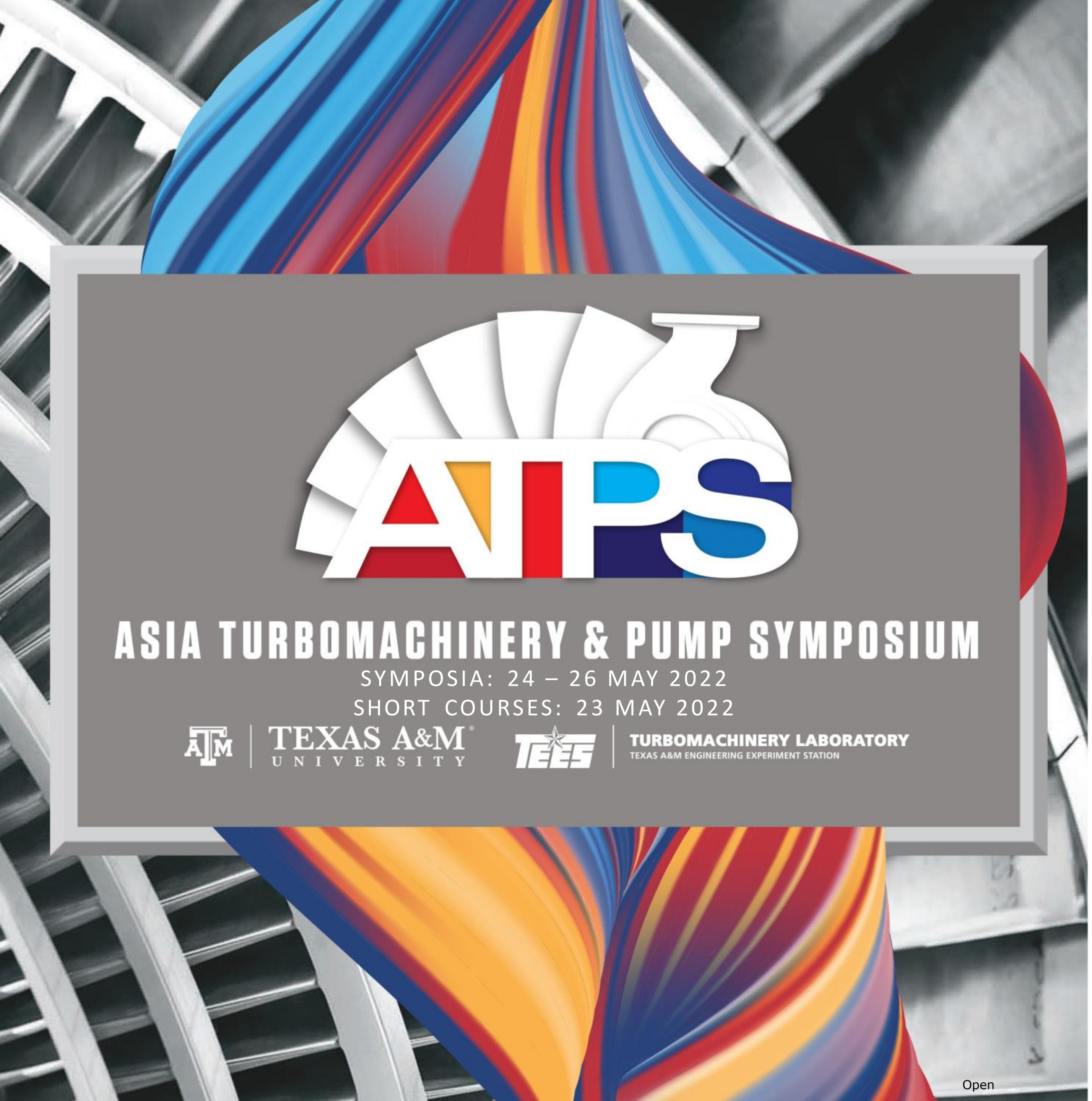


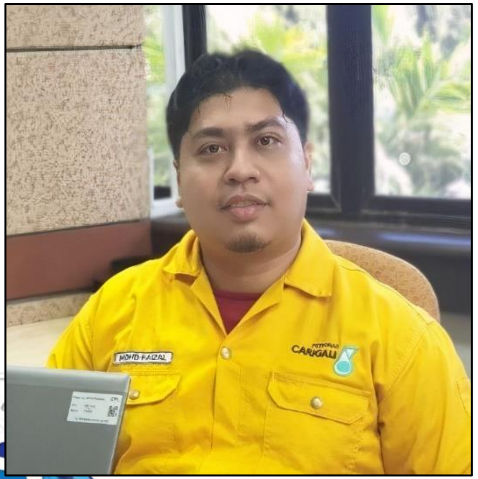
PITTING CORROSION LED TO CATASTROPHIC GAS TURBINE COMPRESSOR BLADE LIBERATION

FADLIL HAFEEZ– PETRONAS
MOHD FAIZAL– PETRONAS

PETRONAS

PRESENTER BIOGRAPHY

Fadlil is a Senior Rotating Machinery Engineer in PETRONAS Carigali Sdn Bhd Malaysia. During his tenure in PETRONAS, his work has focused upon rotating equipment maintenance and troubleshooting. His work over the past 9 years can be summarized as actively involved in machinery upgrading/retrofitting projects, equipment overhaul, refurbishment, and predictive maintenance solution.

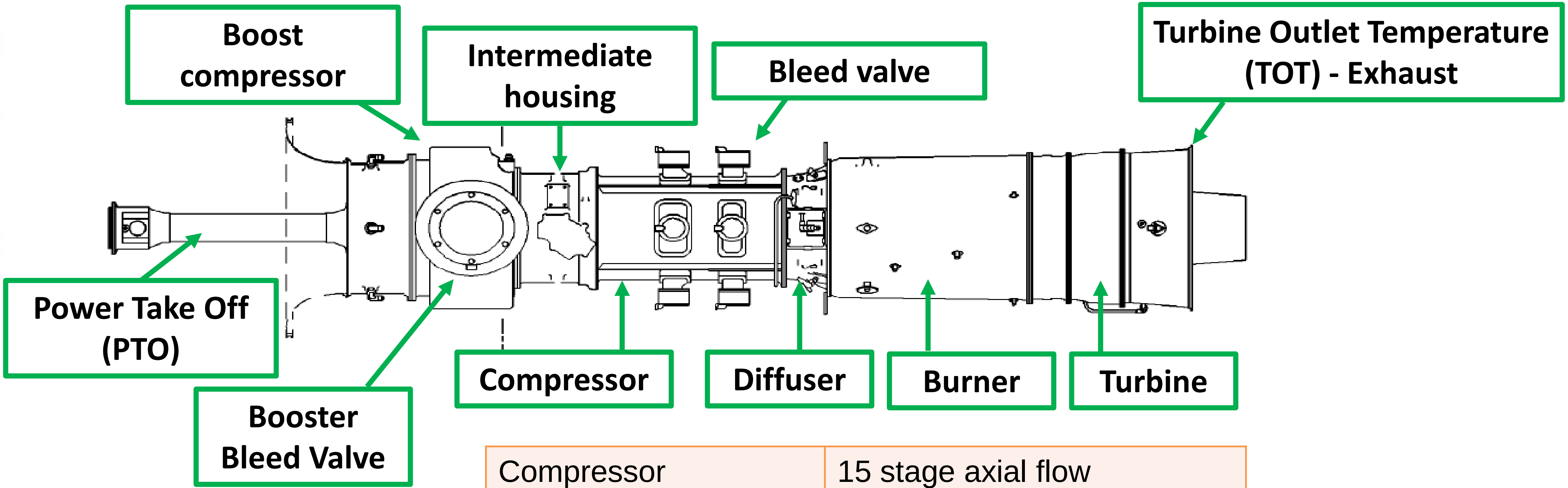


Mohd Faizal serves is a Staff Rotating Engineer for Integration Value Assurance department, in Malaysia Assets, Kuala Lumpur covering various type of machinery troubleshooting, diagnostic, root cause analysis, reliability improvement and maintenance management. He served the organization close to 15 years with multiple job position & roles.

ABSTRACT

A gas turbine's intake system usually has 3-4 stages of filtration. After the primary and secondary filter, the final marine vane separator (MVS) is used. These filters are designed to keep rainwater , debris, and salt from entering gas turbine intake systems. The chemical reaction between salt and MVS can cause flying debris. A MVS made of aluminum will also experience galvanic corrosion caused by sub-micron salt particles. Debris in the air intake system causes erosion, exposing the compressor blade's base material. This process is known as pitting corrosion. In this presented case study, specific examination techniques were used to investigate the traces of debris material at compressor blade in order to relate back to the system weakness to determine the main root cause so that appropriate counter measure can be applied.

ENGINE OVERVIEW



Compressor	15 stage axial flow
Combustor	6 cans
Fuel system	Natural Gas
Turbine	4 stage axial
Power	5.5 MW
Efficiency	30.5%
Exhaust Temperature	513 deg C

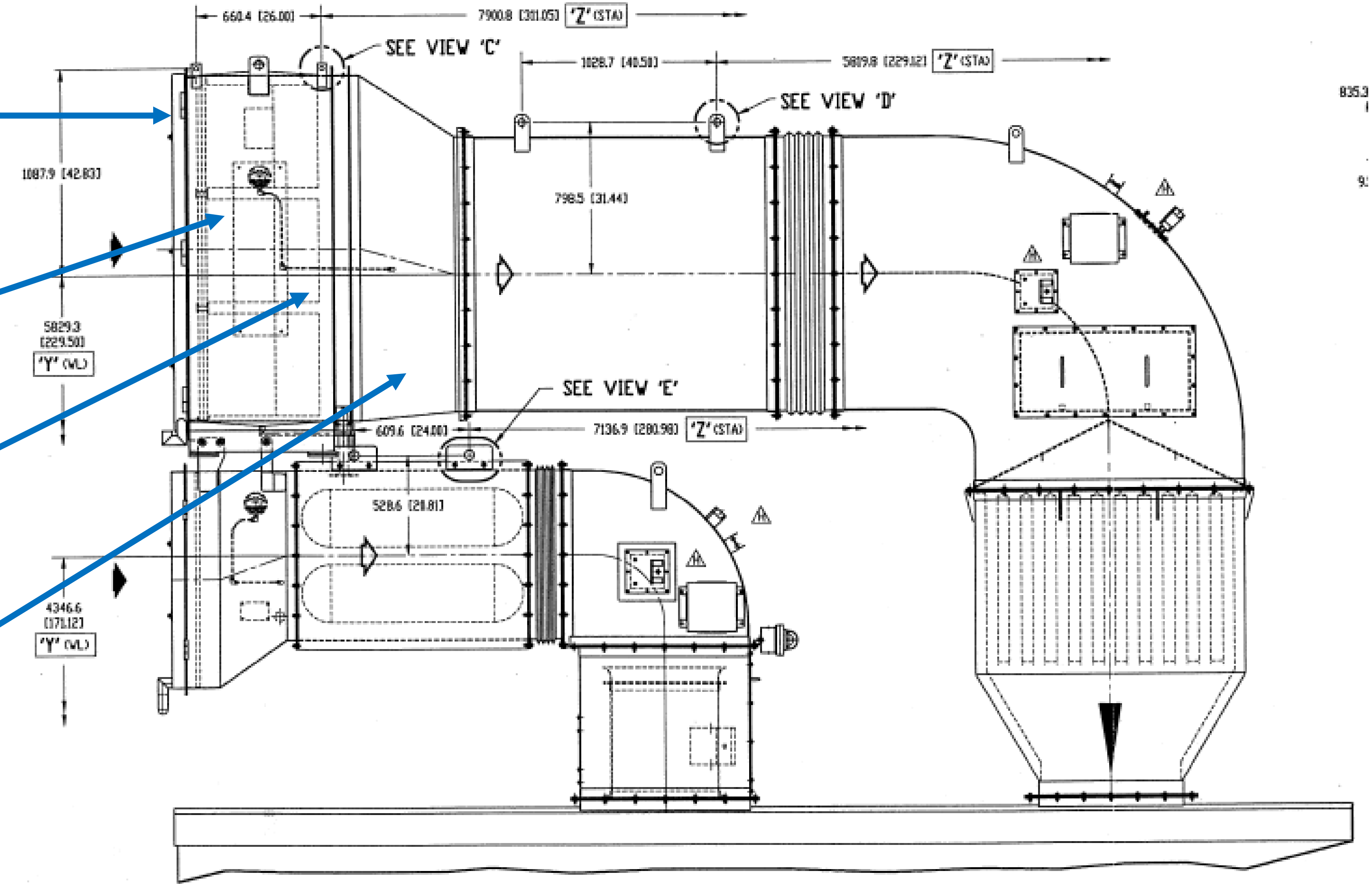
AIR INTAKE SYSTEM OVERVIEW

Stage 1: Marine Vane Separator (MVS)

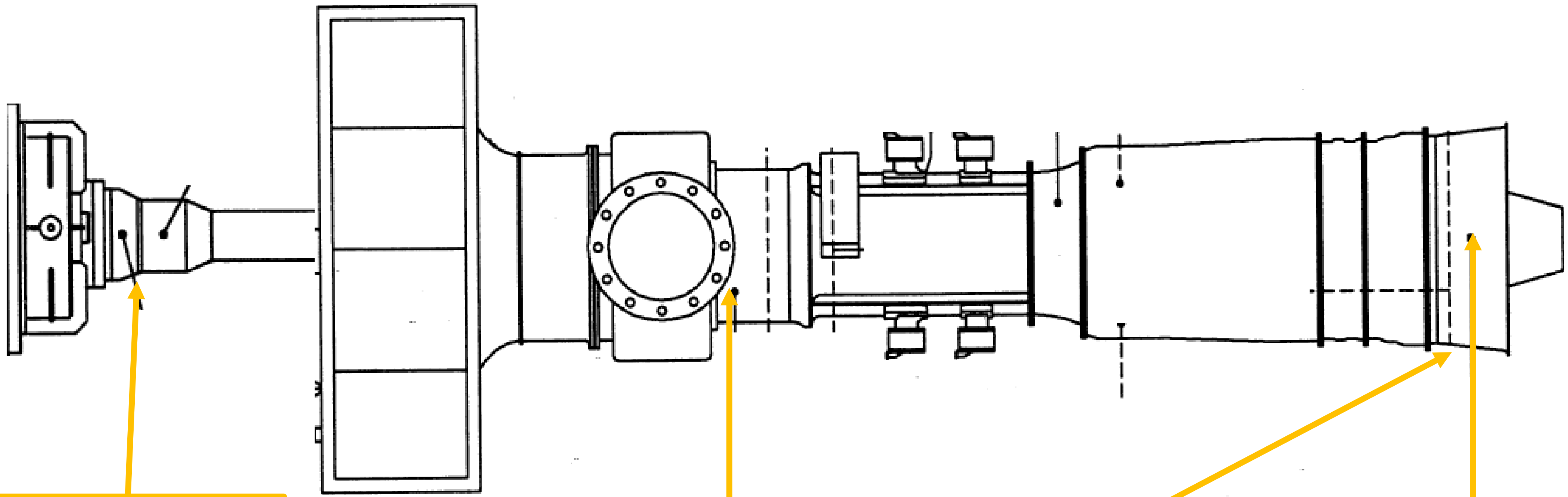
Stage 2: G4 single pocket

Stage 3: F7 10 pocket

Stage 4: Marine Vane Separator (MVS).



MAIN INSTRUMENTATION OVERVIEW



Power Take Off (PTO) Vibration – VE65

Compressor Case Vibration – VE67

Turbine Outlet Temperature (TOT) – TE60

Turbine Case Vibration – VE66

OBJECTIVE

- To share lesson learnt from blade pitting corrosion event which led to turbine blade liberation.

- To share root causes that can contribute to such failure occurrence and address the mitigation plan.

EXECUTIVE SUMMARY

- Turbine generator unit 1 was 1st fired up on 4th July 2016 for 3,244 hours.

- At 15,914 hours, on 23rd January 2020, this engine tripped on Power Take Off (PTO) Housing (VE65) high vibration. Upon further investigation, one of the boost compressor blade (1st stage) was found parted.

SEQUENCE OF EVENT

23-Jan-2020
Unit tripped on PTO high vibration

24-Jan-2020
Performed loop check on all vibration probes.

24-Jan-2020
Start attempt #1: tripped on PTO high vibration.

24-Jan-2020
Checked PTO vibration probe and replace with new sensor. Conducted loop check – all normal

24-Jan-2020
Start attempt #2: Unit tripped on high turbine outlet temperature

24-Jan-2020
Purge crank the unit

24-Jan-2020
Start attempt #3: tripped on PTO high vibration

24-Jan-2020
Inspected MCD and gearbox internal condition - Normal

26-Jan-2020
Conducted boroscope and found compressor blade damage

26-Jan-2020
Performed detail inspection on air intake system

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INSPECTION FINDINGS

One boost compressor blade liberated with the remaining blades exhibited impact damage.

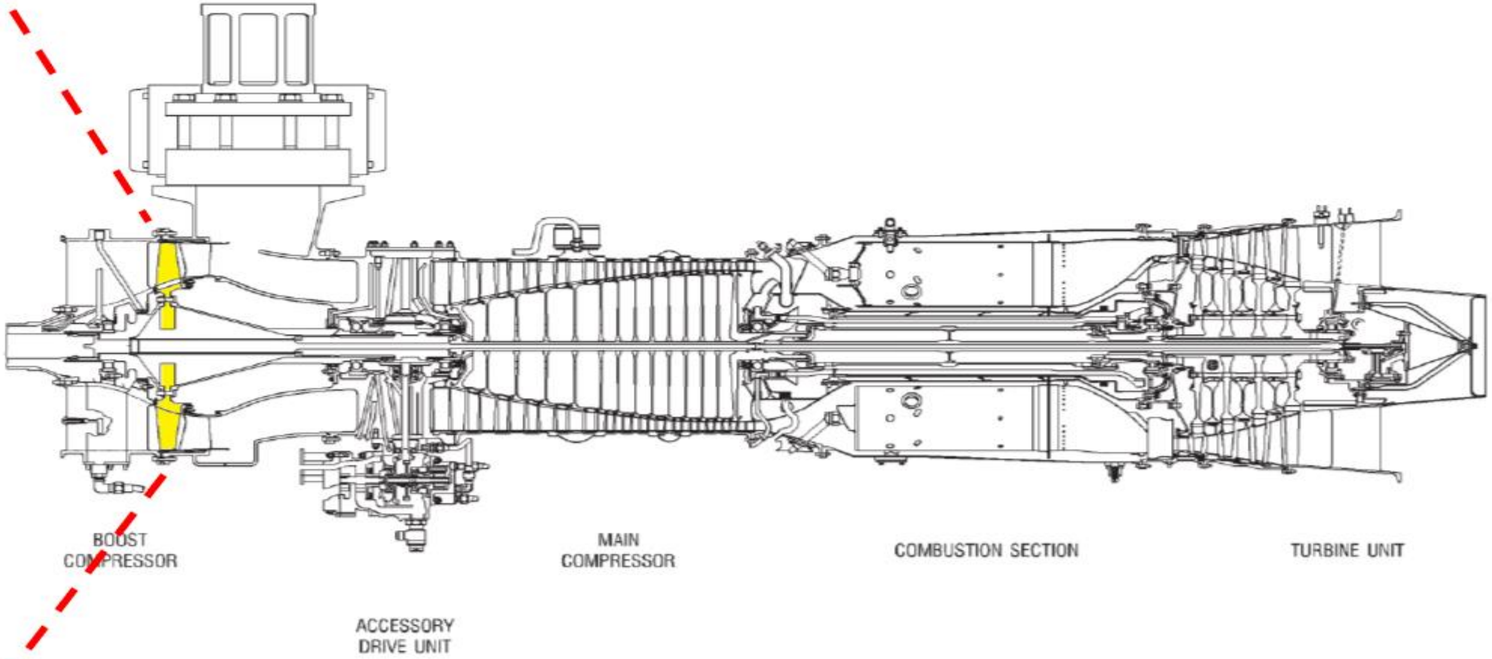


Figure 1: Engine Cutway and Area of Damage

FINDINGS AT AIR INLET SYSTEM

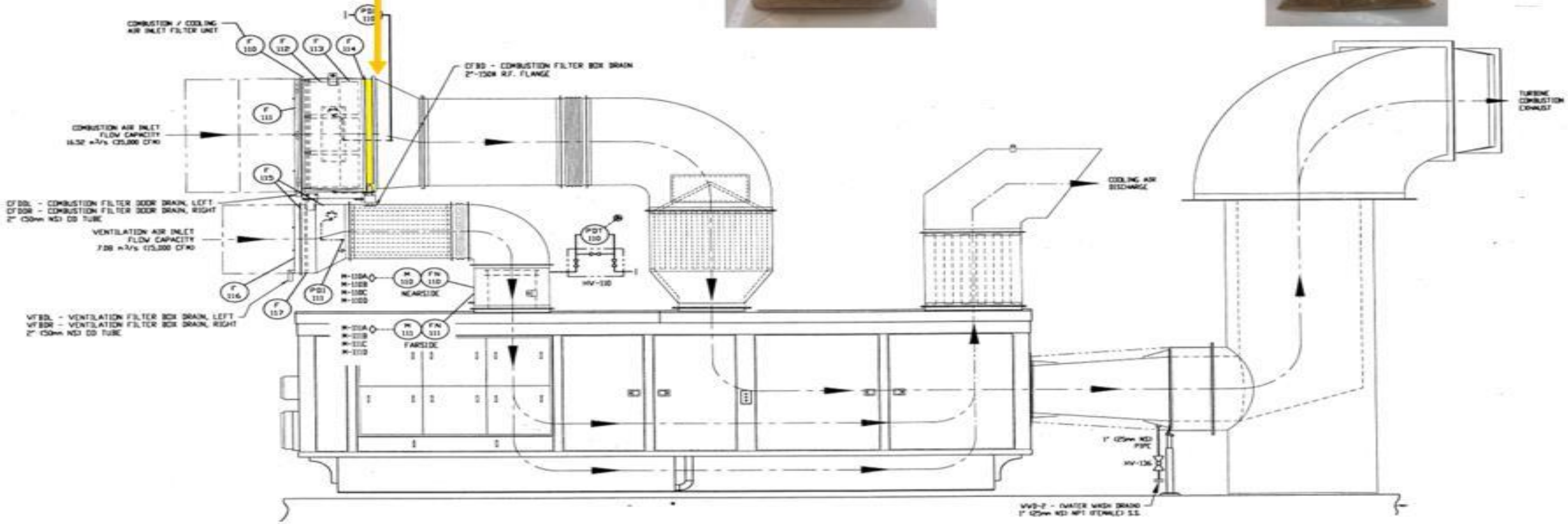
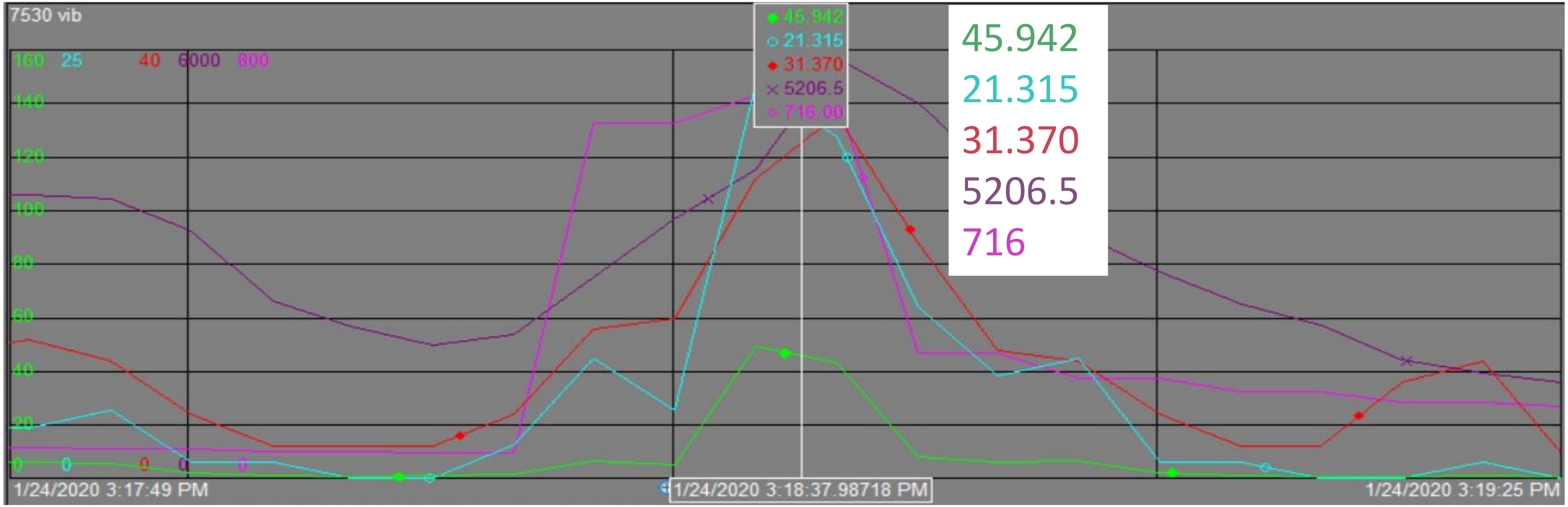


Figure 2: Air Ducting System Configuration

PARAMETERS TRENDING



PTO case vibration [mm/sec]
Turbine case vibration [um]
Compressor case vibration [um]
Engine speed [rpm]
Turbine outlet temperature [degC]

- Turbine outlet temperature showing high reading during engine start up.
- VE-65 Power take off (PTO) vibration reading increase significantly.

TECHNOLOGY USED

(XRD) X-RAY DIFFRACTION

X-ray diffraction (XRD) is a technique used in materials science for determining the atomic and molecular structure of a material.

(VI) VISUAL INSPECTION

VI is physical inspection and evaluation on failed material

(SE) STEREOSCOPIC EXAMINATION

SE is a technique for creating or enhancing the illusion of depth in an image by means of stereopsis for binocular vision

(EDS) ENERGY DISPERSIVE SPECTROSCOPY

Energy-dispersive X-ray spectroscopy (EDX) is a surface analytical technique to identify structure of the sample element

(SEM) SCANNING ELECTRON MICROSCOPIC

A scanning electron microscope (SEM) is a type of electron microscope. It give information about the surface topography and composition of the sample

DEBRIS SAMPLE LAB ANALYSIS

Major Scale Type detected by XRD is:

PROPERTY	METHOD	RESULT	UNITS
Elemental Composition			
Oxygen	EDS	44.80	% (m/m)
Chlorine	EDS	21.67	% (m/m)
Aluminium	EDS	19.41	% (m/m)
Sodium	EDS	9.19	% (m/m)
Magnesium	EDS	1.79	% (m/m)
Sulphur	EDS	1.76	% (m/m)
Iron	EDS	0.75	% (m/m)
Potassium	EDS	0.49	% (m/m)
Silicon	EDS	0.15	% (m/m)
Scale Type by XRD			
Major	XRD	Sodium Chloride	--
Minor	XRD	Aluminium Silicate	--
Minor	XRD	Hydroxide Chloride	--

VISUAL EXAMINATION

Figure 3 – Exhibited a complete, transverse separation through its airfoil just above its platform. The airfoils of the remaining non-fractured blades exhibited considerable impact damage. Failed blade designated as Blade 1 and the adjacent blades designated Blades 29 and 2.

Figure 4 – The airfoils of Blades 2 and 29 exhibited considerable impact damage. Most likely from contact with the liberated airfoil following separation along their leading edges and tips.

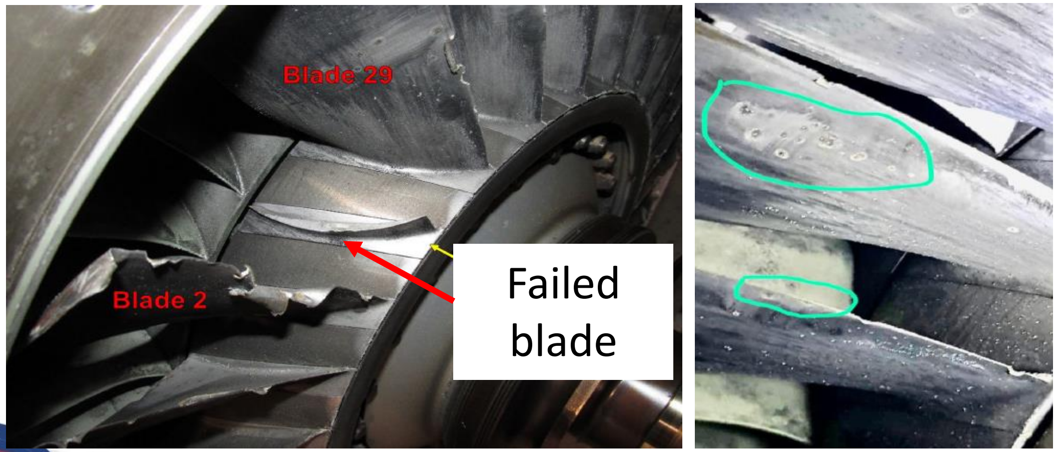


Figure 3: Booster Compressor Blade During Teardown

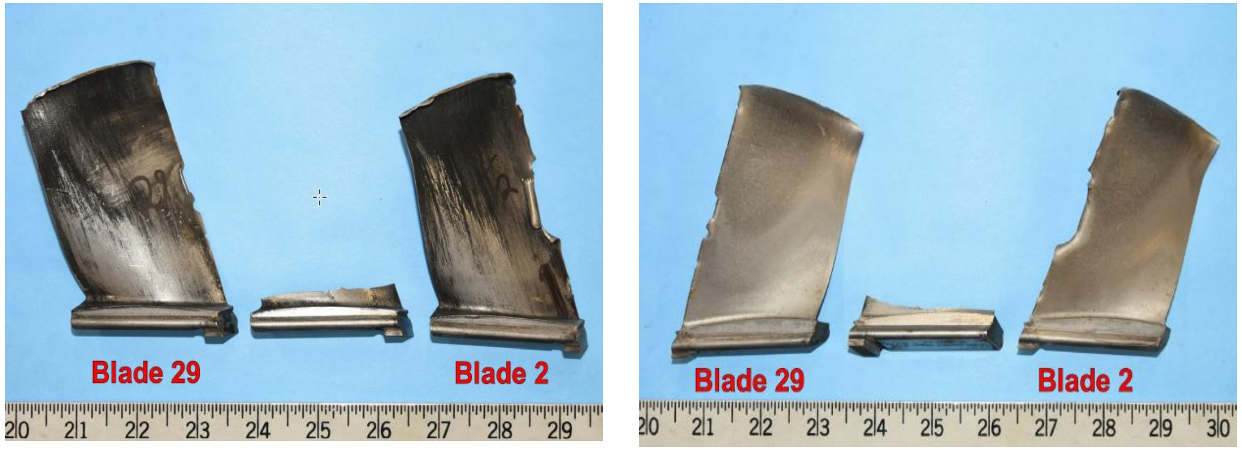


Figure 4: Booster Compressor Blade Surface

STEREOSCOPIC EXAMINATION (1)

Figure 5 – A relatively flat fracture profile was observed.
Figure 6 – At the mid-chord, a more irregular fracture profile was observed, whereas the fracture from the mid-chord to the trailing edge exhibited a slanted profile consistent with overload failure.
Figure 7 – show red-orange deposits on the high-pressure surface of the remaining airfoil segment.
Figure 8 – Isolated pitting, mostly associated with the deposits, was also noted. Blades 2 and 29 have similar deposits and pitting along the platforms

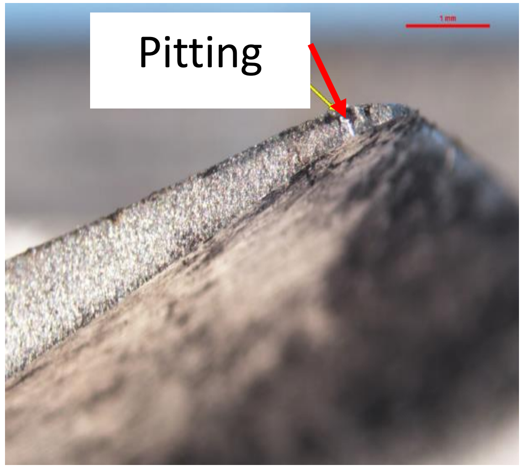


Figure 5: Blade 1 Separation Surface at Leading Edge

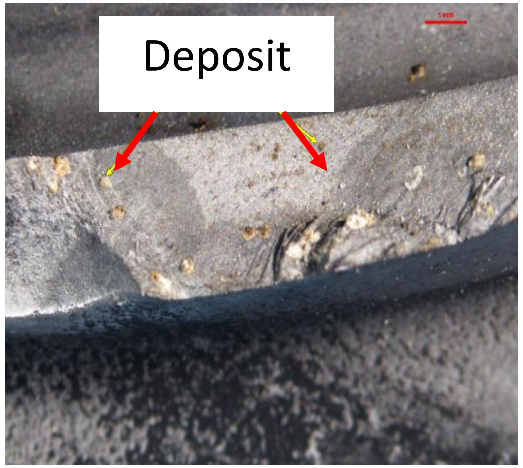


Figure 6: Blade 1 Separation Surface at mid-chord

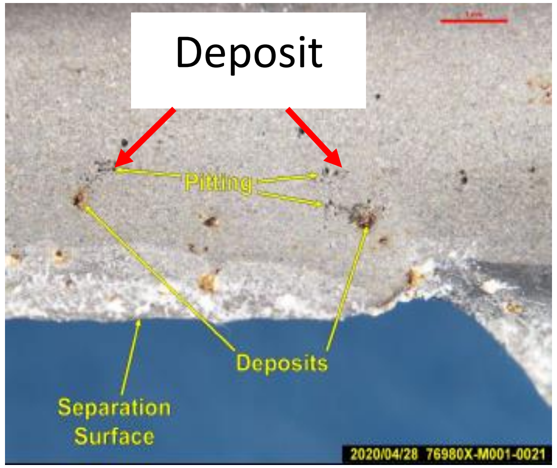


Figure 7: High-Pressure Surface of Blade 1

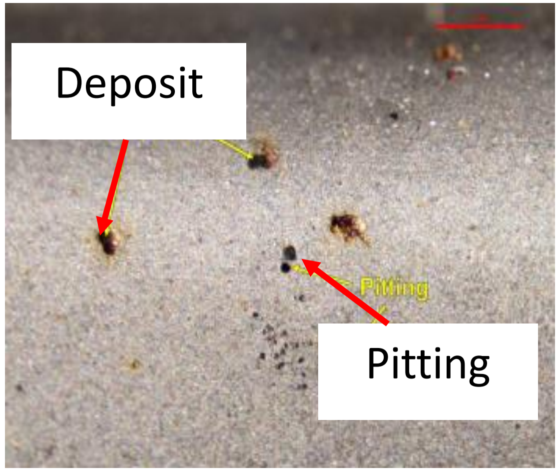
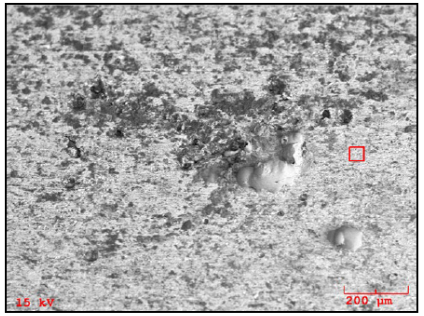


Figure 8: High-Pressure Surface of Blade 2 & 29

ENERGY DISPERSIVE SPECTROSCOPY (EDS)

- Multiple deposits observed immediately adjacent to the separation on the high-pressure surface of Blade 1.

- Figure 9 – EDS test on “clean” non-pitted surfaces of the airfoil was used as a reference.
- Figure 10 – Pitted area revealed the presence of high concentrations of oxygen and chlorine.



Elt.	Line	Conc.	Units
O	Ka	13.82	wt.%
Mg	Ka	0.47	wt.%
Al	Ka	4.34	wt.%
Si	Ka	0.76	wt.%
S	Ka	1.28	wt.%
Cl	Ka	0.66	wt.%
Ca	Ka	0.11	wt.%
Cr	Ka	12.99	wt.%
Fe	Ka	58.88	wt.%
Ni	Ka	4.10	wt.%
Cu	Ka	2.59	wt.%
		100.00	Wt.%

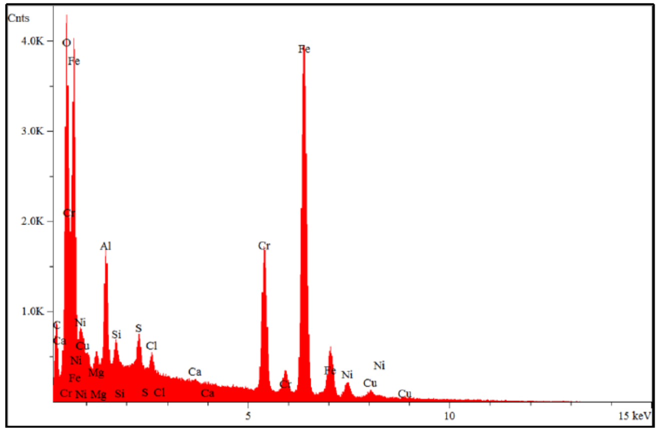
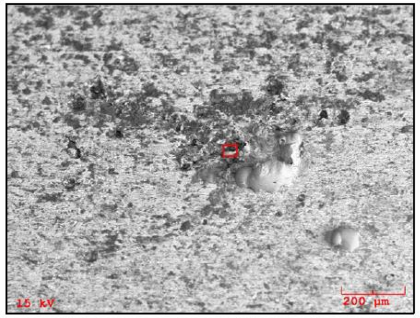


Figure 9: EDS Analysis of Clean Non-Pitted Surface



Elt.	Line	Conc.	Units
O	Ka	36.07	wt.%
Mg	Ka	0.33	wt.%
Al	Ka	5.18	wt.%
Si	Ka	0.30	wt.%
S	Ka	1.46	wt.%
Cl	Ka	7.26	wt.%
Cr	Ka	5.42	wt.%
Fe	Ka	38.39	wt.%
Ni	Ka	2.65	wt.%
Cu	Ka	2.94	wt.%
		100.00	Wt.%

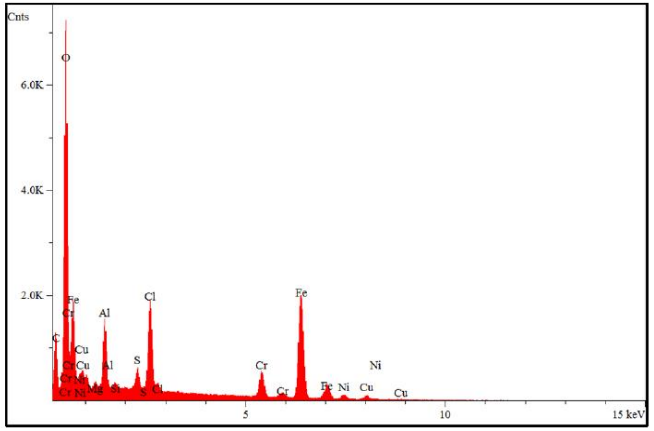


Figure 10: EDS Analysis For Deposits Within Pitted Surface

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SCANNING ELECTRON MICROSCOPIC EXAMINATION (SEM) (1/2)

Figure 11 – Build-up of corrosion product was observed. No evidence of mechanical damage from impact was observed at the leading edge.

Figure 12 – At the leading edge of the separation surface, a prominent pit was observed. A thumbnail-shaped feature appeared to surround the pitting. This fracture feature commonly illustrates the direction of progressive crack growth.

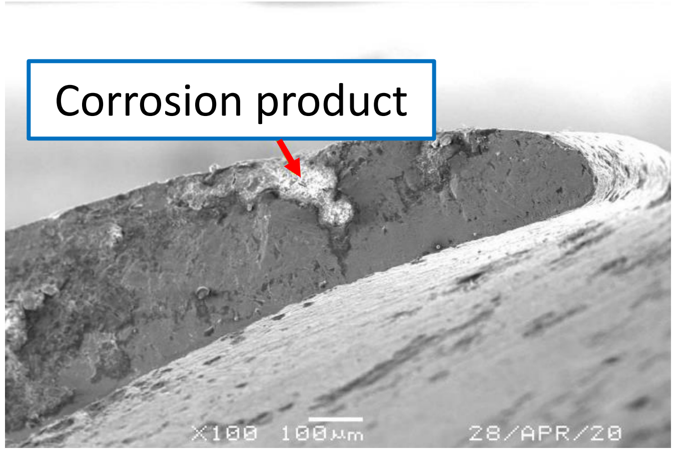


Figure 11: Blade 1 Separation Surface

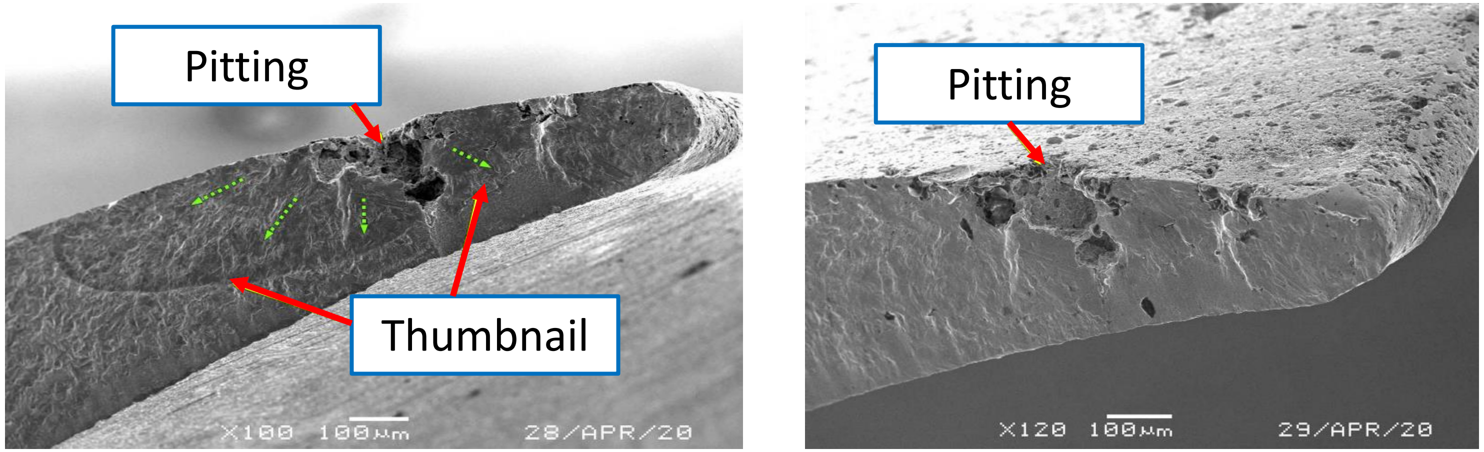


Figure 12: Blade 1 Separation Surface at Leading Edge

SCANNING ELECTRON MICROSCOPIC (SEM) EXAMINATION (2/2)

Figure 13 – Closer to the mid-chord, the separation surface of Blade 1 exhibited a relatively smooth fracture profile.

Figure 14 – Closer examination of the fracture features within this area revealed the presence of microscopic parallel features, known as striations. The orientation of these striations indicated crack propagation from the leading edge to the mid-chord.

Figure 15 – At the mid-chord of the blade, a distinct demarcation in fracture features was observed, as the crack propagation transitioned from progressive to single-event fracture, as identified.

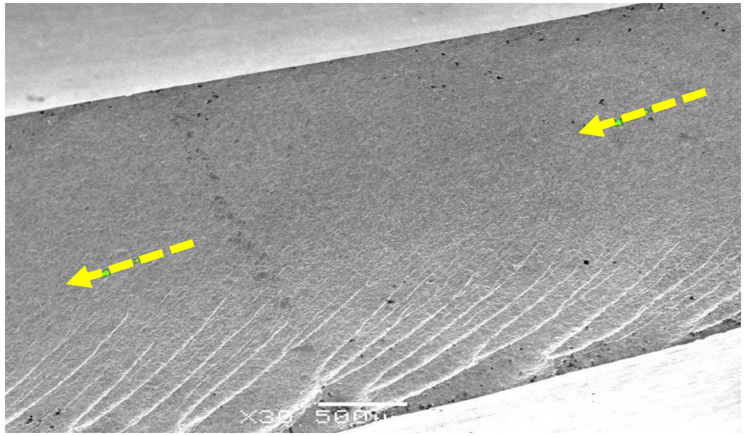


Figure 13: Blade 1 Separation Surface, Between Leading Edge And Mid-chord (Profile)

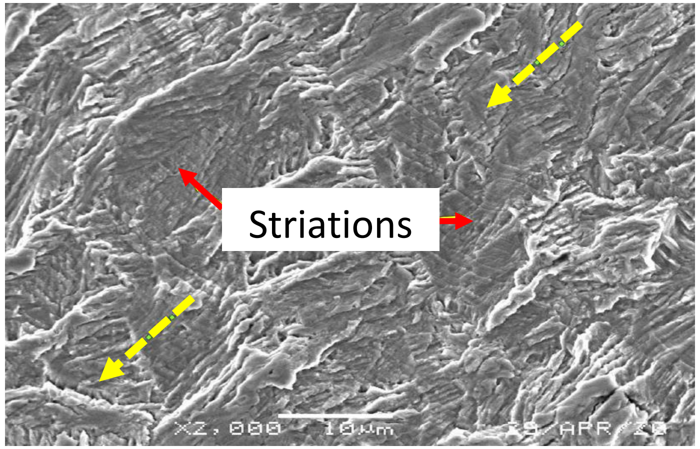


Figure 14: Blade 1 Separation Surface, Between Leading Edge And Mid-chord (Striations)

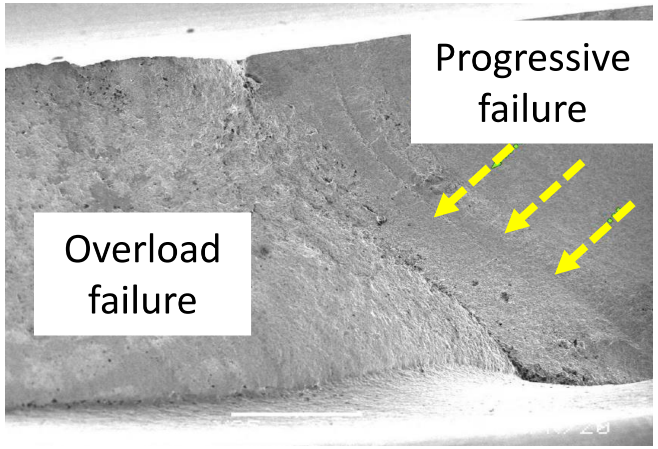
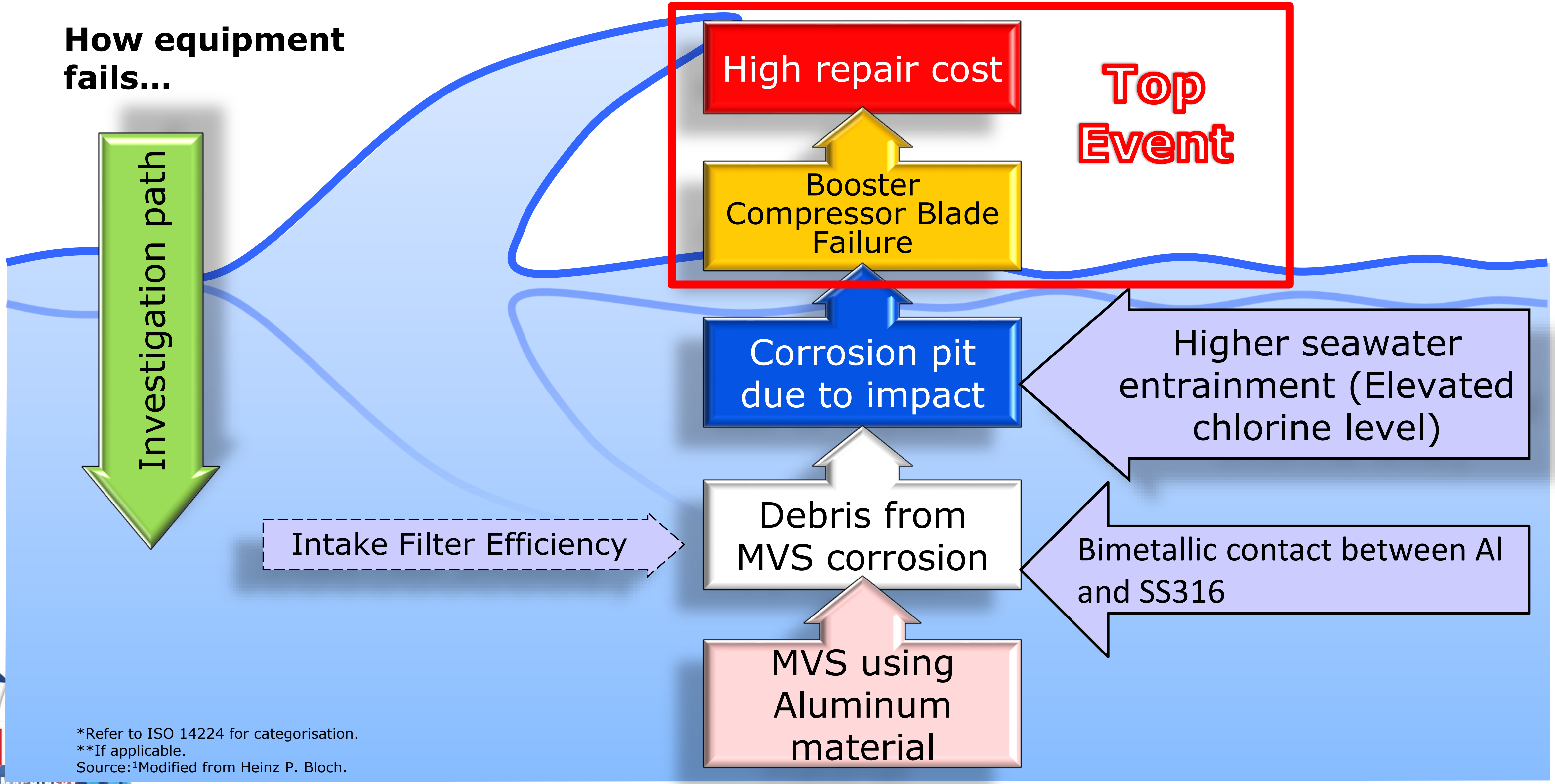


Figure 15: Blade 1 Separation Surface, Mid-chord

METALURGICAL CONCLUSION

- Blade 1 failed from the initiation and propagation of a crack just above the blade platform. Considerable corrosion pit on the high-pressure surface and near the tip of the leading edge.
- A thumbnail surrounding the pitting indicated that a fatigue crack initiated at the pitting and microscopic parallel striations confirmed that the crack continued from the leading edge to the mid-chord.
- The remaining airfoil cross section was insufficient to withstand the imposed service loads and failed in single-event overload. This liberated airfoil then caused the impact damage observed on the other boost compressor blade airfoils.
- A large corrosion pit was observed at the fatigue crack initiation site on the high-pressure surface of the Blade 1 airfoil.
- Deposits exhibited elevated concentrations of chlorine, an element known to facilitate pitting in ferrous alloys. Thus, localized corrosion attack, or pitting, from exposure to a chlorine-rich environment most likely caused the pitting that served as the fatigue crack initiation site.

FAILURE CAUSATION MODEL



*Refer to ISO 14224 for categorisation.
**If applicable.
Source:[1]Modified from Heinz P. Bloch.

IMPLEMENTED MITIGATION

Implemented strategy had been conducted as below:

STRATEGY	MITIGATION
Phase 1	upgrade MVS to stainless steel
Phase 2	upgrade intake system to EPA/HEPA or apply appropriate blade coating

After one year of operation, the strategies have proven to be successful, with very little corrosion seen on a stainless steel MVS and turbine compressor blade.

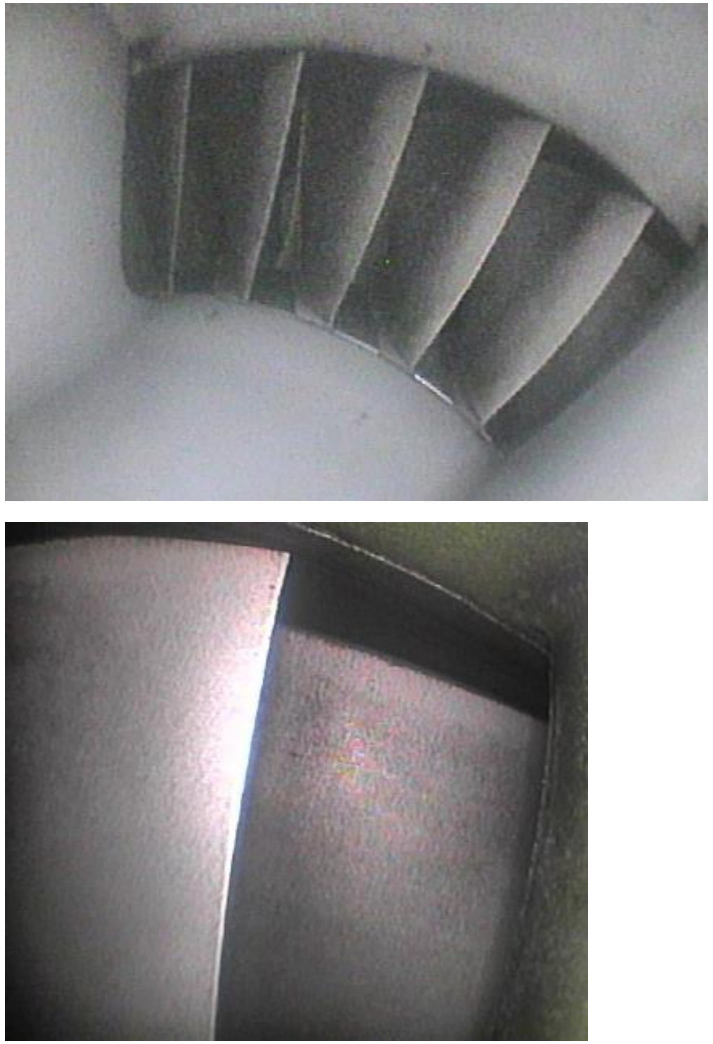
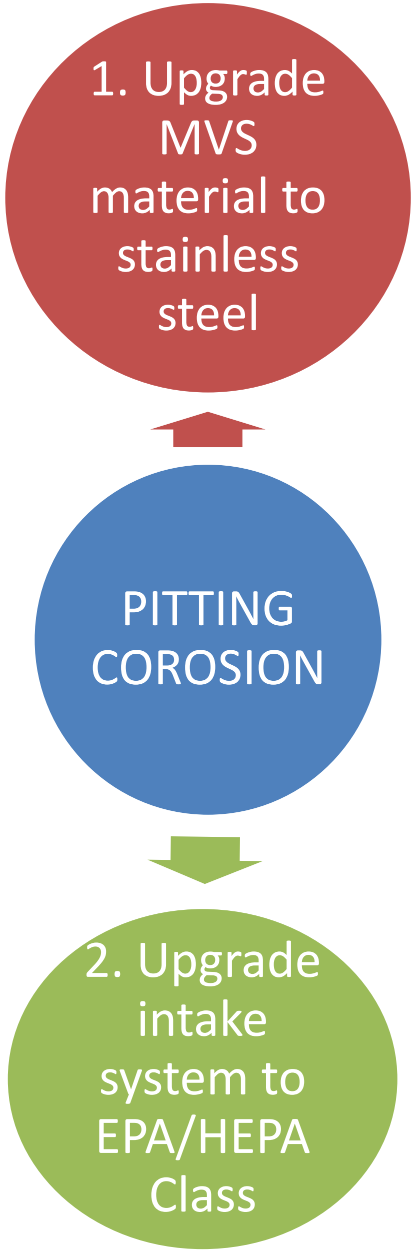


Figure 16: Booster compressor blade



MANAGING PITTING CORROSION

Active Cause	Factor of Error	Recommended Action	Status
• Bimetallic contact (AL & SS) of 4th stage MVS with presence of corrosion agent	• Less than adequate material application	• Amend Maintenance-Plan to include thorough inspection and cleaning of air intake system ducting to remove the debris. • upgrade MVS to stainless steel.	• Completed • Completed
• LTA filtration efficiency	• Less than adequate filter class used in the system	• To conduct inspection every time before unit startup. • To patch any hole identified at the air intake system. • To upgrade filter to EPA/HEPA.	• Completed • Completed • Completed
• Blade corroded and pitting damaged	• Debris ingress is not expected	• To perform borescope inspection during every 4k PPM after detergent wash to identify any sign of pitting.	• Completed

❖ Evaluation for the other facilities having similar configuration had been completed and recommendation has been fully implemented.

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CONCLUSION

- Pitting corrosion will lead to blade damage and failed when reached to the fatigue limit.

- Frequent unit inspection and proper equipment switching plan must be developed to ensure timely inspection can be conducted.

- Its critical to identify the root cause of the failure mechanism to ensure correct solution is being implemented

THANK YOU