taylor and Francis, 2010), 8.

[23] Richard W. Brislin and Tomoko Yoshida, eds., *Improving Intercultural Interactions: Modules for Cross-Cultural Training Programs* (Thousand Oaks, CA: Sage Publications, 1994), 3-12.

[24] Roger Buckley and Jim Caple, *The Theory and Practice of Training* (Sterling, VA: Kogan Page, 2008), 2.

There are certainly other fields in which human error has proven to be a major problem. In aviation, for instance, Mike Sterling points out that "Research has long shown that around 70 percent of all accidents are not caused by technical problems but rather by failures in the 'soft skills.' This includes things like communication, decision making, leadership/followership, teamwork, etc."[25] But the examples of human error by astronauts who have taken part in flight beyond Earth's atmosphere are severely lacking. This is why people who train to perform complex tasks should seek to understand what has made astronaut training successful.

When seven young men reported for work in Virginia one spring day almost sixty years ago, they could not have known just what they were getting into. Their pilot brethren mocked them as "spam in a can." But the seven original astronauts and their successors have demonstrated that their skills honed through training have made them anything but "spam in a can." They have not simply gone along for rides, but have increased the chances of mission success through their flexibility in responding to malfunctions and returning scientific data that has advanced human knowledge of the Earth and the solar system. None has ever died during a spaceflight due to an egregious error of their own making. When people go to Arlington National Cemetery to pay their respects to the crews of *Apollo 1, STS-51L Challenger,* and *STS-107 Columbia,* they can take comfort in the knowledge that all undertook their well-rehearsed actions until the end. As for those original seven who began the process, Scott Carpenter, Gordon Cooper, John Glenn, Gus Grissom, Wally Schirra, Alan Shepard, and Deke Slayton have

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[25] Sterling, E-Mail Correspondence with Author.

all made their final voyages now. But they have left behind the memory of their success and the lessons learned that they spurred which astronauts and instructors will have for all time.

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