

BORESCOPE TECHNIQUES APPLIED TO MAINTENANCE PRACTICES ON MARINE HEAVY-DUTY GAS TURBINES

by

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Mr. Moise has spent 19 years working on gas turbines since he graduated in 1955 from California State Polytechnic College with a Bachelor of Science Degree in Aeronautical Engineering, where his thesis subject was "The Demonstration of Aerodynamic Blade Design Through the Use of a Fluid Mapper" published May 5, 1955.

His professional experience includes work at the General Electric Company Aircraft Gas Turbines Division 1955 through 1961 in various capacities of Engineering Design, Thermodynamics Engineer, and Test Supervisor. Subsequent experience included work at United Aircraft Company as Program Manager on various gas turbine development contracts. Assistant Project Engineer on maintenance, lease and service contracts on industrial and marine gas turbines at the Turbo Power Marine Division. During 1970 through 1973 Mr. Moise had a contract overseas where, as General Manager, he was in charge of setting up a gas turbine parts manufacturing facility and service shop.

Since 1973 he returned to the General Electric Company as Manager of Maintenance on heavy-duty gas turbines and presently as Manager, Marine Maintenance and Service in the Customer Support Department of the Gas Turbine Products Division.

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ABSTRACT

This paper describes the maintenance requirements of the Heavy-Duty Gas Turbine in Marine Applications and the accessibility designed into the turbine to allow the operator to carry out both required repair work and classification society machinery surveys within the minimum time dictated by the vessels dry-docking periods and time in port during loading and unloading operations. Because of the marine requirements imposed on present day vessels including fast turn around and maximum availability, it is important to design a maintenance program using all available maintenance tools, such as the borescope, in order to evaluate the internal condition of the turbine with minimum disassembly and outage time.

INTRODUCTION

The combustion gas turbine, as with any rotating power equipment, requires a program of planned periodic inspection, with repair and replacement of parts to achieve optimum availability and reliability. The major structural components of the heavy-duty combustion gas turbine are designed to long-established standards derived

from steam turbine design and manufacture. Major differences occur between the steam turbine and the combustion gas turbine due to the fact that the combustion gas turbine is a complete, self contained, prime mover. This combustion process to develop energy does not require a boiler with its associated limitations; therefore, the cycle temperatures are considerably higher. The parts that are unique to the gas turbine because of this feature are combustion caps, liners, and transition pieces. These, along with the turbine nozzles and buckets, are referred to as the "hot-gas path" parts.

The inspection and repair requirements of the gas turbine lend themselves to establishing a pattern of inspections, starting with very minor work and increasing in magnitude to a major overhaul, and then repeating the cycle. These inspections can be optimized to reduce unit outages, and maintenance cost for the users' specific mode of operation, while maintaining maximum availability and reliability. Inspections can be classified as operational or shutdown. The operational inspections are used as indicators of the general condition of the equipment and as guides for planning the disassembly maintenance program. The entire scope of inspections can be described as standby, running, combustion, hot gas path, and major as indicated in Figure 1.

STANDBY INSPECTION

Standby inspections pertain to visual type inspections performed during unit shut-down. This inspection includes routine service such as clean-up of leaks, changing out filters, checking oil and fuel piping and other general preventive maintenance items.

Careful adherence to minor operating maintenance can and will have a significant effect on reducing overall maintenance costs and maintaining high reliability.

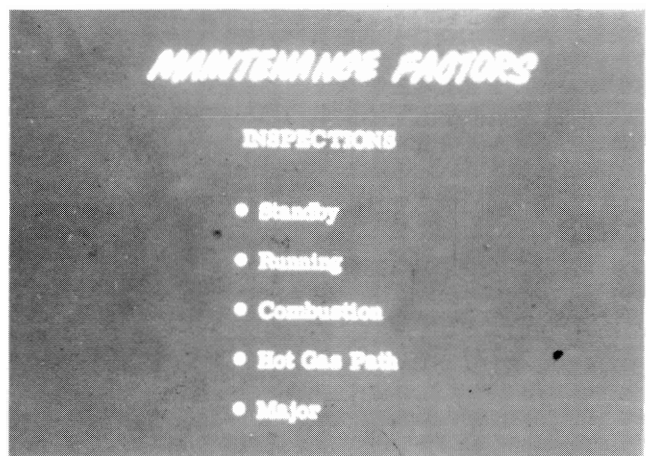


Figure 1. Maintenance Factors.

RUNNING INSPECTIONS

Running inspections consist of the observations made while a unit is in service. The turbine should be observed on a programmed schedule which should be established as part of the unit maintenance program consistent with the operator's requirements.

Operating data should be recorded to permit an evaluation of equipment performance and maintenance requirements. Typical running inspections (Figure 2) include load versus exhaust temperature; vibration; fuel flow and pressure; exhaust temperature control and variation; and start-up time.

SHUTDOWN INSPECTIONS

These inspections are performed at specific intervals when the unit is not in operation. Figure 3 shows a cross section of the 25,000 HP unit indicating specific areas of the turbine that are disassembled for a combustion inspection, a hot-gas path inspection and a major inspection. The gas turbine maintenance criteria and the associated costs are directly affected by the accessibility and ease of maintenance designed into the turbine and associated equipment. Features designed into the heavy-duty gas turbines to facilitate on board maintenance are as follows:

- All casings, both turbine and compressor, are split on the horizontal centerline and may be lifted individually for access to all internal parts.
- With the upper half of the compressor casing removed, all stator blades can be slid circumferentially out of the casings for inspection or replacement. This can be readily accomplished with the rotor in place.
- With the upper half turbine shell lifted, both halves of the first and second stage nozzle assemblies can be removed for inspection, repair or replacement without removal of the turbine rotor.
- All turbine buckets are moment weighed and charted for assembly so that, in an emergency, they can be replaced without rebalancing the rotor. Normally, the rotor balance should be checked after replacing any parts.



RUNNING INSPECTIONS

- **LOAD vs EXHAUST TEMPERATURE**
- **VIBRATION**
- **FUEL FLOW & PRESSURE**
- **EXHAUST TEMPERATURE CONTROL**
- **EXHAUST TEMPERATURE VARIATION**
- **STARTUP TIME**

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Figure 2. Running Inspections.

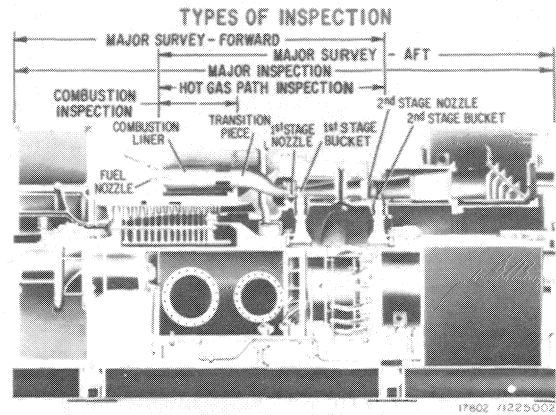


Figure 3. Types of Inspections.

- All bearing housings and liners are split on the horizontal centerline so that they may be inspected and replaced when necessary. The lower half of the liners may be removed with the rotor in place.
- All seals and shaft packings are separate from the main housings and may be readily removed and replaced.
- Fuel nozzles and combustion liners can be removed for inspection, maintenance, or replacement without lifting or moving any of the casings. Removable coverplates close the ends of each combustion chamber.
- All major accessories, as well as filters and coolers, are separate assemblies that are readily accessible for inspection or maintenance. They may also be individually replaced as necessary.

As can be noted, the major inspection for the marine turbine has been divided into two separate inspections in an effort to reduce the down-time required to perform the inspections and at the same time meet the vessel dry docking schedule, and performance of continuous surveys, as required by the Classification Society.

Figure 4 shows the maintenance profile of inspections tailored to the specific need and operation of this vessel assuming a five-year operating cycle and 4,500 hours operation per year.

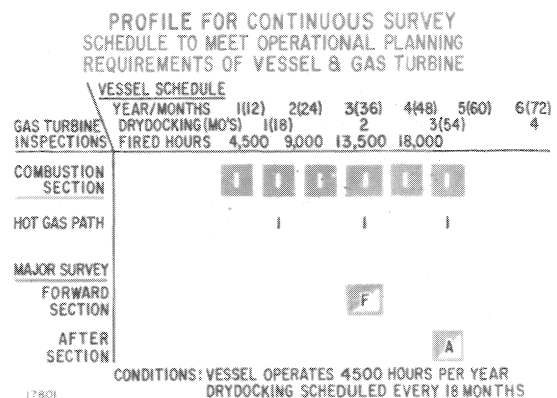


Figure 4. Profile for Continuous Survey.

Figures 5 and 6 show the GTV Iron Monarch. This vessel and its sister-ship, the GTV Iron Duke, are both in commercial service. These vessels are 15,000 DWT roll-on/roll-off steel product carriers owned and operated by the Broken Hill Proprietary Company, Ltd. of Melbourne, Australia. Figure 7 shows the recommended time intervals required for various inspections based on the use of residual fuel.

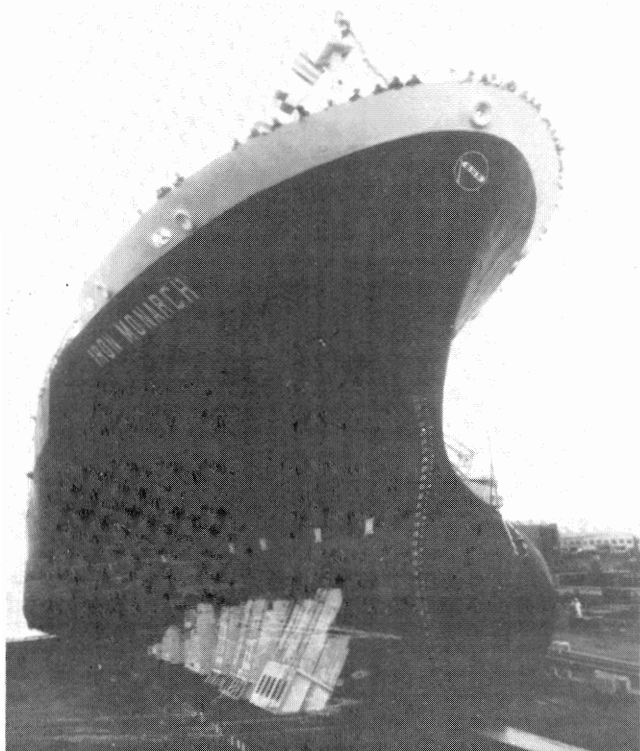


Figure 5. G.T.V. Iron Monarch at Launch.

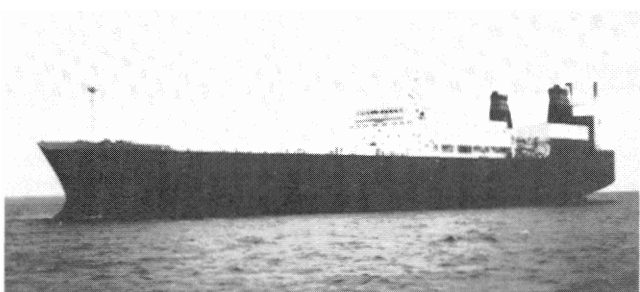


Figure 6. G.T.V. Iron Monarch—Sea Trials.

FUEL NOZZLE INSPECTION

The fuel system should be observed for general fuel flow versus output relationship. Fuel pressures throughout the fuel system should be observed. Changes in fuel pressure can be an indicator that maintenance work is required. Changes in fuel pressure to the nozzles indicate plugging and, when the differential between individual nozzles approaches 10 percent, the nozzles require cleaning. Figure 8 shows the selector valve that allows checking the pressure individually for each nozzle. Low suction pressure to the main pump must be investigated and

GAS TURBINE (RESIDUAL FUEL)	
•	FUEL NOZZLES 750-1500 FIRED HRS.
•	COMBUSTION SECTION 2500-3500 FIRED HRS.
•	HOT GAS PATH 5000-7000 FIRED HRS.
•	MAJOR OR MAJOR SURVEY 20,000-28,000 FIRED HRS.

Figure 7. Time Intervals for Inspections.

corrected to avoid cavitation and unnecessary maintenance. High differential pressure across the fuel filters indicates the need for changing filters. Dirty and improperly maintained fuel filters result in premature plugging of the fuel nozzles and accelerate wear on the fuel metering devices. Proper treatment and handling of fuel is a major factor in reducing and/or eliminating problems with the fuel system.

COMBUSTION INSPECTION

A short "shutdown" inspection is required to change out fuel nozzles and to check the combustion liners and crossfire tubes. These parts require the most frequent attention, as continued operation with a deteriorated combustion system can result in much shortened life of the downstream parts, such as turbine nozzles and buckets. It is also inherent in the gas turbine design that these parts are the first to require repair or replacement. Therefore, the importance of this inspection in the maintenance program must be emphasized.

Figures 9 and 10 show the areas of the turbine that are disassembled for a combustion inspection. The combustion cans can be removed forward for inspections or maintenance without lifting or moving any of the casings. Removable coverplates close the ends of each combustion chamber. Figure 11 shows a combustion liner crossfire tube, vortex generator, and primary combustion holes.

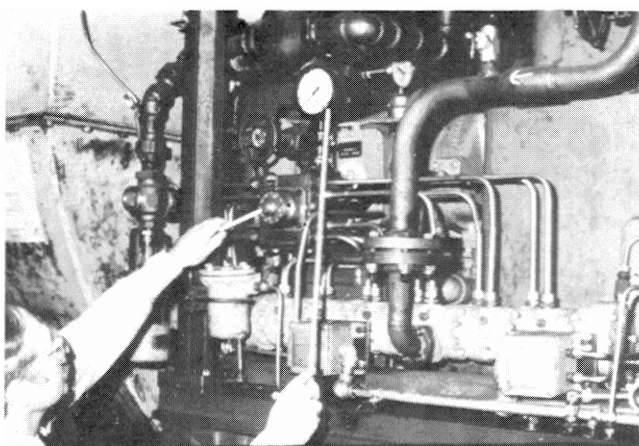


Figure 8. Fuel Nozzle Selector Valve.

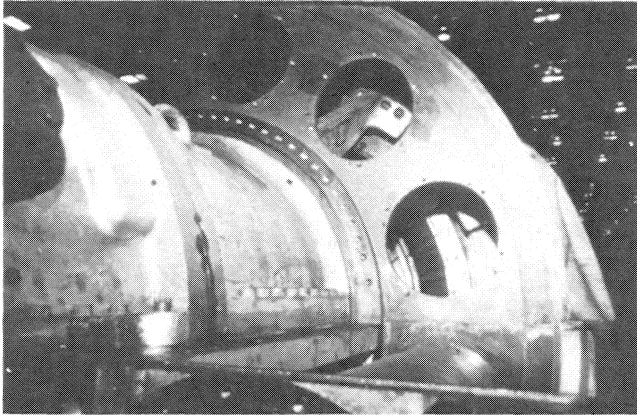


Figure 9. Combustion Can Locations.

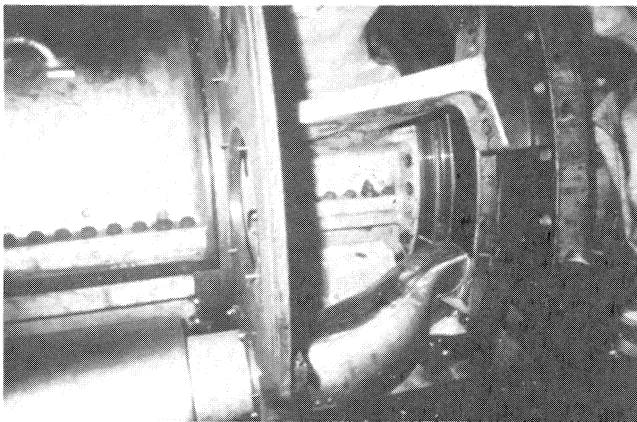


Figure 10. Combustion and Transition Piece.

The inspection should be directed towards checking for cracks around the crossfire tubes and primary combustion holes. If cracks are detected as shown in Figure 12, they are easily repaired by welding. In addition to the suggested spare parts for the combustion inspection, down-time can be minimized with an "out and in" policy. Using this approach, no time is used in inspecting or repairing of the various pieces. New combustion liners, crossfire tubes, transition pieces, and first stage nozzles are installed, and the unit is closed up without lost time. The part removed are inspected and repaired after the unit is back in service and held ready for the next "turnaround." This approach provides minimum down-time, maximum-utilization of manpower and equipment, and avoids unscheduled delays that result when parts must be repaired before the turbine can be reassembled.

HOT-GAS PATH INSPECTION

This is an inspection of those gas turbine parts directly exposed to the hot combustion gases. The scope of this inspection includes the work covered in the combustion inspection outlined above, plus internal inspection of the turbine area. This requires removal of the upper-half turbine casing and turbine nozzle assemblies.

Figure 13 shows the first stage turbine buckets exposed after removal of the upper half turbine casing. This work was done in the machinery room on board the GTV

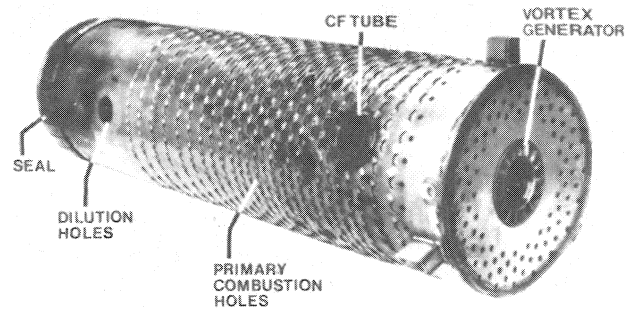


Figure 11. Combustion Liner.

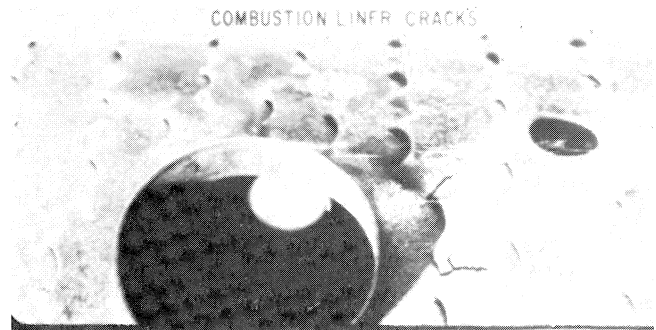


Figure 12. Combustion Liner Cracks.

Iron Monarch for the purpose of training shipyard maintenance crews and engineering personnel. Each one of the buckets is individually balanced and weighed such that if some of the buckets are found defective, they may be changed without rebalancing the rotor. The buckets must be checked by using red dye or zyglo to detect cracks. Figure 14 shows the coverplates being inspected on the first stage buckets. Figure 15 shows the second stage wheel being supported by a typical chain block lifting arrangement in the engine room.

MAJOR INSPECTION

Major inspection should be scheduled for up to 20-30,000 hours or more, depending upon the load, duty, and operating requirements.

Besides that of combustion and hot-gas path inspection, the work scope of a major inspection includes the laying open of the complete turbine at the horizontal joints with the following inspections being performed on individual items:

- Removal of turbine buckets and a liquid penetrant check of buckets, wheel dovetails, and turbine nozzles.
- Inspection of bearing liners, seals, and journals.
- Liquid penetrant check of axial-flow compressor items such as rotating and stationary compressor blading.
- Inspection of the inlet and exhaust sections.

Figure 16 shows the upper half of the casings completely removed and the unit on "half-shell."

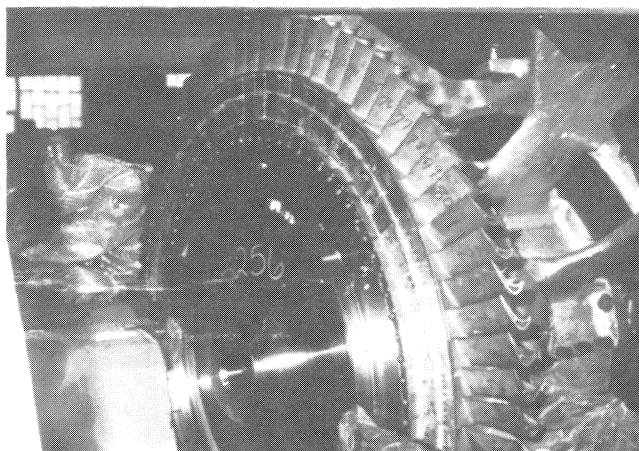


Figure 13. First Stage Turbine Buckets.

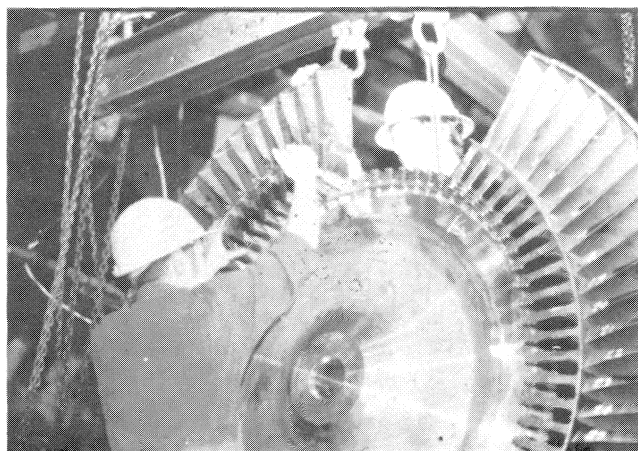


Figure 15. Second Stage Buckets.

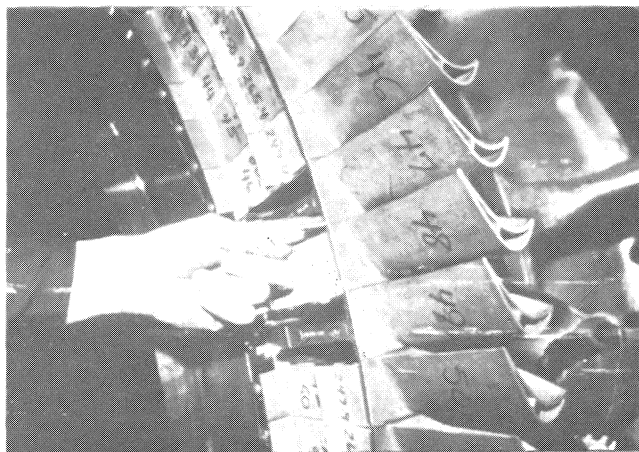


Figure 14. Inspection of Coverplates.

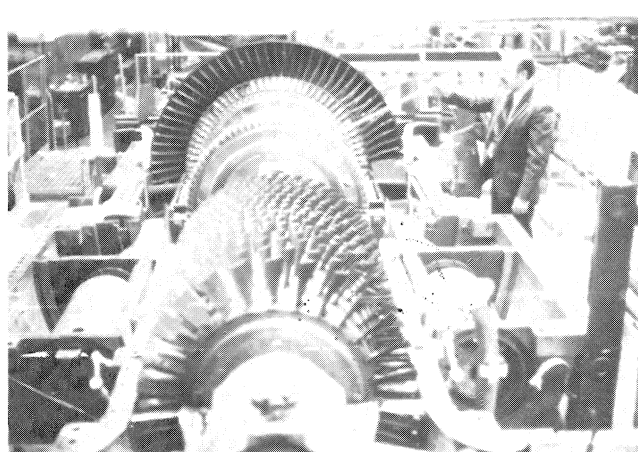


Figure 16. Major Inspection—Unit on "Half-Shell."

The key to performing this inspection with minimum turnaround time is detailed preplanning and organization of the work to be performed. The maintenance engineer must program his scheduled maintenance outage by insuring that the required replacement parts have been identified, have been ordered and are on hand, required special tools are at the site, and adequate manpower is available when needed. The use of periodic borescope inspections will contribute in a great measure towards increasing his ability to predict the replacement of parts required and any other internal problems that can only be determined by visual inspections.

BORESCOPE INSPECTIONS

Borescope inspection access holes are being provided on the General Electric 12,000 HP, 25,000 HP, and 60,000 HP Heavy-Duty Gas Turbine models. These provisions, consisting of radially aligned holes through the casings and internal stationary shrouds, have been designed to allow the penetration of the optical borescope probe through sections of a non-operating turbine for visual observation of the rotating and stationary parts without removing the turbine or compressor upper cases. Figure 17 shows a schematic of the 25,000 HP model

turbine showing the location of the borescope ports and the areas accessible for inspections.

Figure 18 shows a typical borescope access port and its screwed plug. Figure 19 shows the required borescope equipment consisting of a rigid or flexible scope, a flexible light pipe and light projector.

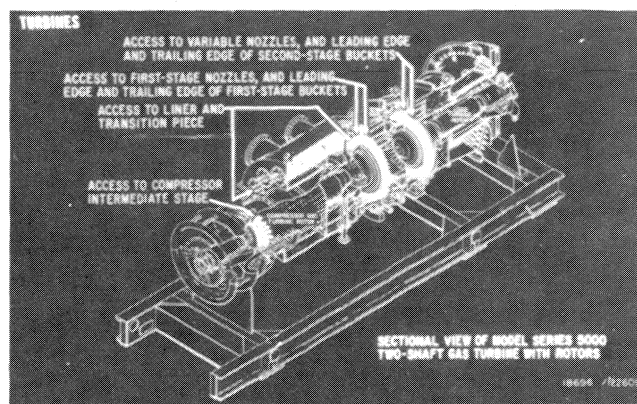


Figure 17. Borescope Planes of Entry.

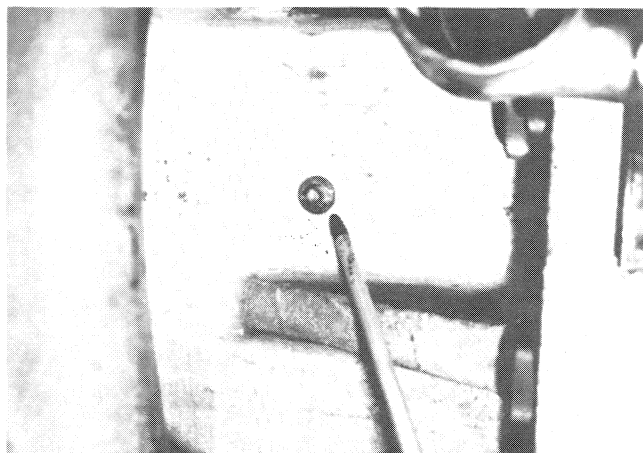


Figure 18. Borescope Access Port.

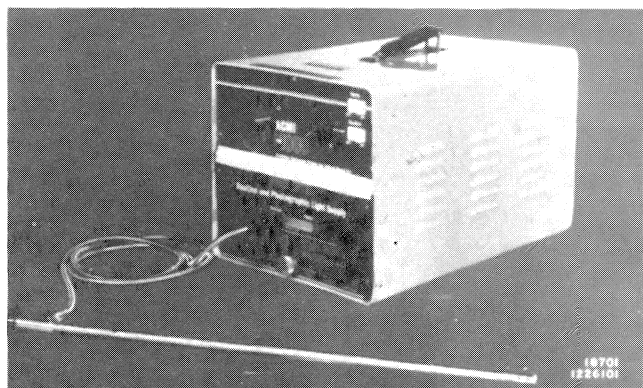


Figure 19. Borescope Equipment.

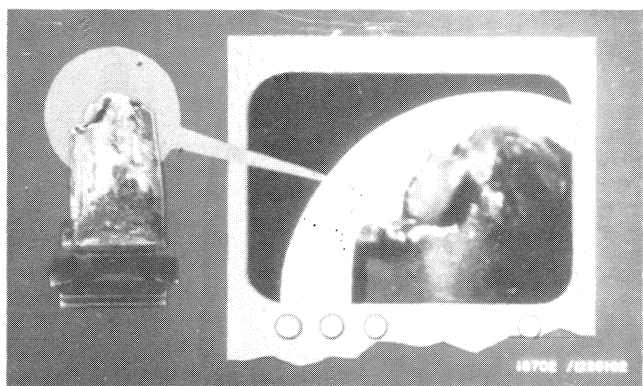


Figure 20. TV Monitor Representation of Borescope Inspection.

Auxiliary items which may be used for making a permanent record of the optical image obtained through the borescope are a 35 mm camera, or as shown in Figure 20, a low-light-level TV camera attached to the borescope eyepiece may be used to present the image on a monitor screen for group viewing.

The inspection access and detail of observation for the compressor and turbine sections is shown in Figure 21.

Figure 22 shows a schematic of a flexible scope inserted through the combustion can through the transition piece and reaching the first stage turbine nozzle and buckets.

An actual borescope inspection sequence of the first stage nozzle area is shown in Figures 23 through 27. As can be seen, the fuel nozzle has been removed from the combustion can (Figure 23 and 24) and the flexible scope inserted through the can and transition piece (Figure 25). The light source and pipe are connected to the borescope (Figure 26) and the actual inspection being performed is shown in Figure 27. A record of the inspection should be maintained and identified such that the planned maintenance program will accumulate a sequence of inspection records to allow the maintenance planner to project rates of deterioration, and determine the current condition of the part in relation to past inspections. These records should commence from "as new" or after a major inspection and will provide continuous monitoring of the condition of the unit through its operation. Figures 28 and 29 show typical borescope record sheets where notation is made on the conditions of the parts inspected. Figure 30 shows a typical time sequence for conducting a complete borescope inspection in the compressor and turbine sections. If the condition of the unit is good and the parts observed are clean, free of deposits or damage, the planned inspection intervals can be considerably extended and optimized to coincide with the hull maintenance and thus allow for minimum turbine down time.

Figure 31 shows that planned borescope inspections performed in conjunction with scheduled inspections can extend the time interval between inspections. Should signs

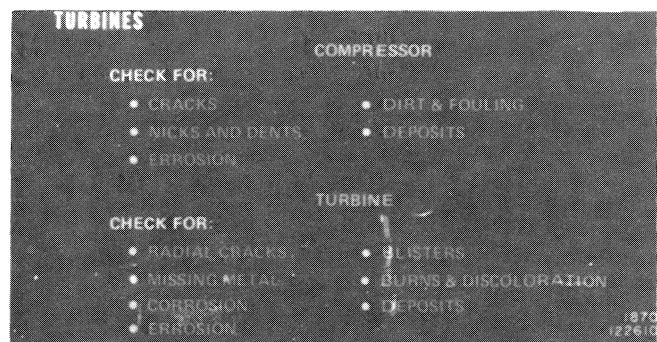


Figure 21. Borescope Inspection Areas.

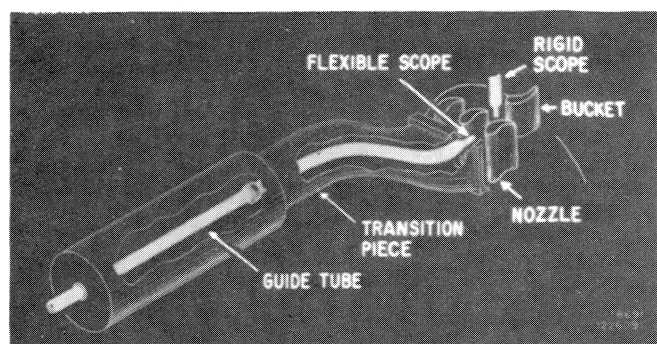


Figure 22. Flexible Scope Through Combustion Can and Transition Piece.

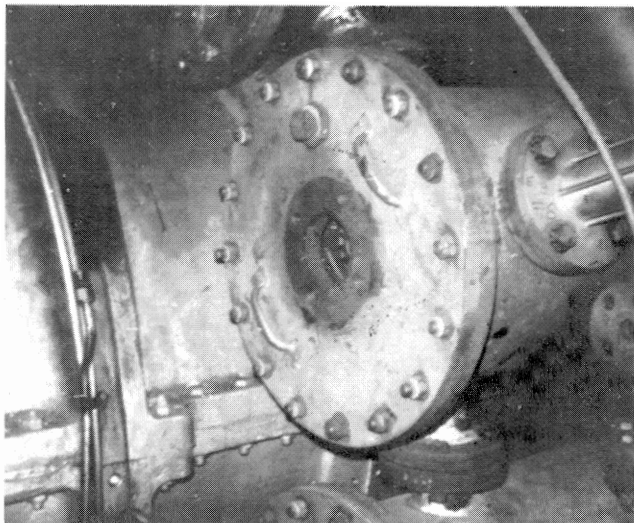


Figure 23. Combustion Can Exposed for Inspection.

of deterioration be detected during a borescope inspection, the maintenance planner has the opportunity to determine his parts requirements and plan the scheduled outage for repair.

The borescope is a monocular device and as a result, inexperienced operators may underestimate distance or size. For example, a component located very close to the probe will appear larger such that a small deposit or dirt particle will be magnified. It is, therefore, necessary for the operator to be trained and qualified to make judgments on component condition. Training, familiarization with the use of borescope equipment, and experience with the components to be viewed as well as the type of deterioration that can occur, will provide the operator with the necessary knowledge to analyze and identify the condition of the parts inspected. Figure 32 shows a borescope view of the first stage turbine nozzle cooling holes. Figure 33 shows fuel ash deposit on the first and second stage turbine buckets before and after nutshell cleanings. Figure 34 shows a small damaged area due to foreign object ingestion at the leading edge of the bucket.

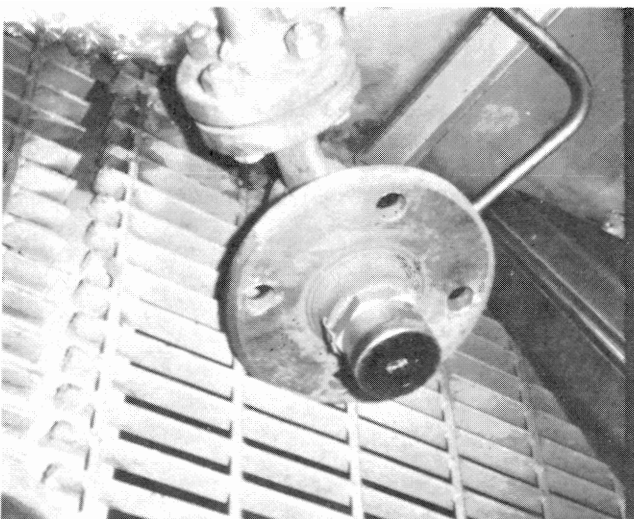


Figure 24. Fuel Nozzle Removed.

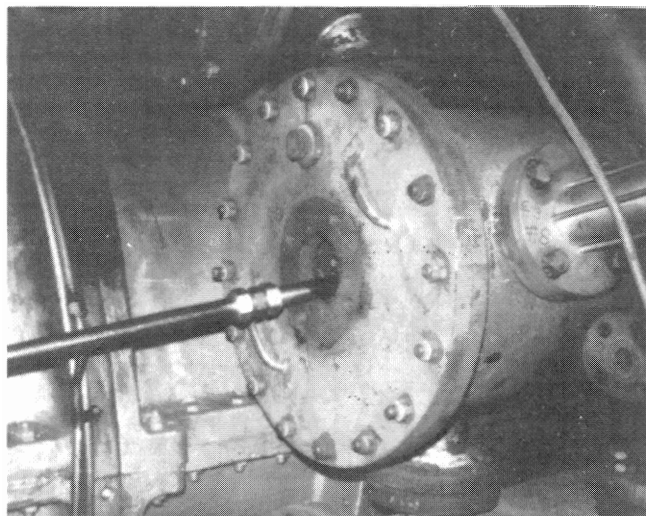


Figure 25. Borescope Probe Inserted Through the Combustion Can.

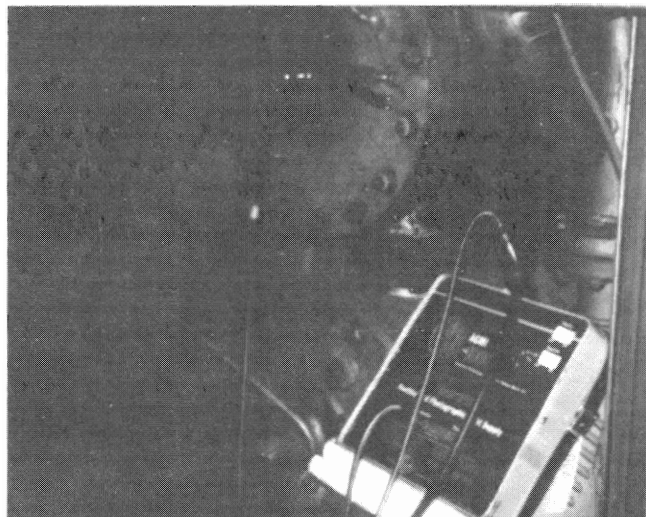


Figure 26. Connected Light Source and Pipe to the Borescope.

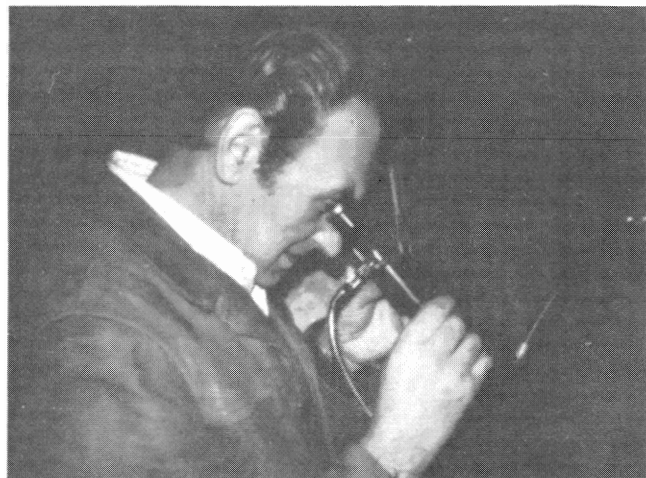


Figure 27. Borescope Inspection Being Performed.

GAS TURBINES

BORESCOPE INSPECTION RECORD

BORESCOPE INSPECTION RECORD		TURBINE S/N	FIRE HRS
		NO. OF STARTS	INSPECTION DATE
TURBINE ROTORS			
BORESCOPE PORT NO.	STAGE	LEADING EDGE	TRAILING EDGE
1	1		
1A	1		
2	2		
3	3		

PHOTO RECORD OBTAINED	CAMERA TYPE/NO.	FILM TYPE	SPEED	RECOMMENDED EXP.	ACTUAL EXPOSURE

18706 1226106

Figure 28. Typical Borescope Inspection Record.

GAS TURBINES

BORESCOPE INSPECTION TIME SEQUENCE

SETUP	REMOVE/REPLACE PLUGS MOUNT/REMOVE FIXTURES 30 MIN/HOLE	TIME
2 COMPRESSOR PORTS 4 TURBINE PORTS <td></td> <td>3 HRS</td>		3 HRS
VIEWING: COMPRESSOR & TURBINE AREAS		3 HRS
REVIEW & PHOTOGRAPH SELECTED PARTS		2 HRS
ANALYZE & REPORT RESULTS		4 HRS
TOTAL TIME		12 HRS
TWO MAN CREW		24 MAN HRS

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Figure 30. Borescope Inspection Time Sequence.

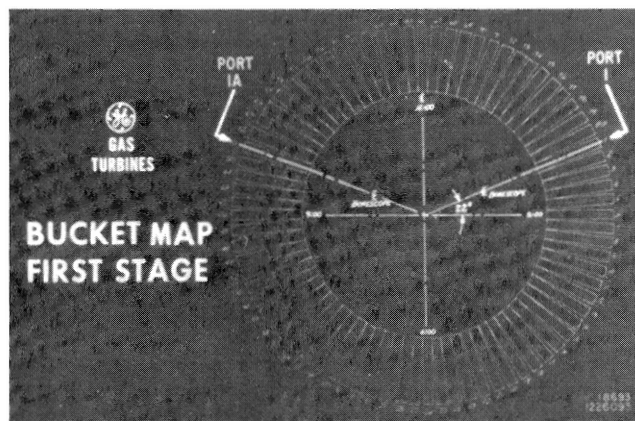


Figure 29. Typical Borescope Inspection Record for the First Stage Bucket.

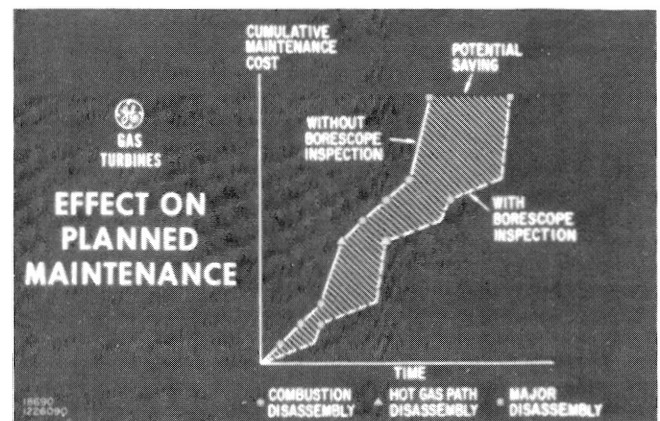


Figure 31. Effect on Planned Maintenance.

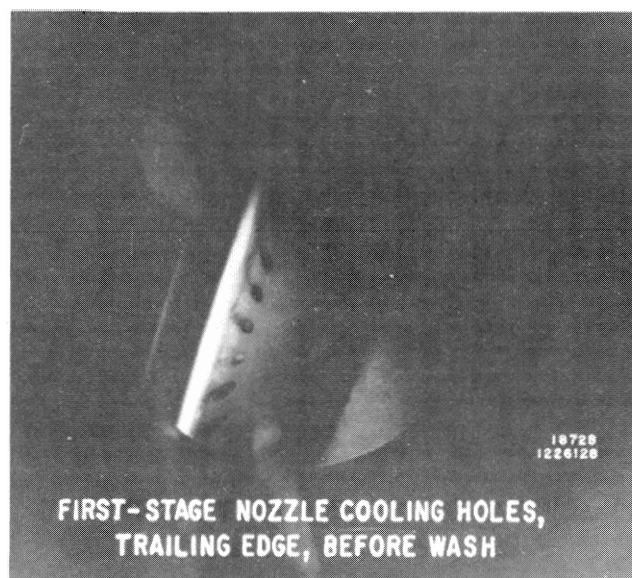


Figure 32. First Stage Nozzle Cooling Holes.

SUMMARY

This paper summarized actual maintenance inspections conducted on heavy-duty gas turbines in marine applications. The engine room space limitations coupled with the requirement of fast turnaround make the use of the borescope technology and equipment an important maintenance tool. The borescope in the hands of a qualified operator permits rapid inspections of the internal condition of the gas turbine plant with minimum outage time, manpower and cost. Figure 35 indicates the ca-

pability of borescope inspections to considerably help in planning a maintenance program based on known machine condition, permitting reliable projections of maintenance requirements to support the owner's decision of down-time economics versus maintenance repair cost.

The General Electric Company Gas Turbine Customer Support Department places high priority in the development of maintenance practices and techniques to increase the availability and reliability of heavy-duty gas turbines, and as results are obtained they will be made available to our customers.

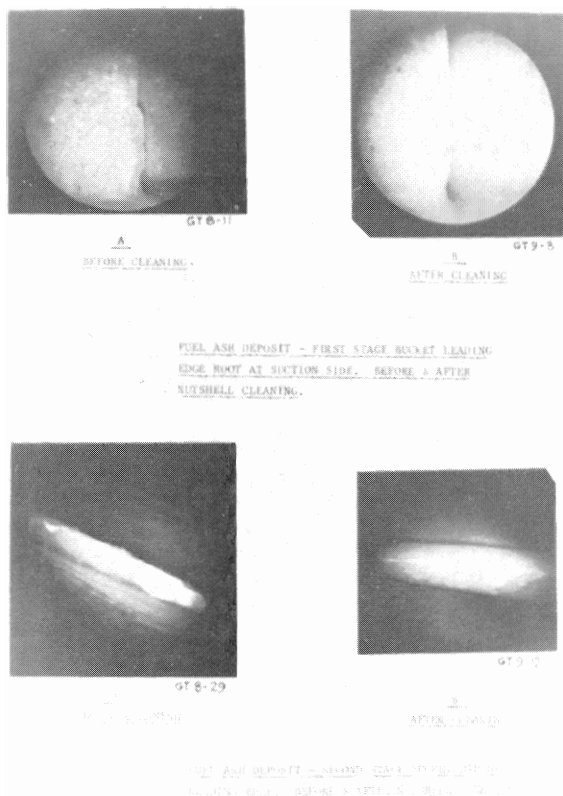


Figure 33. Fuel Ash Deposits as Seen Through the Bore-scope.

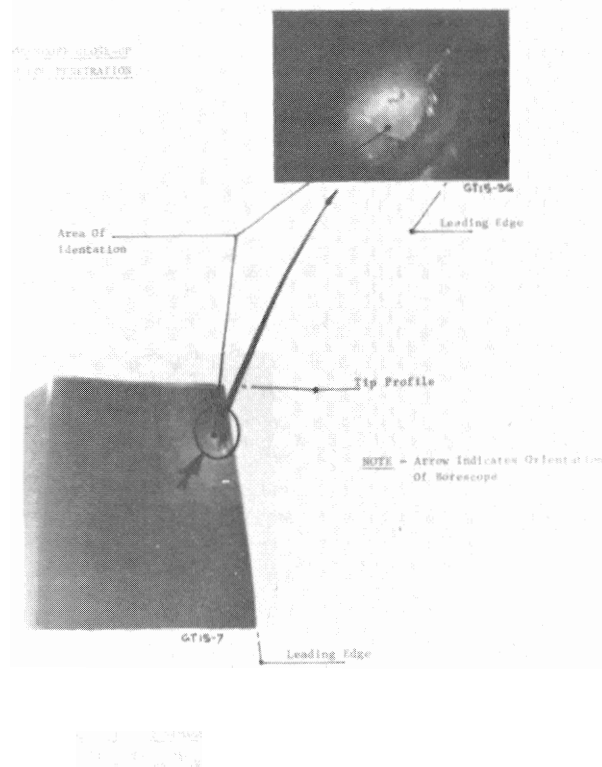


Figure 34. Foreign Object Damage Observation.

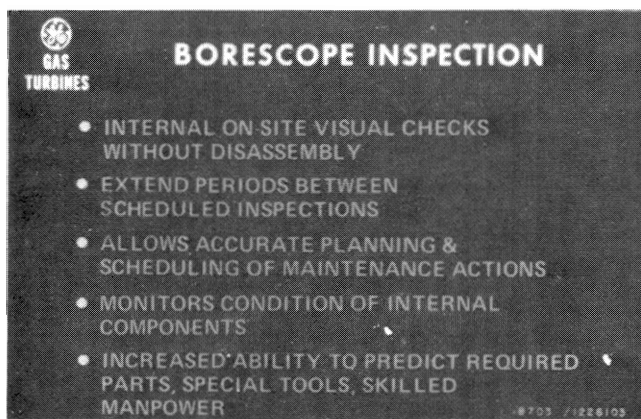


Figure 35. Bore-scope Inspection Advantages.