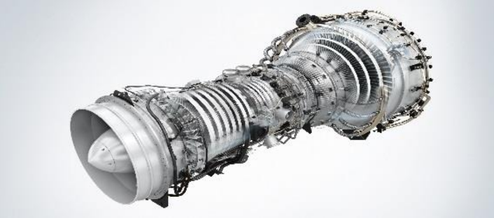


TRANSCANADA TURBINES

Corporate Presentation

INDUSTRIAL RB211 USER GROUP

ETN

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Introductions

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- **Fraser McCurdie - LTSA Project Engineer**
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Highlights and Improvements

LM2500+ G4 Authorization

- **In March 2020 TCT's OEM license switched over to the Aero Alliance group.**
- **As part of this switch, the LM2500+ G4 was added to our existing capabilities.**
- **TCT have the tooling, competence, and test capability in place to support as needed.**
- **We are please to be able to provide competition on this space**

AERO ALLIANCE

Aero Product & Services JV, LLC

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16 March 2020

TransCanada Turbines Ltd.
998 Hamilton Boulevard NE
Airdrie, AB
T4A 0K8

Subject: TransCanada Turbines (TCT) LM Service Center Authorization and Capability

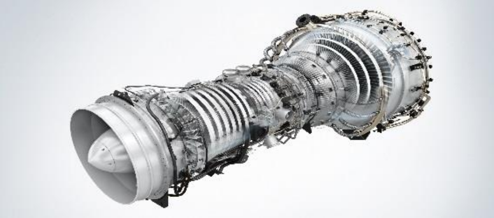
Subject to the terms and conditions of the licensed service provider's agreement between TCT and GE, TCT is authorized and qualified to provide full Level 4 maintenance, repair, overhaul and test on specific models of the LM2000 gas generators and gas turbines, LM2500 gas generators and gas turbines, LM2500+ gas generators and gas turbines (excluding the High Speed Power Turbine), limited license for LM2500+ G4, and the LM6000 family of gas turbines.

This agreement has been in effect since 1 January 2009 and as of the date of this Letter of Authority; the agreement is in full effect. GE and TCT are not at liberty to discuss the provisions of the license agreement, including term.

With regards,

Julie Yocco

Julie Yocco



Issue Index: *2020 #121*

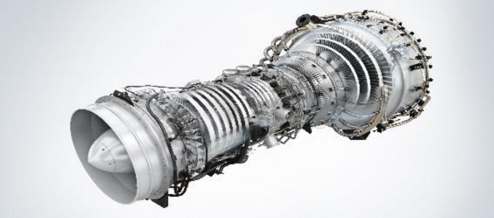
Possible Hexavalent Chromium Findings

Original: ETN 2019, CAT-1 issue (2019 #121)

Reported by Users

Yellowish Residue Found

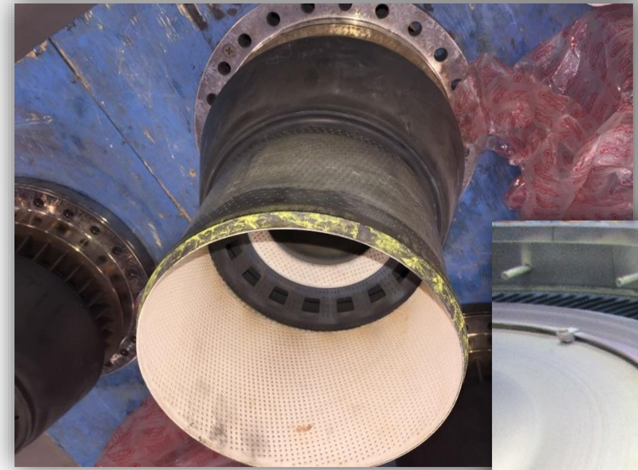
Several OEMs have circulated Service Bulletins on the health risks of Hexavalent Chromium. The actual situation for RB211 engines is unclear.




Hex Chrome at the Depot

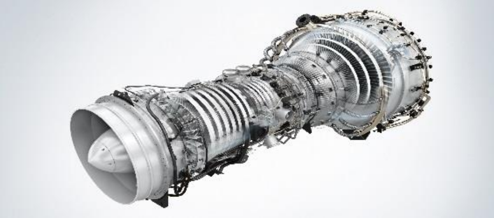
Issue Index: 121

Siemens: A residue, yellowish in colour, has been found on some components in the hot sections of some Siemens gas turbines, that include but not limited to the gas flow path and exhaust casing insulation. In some cases, tests have found hexavalent chromium (Cr(VI)) in this residue. Cr(VI) is a highly regulated substance, and has been identified as a human carcinogen by recognized governmental and health authorities




Siemens Published Bulletins:

- Depot facing: OIA-GEN-066
- Operator facing: PSW 01-0008-01




Hex Chrome at the Depot

Issue Index: 121

TCT Actions:

HA/SWP Published:

- Awareness and identification of hazard
- Testing process for Hex Chrome
- PPE and safety precautions to control hazard
- Procedure to remove and dispose Hex Chrome containing deposits from engine parts

Operator Considerations:

- Conduct a Hazard Assessment + Develop SWP
- Site activities involving removal and contact with DLE DCN/Comb/Supports, T455's, BOV's are most likely to result in possible exposure.
- Provide training and awareness to maintenance personnel
- Use PPE and follow your SWP
- Establish safe practice to clean-up/remove deposits and prevent any deposit becoming airborne.
- Dispose of contaminated waste IAW local regulations.

Hex Chrome in the Field

Issue Index: 121

- Not managed to get testing kits in UK/Europe
- Need to assume worst case based on deposit appearance.
- For 8k Maintenance – likely on BSI plugs or T455 T/C's

<u>Measures if found</u>

- Make Site Contact Aware.
- Use Correct PPE (Safety Glasses & Boots, Nitrile Gloves, Overalls)
- N95 Mask and Disposable overalls to be worn when cleaning part.
- Clean residue and powder by wetting a rag with Kroil /LPS 1 oil and wiping it.
- Double bag any disposable parts, rags etc. in a plastic bag and place in designated hexavalent chromium waste bin. (Comply with site measures for Hazardous Waste)

Hex Chrome in the Field

Issue Index: 121

Measures if found (cont.)

- Ensure parts are clean to prevent airborne release or contact with skin.
- Clean local area of remaining residue. i.e. Fallen powder deposits with wet rag.
- Remove disposable coveralls, gloves and mask and dispose by double bagging.
- Comply with site procedures for disposing of the hazardous material.
- Wash hands thoroughly with soap and water

Issue Index: *2020 #127*

HPC Stage 1 Blade Failure

Original: ETN 2020, CAT-1 issue

Reported by Users

Engine failed in operation resulting in severe damage to HPC

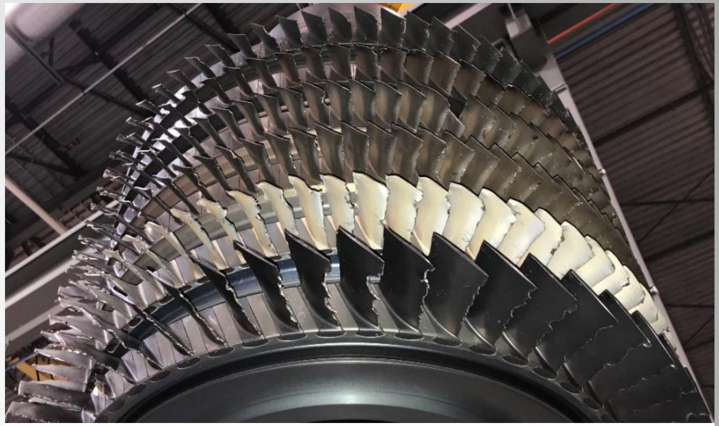
Cause For Removal:

- Engine trip event followed by multiple, unsuccessful start attempts.
- Exhaustive troubleshooting prompted a borescope inspection, where severe damage was observed to the HPC gas path.

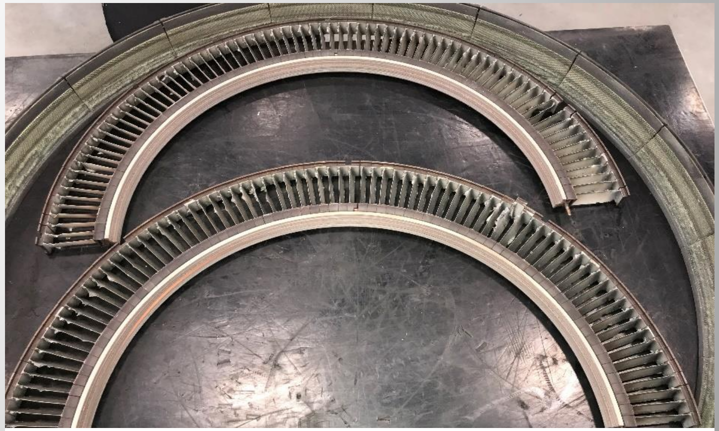
- Engine removed from berth and inducted at TCT Depot for investigation and repair.

Depot Observations – 04 Module

- Extensive damage to HPC Blades and Vanes with nicks, dents and tears present in all stages
- HPC Stage 1 Blades: QTY.2 blade airfoils liberated
- HP OGV: ledge edge nicks and dents
- Material splatter and minor impact damages observed on the HPT Blades and HPNGV's.



HPC Stage 1 -6 Blade Condition



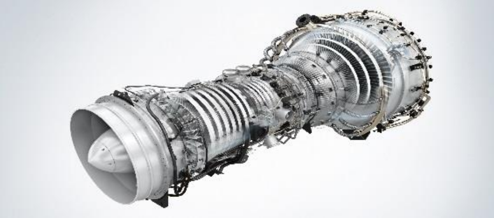
HPC Stage 2 Vane Condition

Depot Observations – 04 Module

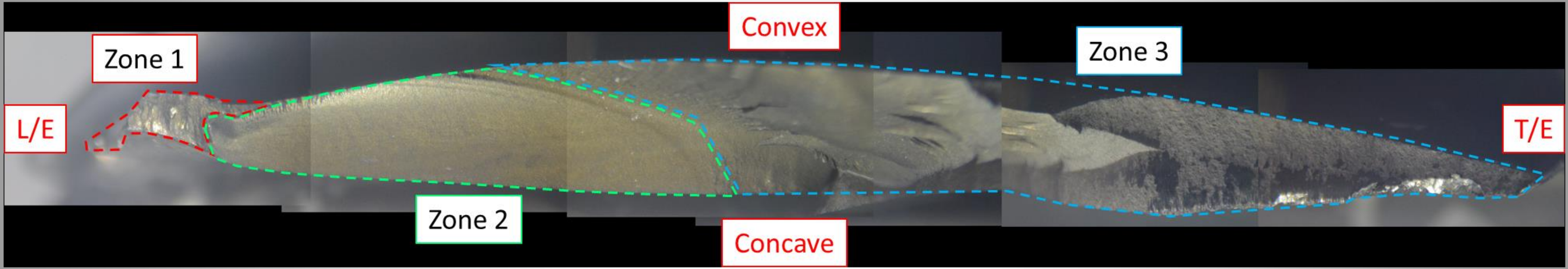
HPC Stage 1 Blade Airfoil liberation locations


Blade #59


Blade #6



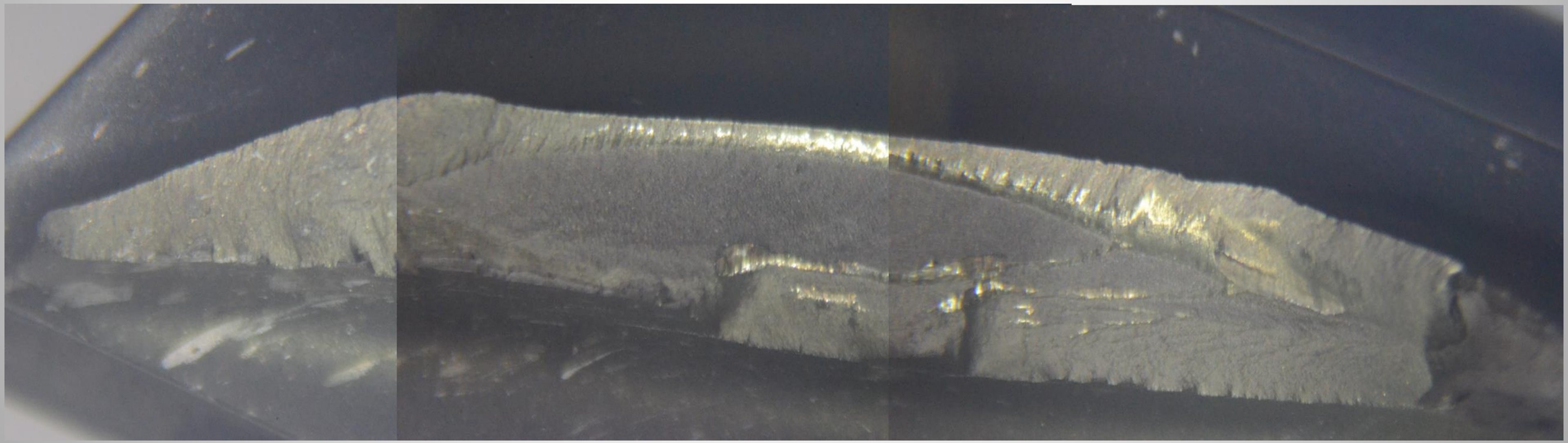

Preliminary Findings - HPC Stage 1 Blade #59



- Zone 1: Leading edge deformation moving from the concave surface to the convex. Leading edge tear condition has visible oxidation present
- Zone 2: Thumbnail shaped, flat and visibly oxidized fracture surface. Characteristics are consistent with stable fatigue crack growth.
- Zone 3: Fracture surface consistent with overload condition.

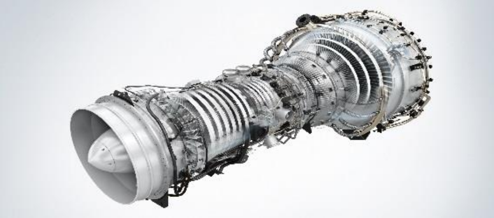
Preliminary Findings - HPC Stage 1 Blade #6

- Fracture surface is consistent with an overload failure condition
- Probable that this blade sustained an impact from an object



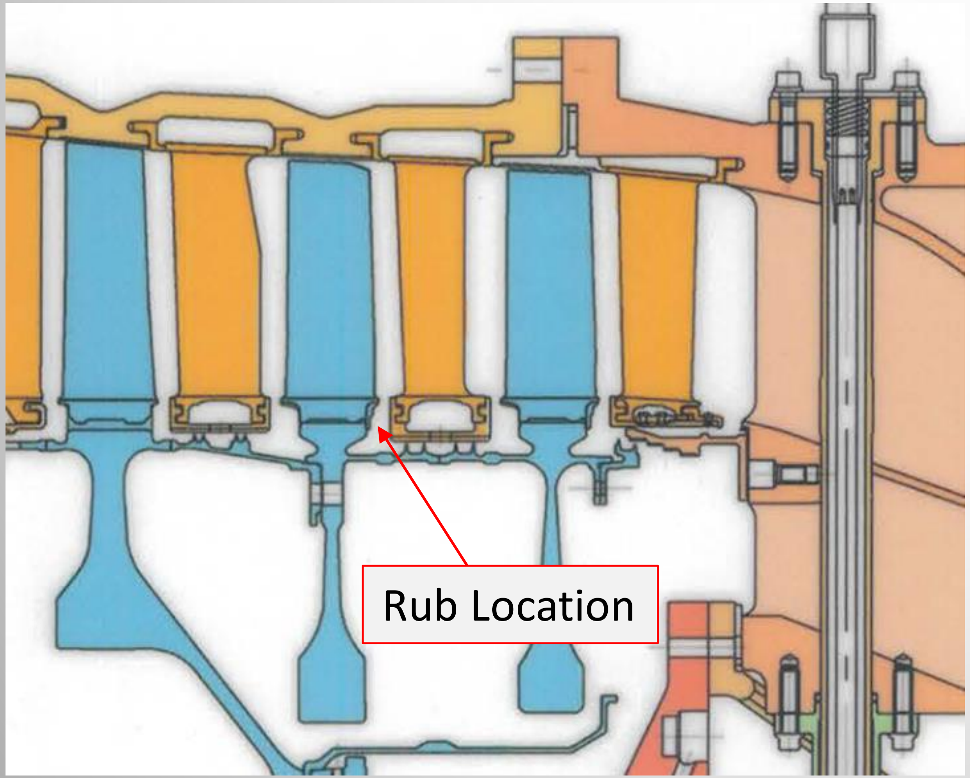
Preliminary Findings - IPC Stage 6 Shroud/Vane Assembly

- Upper shroud segment: 350mm of shroud lost location allowing for forward movement.
- Loose shroud condition resulting in:
  - multiple non-parallel, non-overlapping knife seal cut paths in the abradable lining
  - Rubbing with the aft face of the IPC stage 6 disc rim
- Foam injection still present although highly degraded and burnt
- Heavy fretting, material loss and bluing present in both the shroud and end vane




Depot Observations – 02 Module

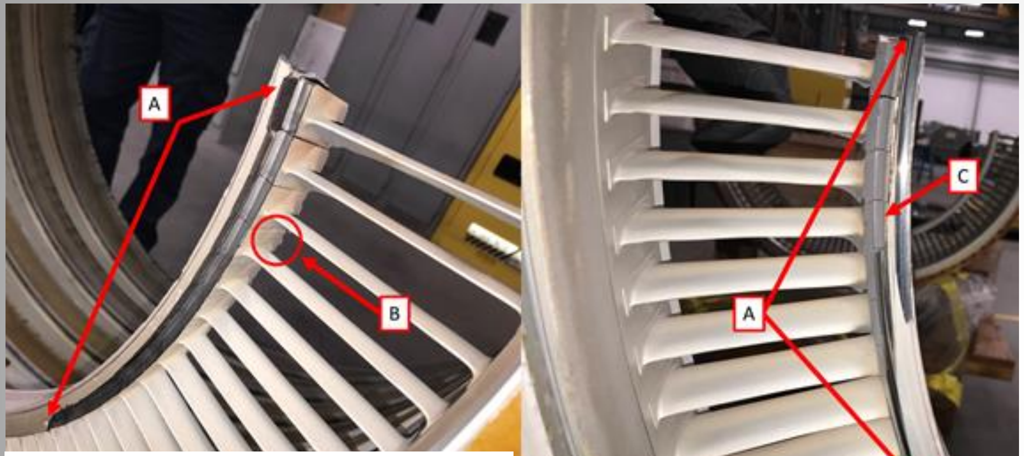
- IPC Stage 6 disc and blades were found to have heavy rub condition as evidence of bluing and wear marks.



Heavy Rub on aft face of IPC stage 6 Disc Rim

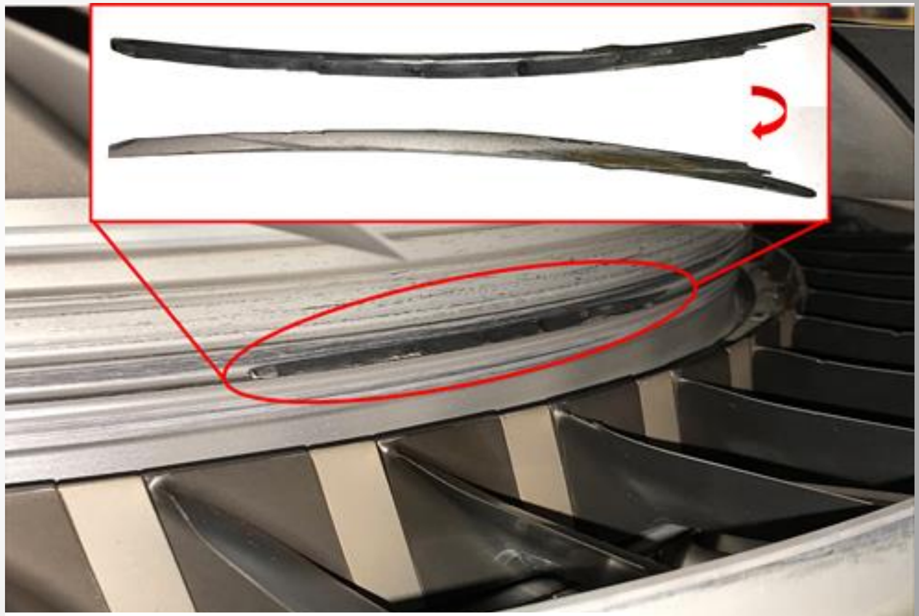
Stage 6 shroud condition at split line

Depot Observations – IPC Stage 6 Shroud/Vane Assembly

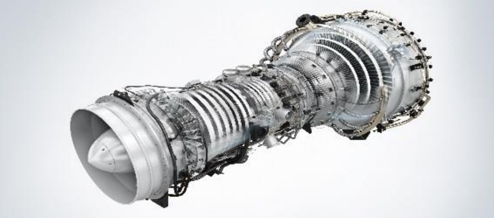


Stage 6 Shroud Damage

Stage 6 Shroud Wear

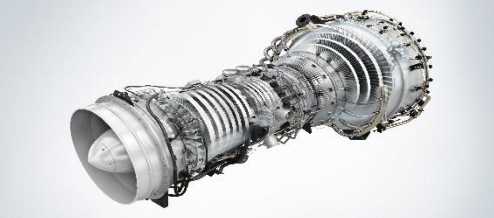


Recovered debris



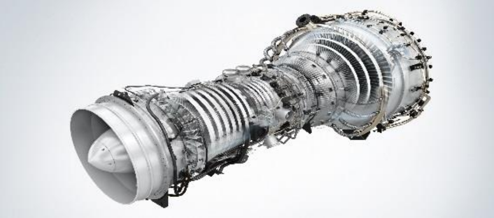

Summary:

- Start attempts at site prompted troubleshooting leading to a subsequent borescope
- Damage to the IPC and HPC gas paths identified and routed to TCT Depot in Canada
- TCT Engineering led initial investigation performed
- QTY.1 HPC Stage 1 blade fracture surface consistent with cyclic fatigue
- QTY.1 HPC Stage 1 blade fracture surface consistent with overload failure from a probable impact
- IPC Stage 6 inner shroud found to have lost location allowing free forward movement due to material loss
- Investigation ongoing at Siemens to determine exact root cause




Final Thoughts on IPC Vane/Shroud Failures

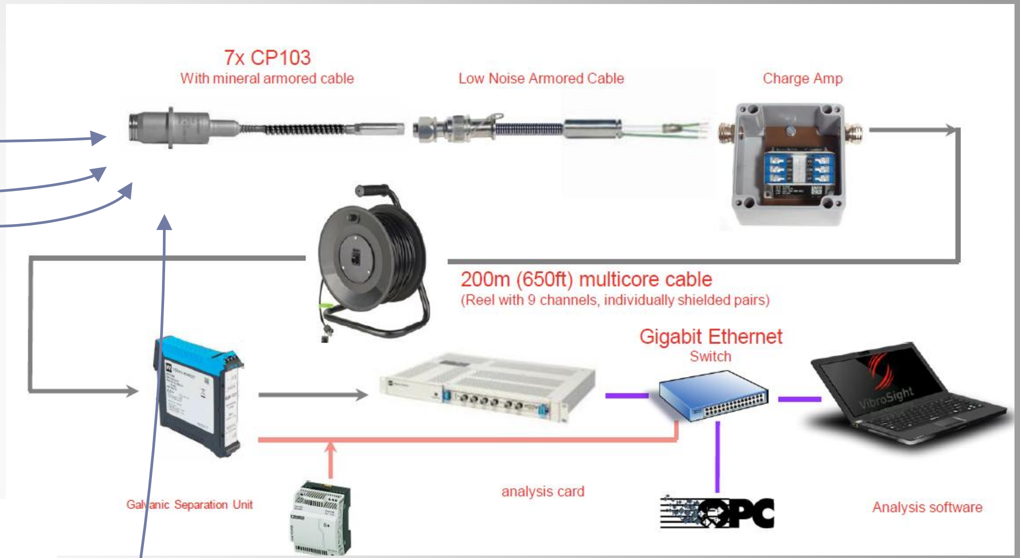
- History of IPC shroud failures on RB211’s.
- Failure mechanism is driven by vibration and wear.
- Vane feet hard coating and foam damping media to attenuate.
- Damping media degrades over time; becomes brittle and loses damping quality.
- Siemens instructs foam damping media replacement at 25k hrs so replacement is performed every OVH and Midlife.
- Damping material life likely dictated by progressive degradation (time at temperature).
- Reference PAB 02-0006-01.

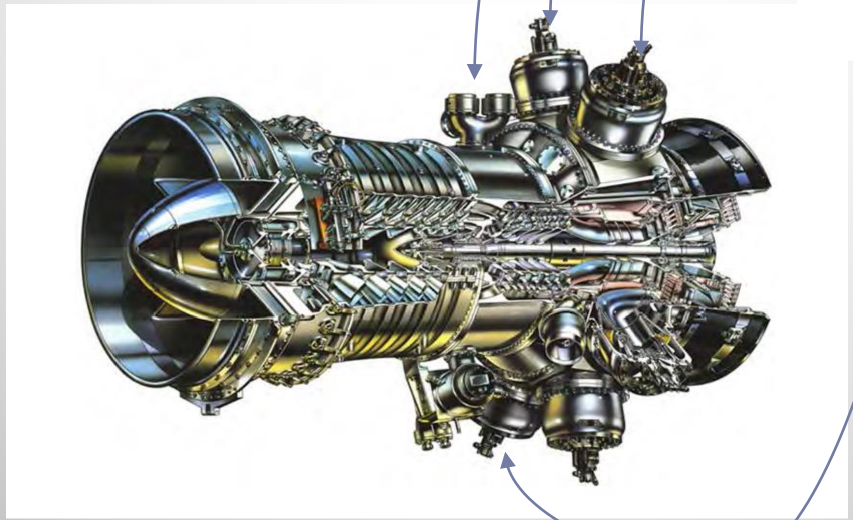



CP103 Noise Mapping Kit

- TransCanada Turbines have recently purchased a portable noise mapping kit for RB211 DLE engines including:
  - CP103 sensors (x 7)
  - Charge amplifier
  - Field wiring
  - Galvanic separation units
  - Analyzer / AD interface
  - Software with historical data logging and real time display capabilities
  - Transport boxes
- Minimum of 9 combustion channels system (7 temporary probes + 2 permanent)
- Minimum of 5 band extractions per channel: D band, DE band, E band, F band and Full.
- Ability to correlate combustion dynamic data with other parameters received by OPC and also export combustion data via OPC
- Minimises downtime and labour work, no need to swap out the 2 x permanent CP103 sensors out

CP103 Noise Mapping Kit





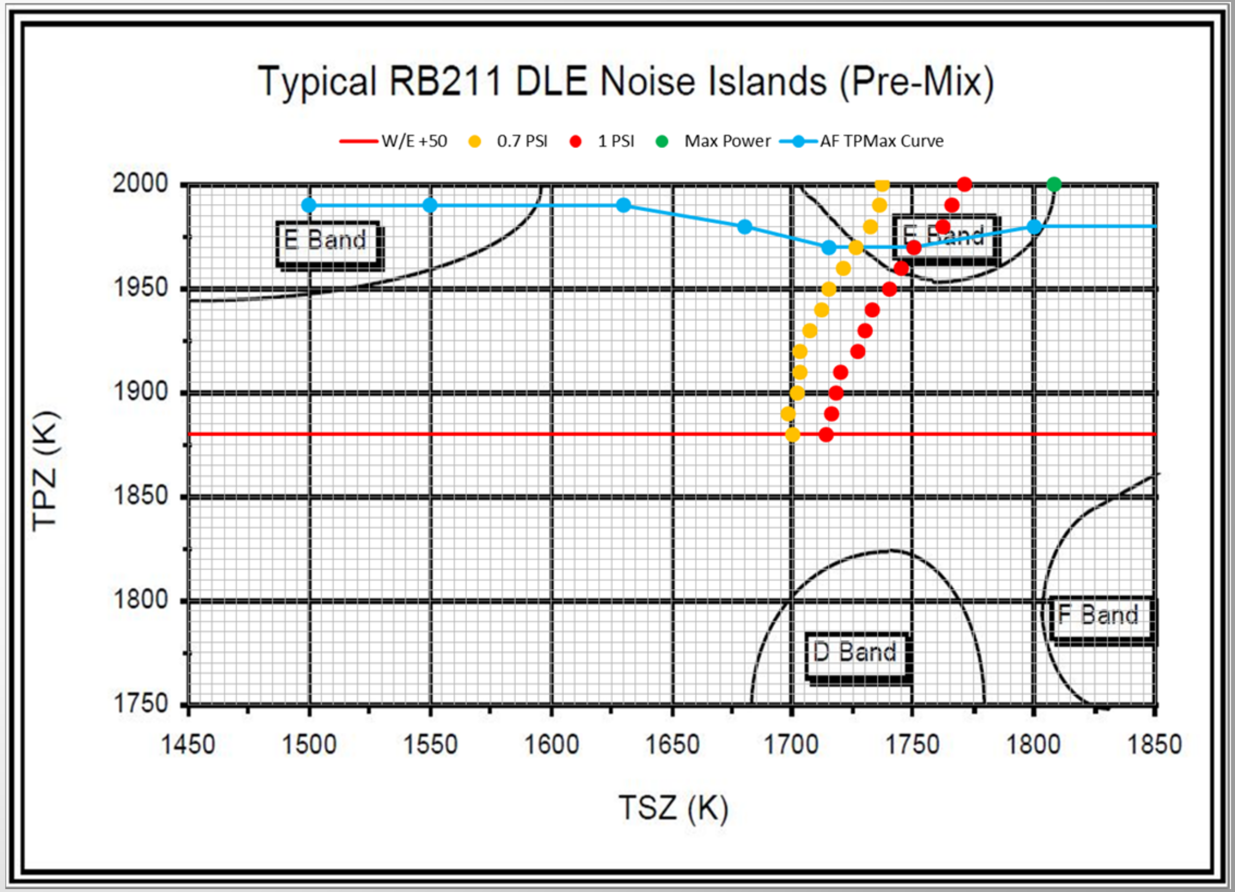
CP103 Sensors
& Cables

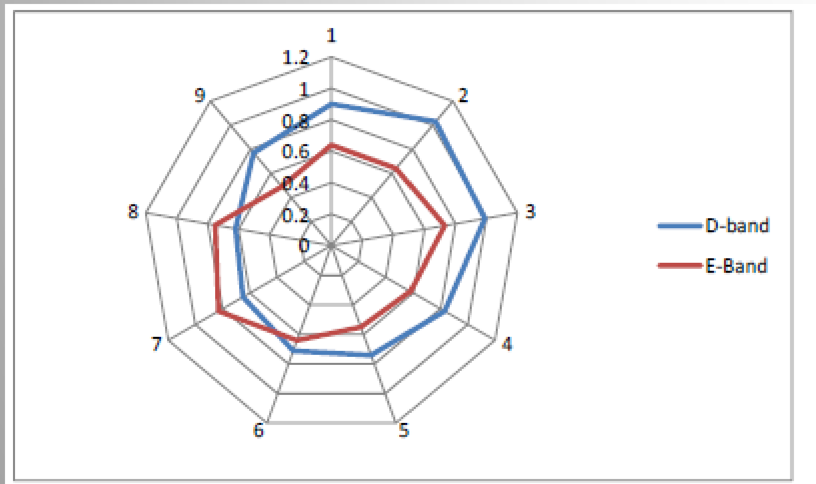
Field Developments with Kit

- GT DLE Customers experiencing high D- Band (550 Hz) noise at high power as the engine ages. Approx. >18k hour TSO.
- Initial Investigation with noise kit found that the D-Band noise was common to all combustors.
- Noise was at an elevated level in that engine would reach the 2nd Level of noise control (TPZ Offset)
- With TPZ Offset, as this is D-Band. It will increase the TPZ.
- Customers experience high NOx at full power. To the point where they cannot comply with their emissions limit.

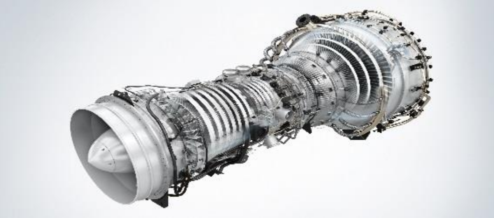
Field Developments with Kit

- The noise kit allowed a pot to pot profile to be determined
- D-Band was found to be common to all combustors
- Wall of D-Band present at 1700K TSZ.
- No “way around” the D-Band noise.





Typical Noise Profile – TPZ 1990K, TSZ 1766K

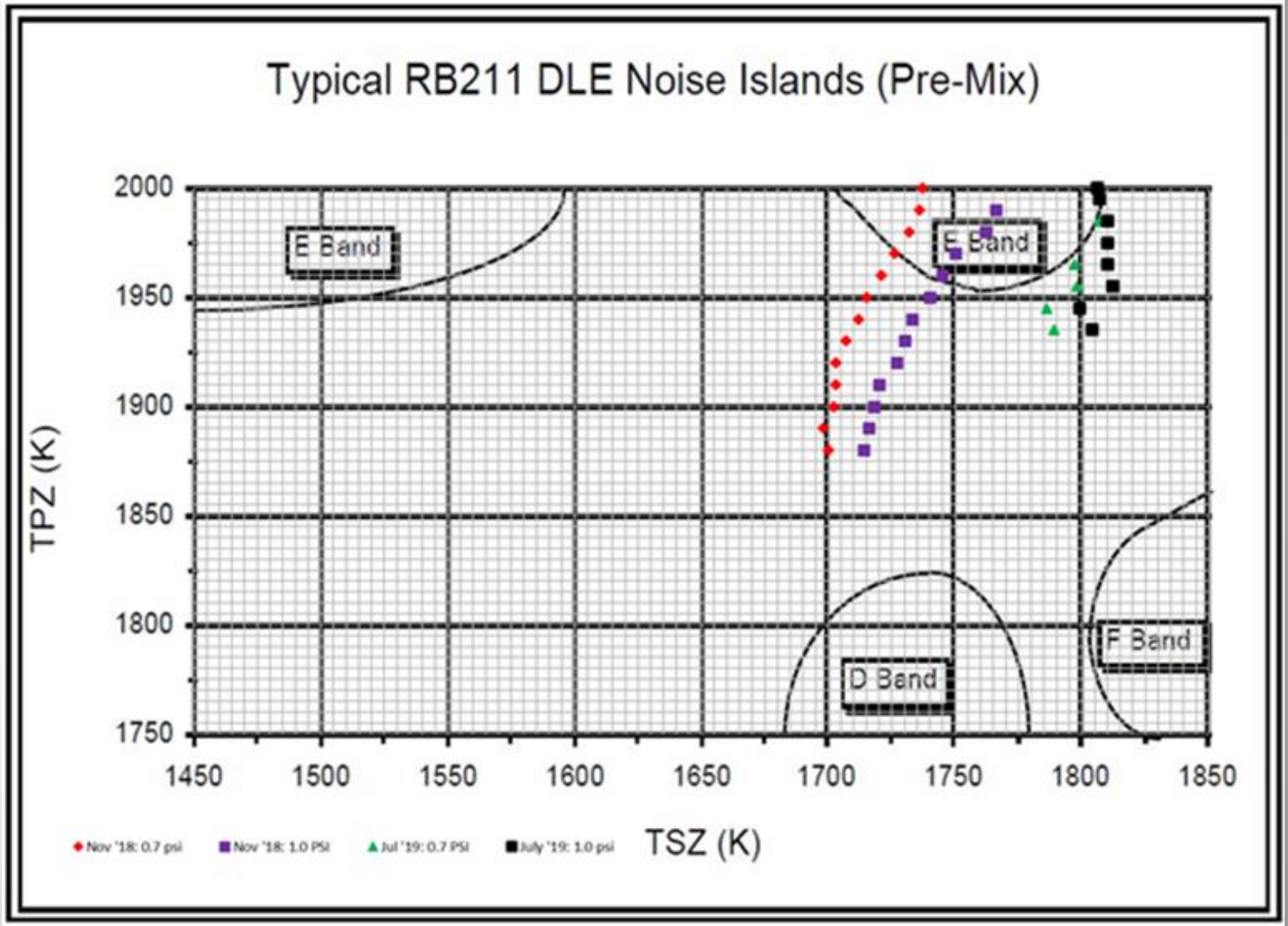



Field Developments with Kit

- The noise kit helped determine that further actions was needed.
- Empirical experience from the TCT test bed determined that replacing discharge nozzles has a good effect on improving D-Band noise profile.
- Was agreed with the customer that we would overhaul all x9 discharge nozzles, then re-install and map with the field noise kit.
- This level of work would not be possible in the field without the CP103 kit, since it allows pot to pot monitoring of noise.

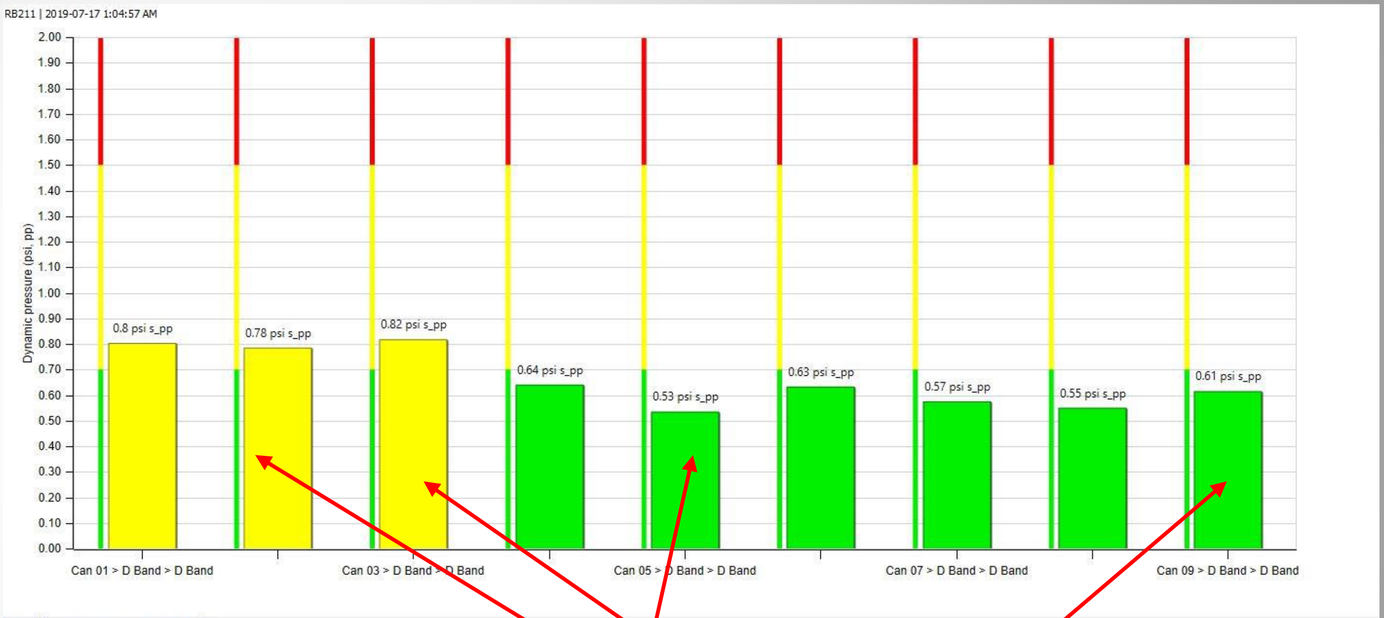
Field Developments with Kit

- The effect of the discharge nozzle replacement can be seen here.
- Significant shift up the TSZ scale of the D-Band noise. 0.7 psi isobar now at approx. 1800 K compared to 1700K pre-discharge nozzle overhaul.
- Noise control activation point is 0.8 psi.



Field Developments with Kit

- Kit allowed for further optimisation with individual combustor swaps, in an attempt to even out the noise profile.



Legend | DMS KIT XMC RB211 > XMC16 Slot1

Bar	Visible	Timestamp	State	Value	Location
Can 01 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.8 psi s_pp	0° US
Can 02 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.78 psi s_pp	0° US
Can 03 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.82 psi s_pp	0° US
Can 04 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.64 psi s_pp	0° US
Can 05 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.53 psi s_pp	0° US
Can 06 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.63 psi s_pp	0° US
Can 07 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.57 psi s_pp	0° US
Can 08 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.55 psi s_pp	0° US
Can 09 > D Band > D Band	☑	2019-07-17 1:04:57 AM		0.61 psi s_pp	0° US

Group all | Baseline

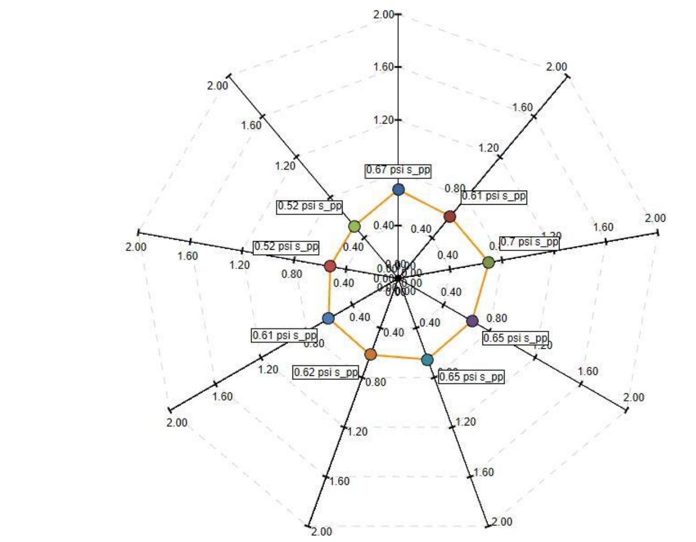
Field Developments with Kit

- More even D-Band noise profile.
- Within site limits for noise control.
- No TPZ Offset.
- NOx emissions fully optimized within site limits.

- TCT has carried this work out x3 times in 2019/20.
- Each time, overhauling the discharge nozzles had a positive effect on D-Band noise profile.
- This work couldn't be done in the field without the kit.

- Mitigating the need for full overhaul earlier in the engine life.
- No engine removal required. Exchange options available also

RB211 | 2019-07-19 4:53:52 AM



Legend | DMS KIT XMC RB211 > XMC16 Slot1

Point	Visible	Timestamp	State	Value	Location
Can 01 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.67 psi s_pp	0° US
Can 02 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.61 psi s_pp	0° US
Can 03 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.7 psi s_pp	0° US
Can 04 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.65 psi s_pp	0° US
Can 05 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.65 psi s_pp	0° US
Can 06 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.62 psi s_pp	0° US
Can 07 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.61 psi s_pp	0° US
Can 08 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.52 psi s_pp	0° US
Can 09 > D Band > D Band	☑	2019-07-19 4:53:52 AM		0.52 psi s_pp	0° US

Compensation Baseline

Issue Index: *2020 #123*

GT-DLE HP Turbine Blade Failure

Original: ETN 2019, CAT-1 issue (2019 #123)

Reported by Users

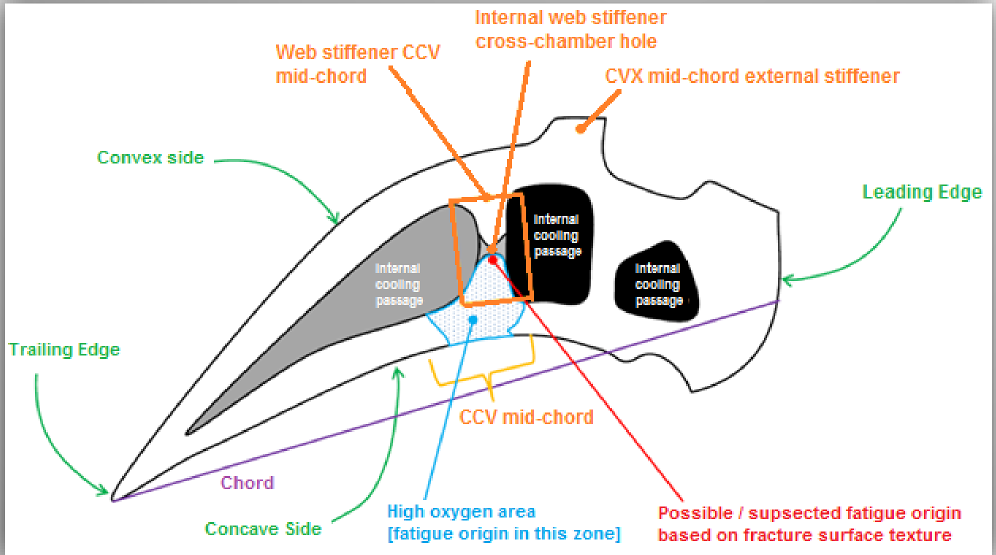
> “Sudden failure of a blade occurred 11,280 hours after the 50,000 hr overhaul and caused serious damage to the HP / IP and PT’s downstream blade and vanes”

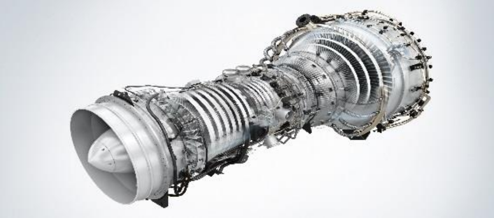
TCT addressed this topic last year with details of the event analysis. The following slides are a re-cap plus updated information.

Issue Index: *2020 #123*

Re-Cap - Summary of Event Analysis

- Single HPT blade failure after 11,280hrs.
- Investigation conducted by TCT. Subsequent contributions from Liburdi and Siemens.
- Initiation site at internal web in blade shank; HCF propagation.
- The origin area did not exhibit any apparent 'defects' or 'deficiencies'.
- No significant environmental contaminants identified.
- TCT concluded that it was unlikely that environmental mechanisms caused or contributed to the failure (i.e. Sulphidation, hot corrosion).

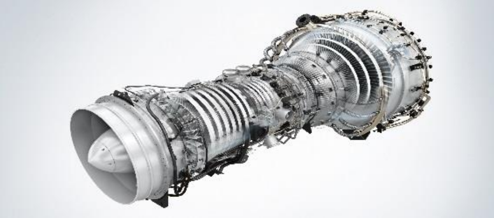





Issue Index: *2020 #123*

GT HPT Blade Failure Fleet History

- Total 6 HPT blade failure events in fleet including subject event (up to 2018).
- All failures are DLE engines.
- 4 events were mid-height airfoil failures; believed to be caused by resonance due to loose outer shroud interlocks (possible contribution from under-platform damper performance).
- 2 events were root shank failures (2018 subject event and a 2014 event).
- 2014 event investigation attributed cause to hot corrosion/sulphidation due to presence of Hydrogen Sulphide, Sulphur Dioxide plus other 'salts' containing Potassium, Sodium and Calcium.




Issue Index: *2020 #123*

Investigation Update

Liburdi Analysis

- Qty 6 blades sent to Liburdi for analysis (qty 1 sectioned).
- No significant metallurgical degradation.
- General condition of base alloy and coating indicated operating temperature was not excessive.
- Minor hot corrosion on internal pages in airfoil (considered typical).

Siemens Analysis (of Historical blades)

- Siemens conducted cut-up analysis of several HPT blades from operator (previously run/removed blades from subject engine GT1 berth, and sister engine from GT2 berth).
- GT1 berth blade – no observed cracks in root cooling passage.
- GT2 berth blade - cracking observed in the root cooling passage, typical of corrosion fatigue or stress corrosion. Evidence of Na and S identified by EDS analysis.
- Siemens recommended to investigate the source of airborne corrosive elements and assess the air quality of both berths.

Investigation Update

Issue Index: *2020 #123*

TCT's Current Opinion

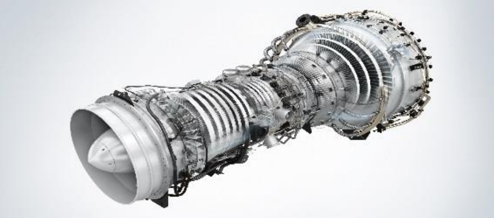
- Unlikely a fleetwide concern. Appears to be isolated event.

Contributing factors:

- Potential contribution to the failure from environmental conditions (evidence is somewhat weak).
- Possible issues with casting process (e.g. core pattern shift resulting in shank cooling passage dimensional differences).
- Possible higher stresses than anticipated in the blade shank area (static and/or cyclic).
- Cracking likely a combination mechanism (i.e. stress corrosion/corrosion fatigue) due to localized high static and/or cyclic stresses superimposed with environmental factors.

Operator Mitigations & Fleet Risk

- Siemens does not appear to consider HPT blade shank failures to be a significant fleet risk (no formal fleetwide actions or MROC advisories have been issued).
- Best Practice, identify and assess environmental factors – Air inlet filtration, airborne corrosive elements, fuel gas cleanliness.
- Not practical to monitor/predict blade failure. Data trending/predictive monitoring/BSI inspections will not mitigate risk.
- HPT blades remain single life items with 25K hour life.




Lube Oil dp Troubleshooting

Original: ETN 2019, CAT-1 issue (2019 #107 | 2020 #124)

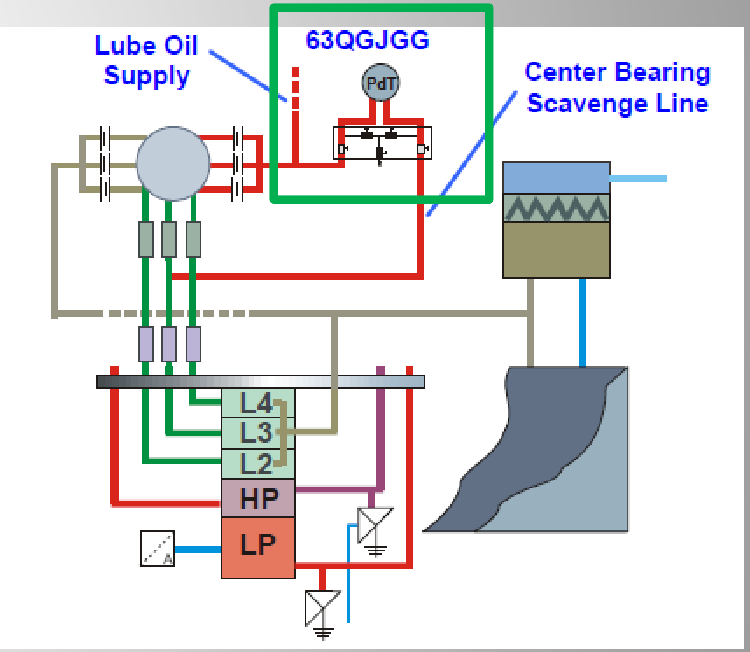
Reported by Users

Tripping on center bearing LO dp

Lube Oil – Centre Bearing DP

Issue Index: 124

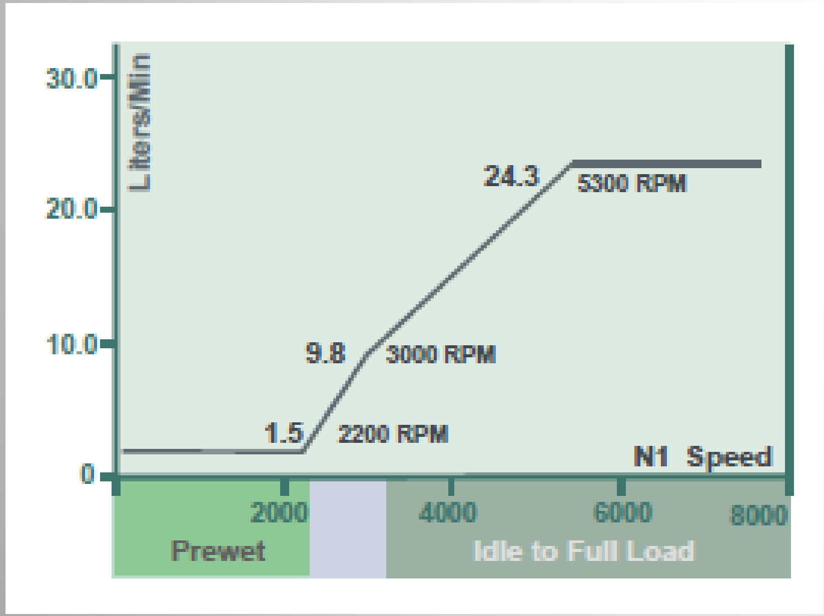
- Differential Pressure Transmitter monitors the performance of the lube oil scheduling.
- Monitors Difference between L1 (Lube oil supply pressure) and L3 (Centre bearing scavenge pressure)
- Control system monitors the pressure to give a determination if the GG is over or under lubricated. i.e. a measure of the performance of the lube oil system.
- The accuracy of the transmitter is dependent on its location. It should be located within 2 meters of the RB211 battery plate and below the centreline of the gas generator.

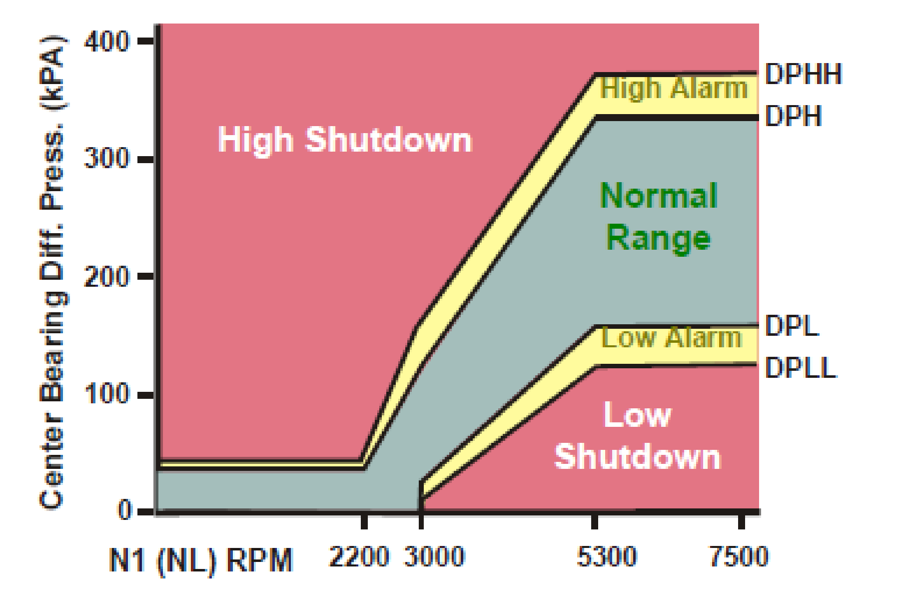


Lube Oil – Centre Bearing DP

Issue Index: 124

- The following shows the relationship between ideal lube oil flow vs. GG speed and centre bearing differential pressure vs. GG speed.
- For ideal Lube oil delivery, the GG should operate within these limits.





Lube Oil – Centre Bearing DP

Issue Index: 124

- The following alarm and trip limits are built into the ECS logic to protect the engine.

N1 Speed	Low Alarm	High Alarm	Low S/D	High S/D
0 - 2200	-	30	-	35
3000	10	120	20	160
5300 - 7500	120	345	120	380

All alarm and shutdown signals from the controller are on a 30-second delay. If the differential pressure return to their normal range, no alarm or shutdown will be generated.

- It is important that if the engine alarms or trips on either of these that investigation work is carried out:-
  - ❑ Check lube oil system performance (leaks, pumps, scheduling valve, correct flow output)
  - ❑ Off-engine bucket test.
  - ❑ Always check the MCD's if a trip like this occurs.
  - ❑ Check Scavenge baskets for blockage.
  - ❑ Confirm trip is real by verifying instrumentation.

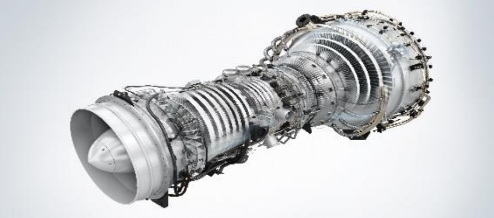
Issue Index: *2020 #103*

IP Turbine Blade Edge Cracking

Original: ETN 2019, CAT-1 issue (2019 #103)

Reported by Users

Trailing edge crack in IP Turbine blade leading to removal from engine in advance



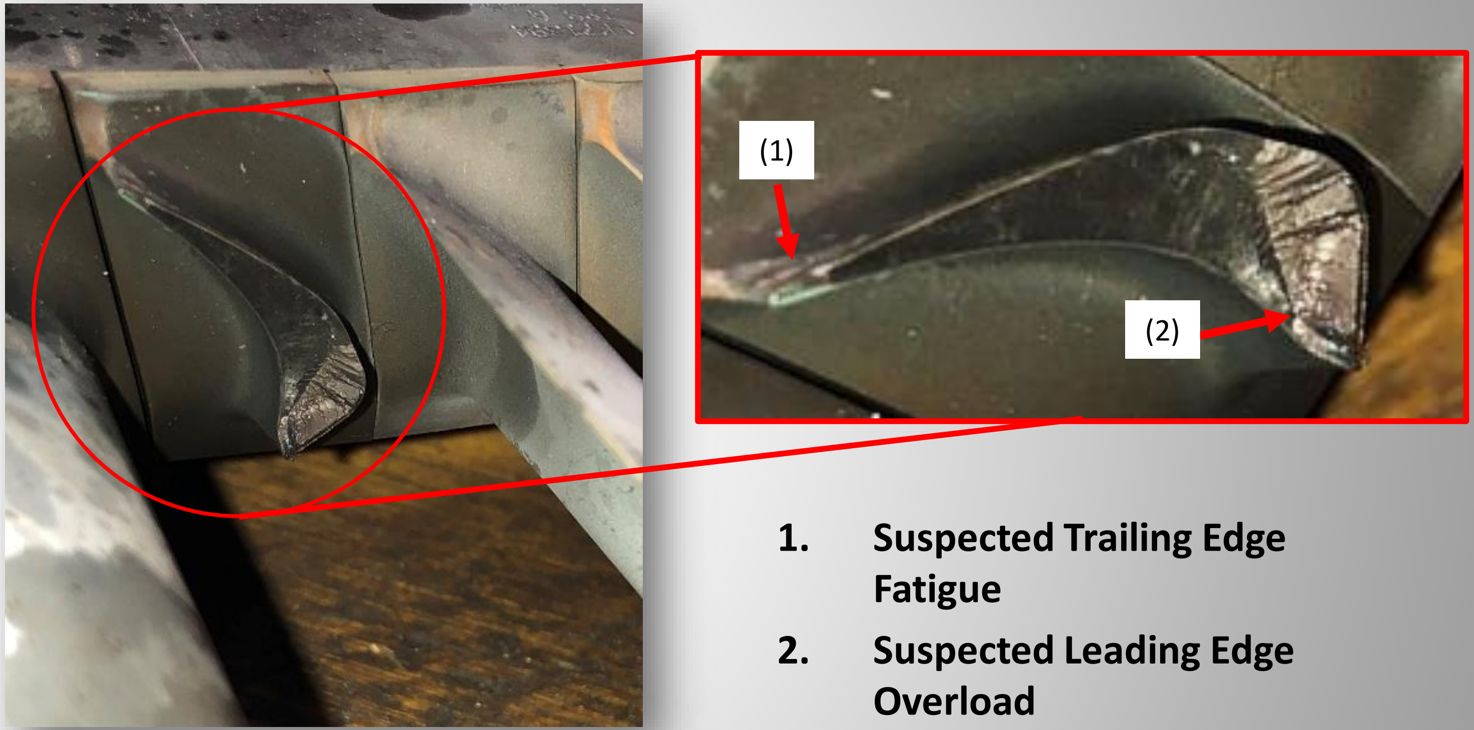

Issue Index: *2020 #103*

IP Turbine Blade Crack Propagation

- Prior to 2019, TCT has not witnessed an IP Turbine Blade failure on –GT or –GT-DLE
- April 2019, TCT was contracted by a first-time client to perform a Failure Analysis on an IP Turbine Blade Failure they recently experienced in the field (RB211-GT), 25k TSO, 75k TSN.
- Engine strip is currently progressing – photos of preliminary findings on the following slides

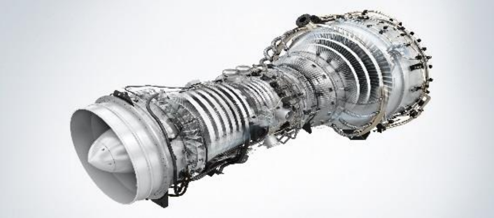
Issue Index: *2020 #103*

IP Turbine Condition As Found



Incident IP Turbine Blade

1. **Suspected Trailing Edge Fatigue**
2. **Suspected Leading Edge Overload**



Issue Index: *2020 #103*

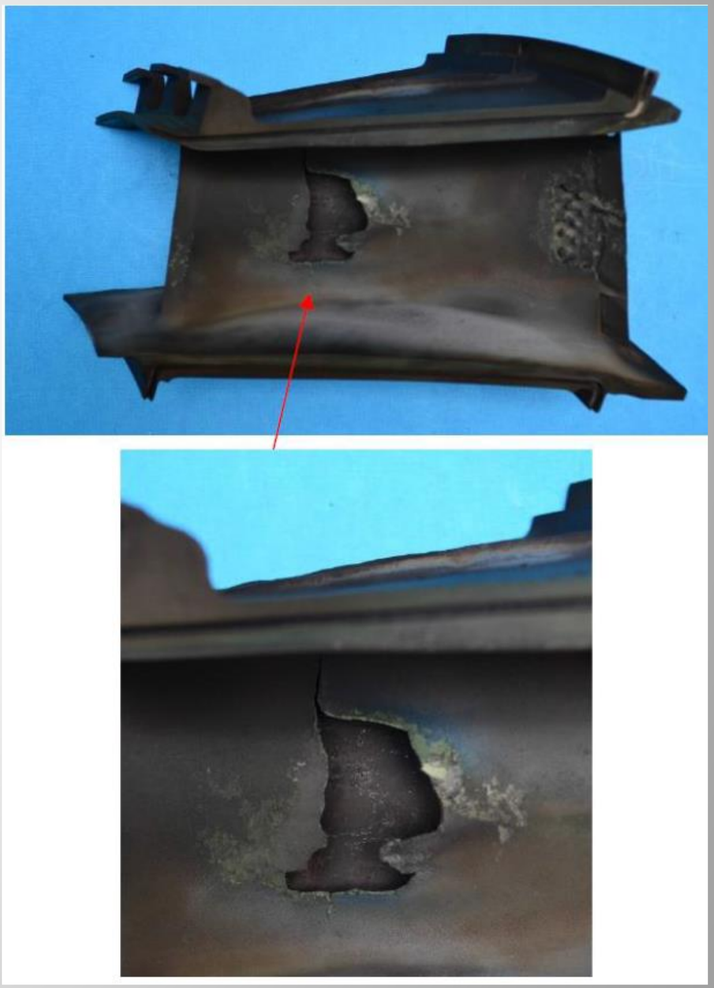
IP Turbine Blade Failure Investigation

- TCT’s investigation completed in the weeks after the 2019 ETN RB211 Conference
- Summary of Blade Analysis Findings:
  - IPT Blade fractured approx. 0.2” above the root platform
  - Crack origin at the Trailing Edge of the suction side
  - Metallurgical evaluation concluded the failure was crack propagation in high cycle fatigue (HCF)
  - There was no evidence of inherent material defect at the fracture origin
  - There was no evidence of a distinct FOD or DOD event as an initiator to cracking/fatigue
  - There was no evidence of environmental contamination on the incident blade

Issue Index: *2020 #103*

IP Turbine Blade Failure Investigation

- Other Engine Component Findings:
  - Qty 1 IP NGV had degraded to the point of complete breach through its airfoil skin
  - IP Turbine Disc Firtrees exhibited galling over the entirety of the disc.
    - Condition subsequently rejected by Siemens Engineering via TLRF



IP Turbine Blade Failure Fault Analysis Tree

Issue Index: *2020 #103*

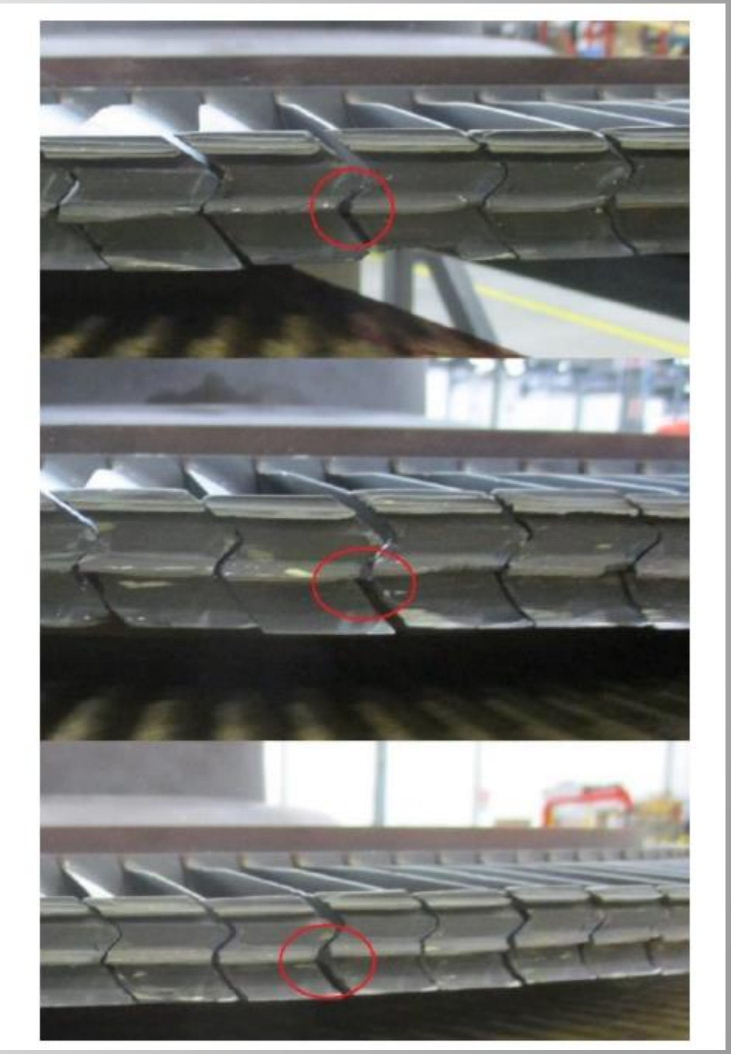
Fault Mode	Possible Contributor to Failure	Unlikely to be Contributor
Abnormal Engine Operation		Engine found to be operating within limits
Manufacturing or Material Defect		Material Defect ruled out on recovered section of failed blade
Abnormal IP Turbine Blade / Disc Condition	Blade looseness/resonance • Blade Creep Untwist • IPT Disc firtree galling	
Environmental Factors		No evidence found on IPT Blades
FOD / DOD Event	Impact to liberated portion of blade plausible to have damaged airfoil, initiating excitation/fatigue	
Upstream Airflow Disturbance	IP NGV airfoil breach causing once-per-revolution excitation	
Blade Design Limitation	OEM Design Limitation	

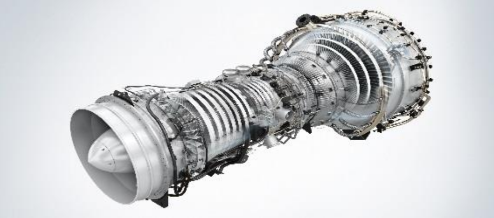
Issue Index: *2020 #103*

Abnormal IP Turbine Blade / Disc Condition → Blade looseness/resonance

- Blade Creep Untwist
- IPT Disc firtree galling

- In theory, excessive shroud looseness could cause excitation and result in HCF
- Under normal operating conditions, blade creep can result in untwist of the blades. Creep untwist beyond design expectations could result in loss of shroud interlock and subsequent looseness/excitation
- Lab analysis discovered a degree of lean/untwist that was higher than previous GT IPT Blades (limited GT fleet sample size)






FOD / DOD Event → Impact to liberated portion of blade plausible to have damaged airfoil, initiating excitation/fatigue

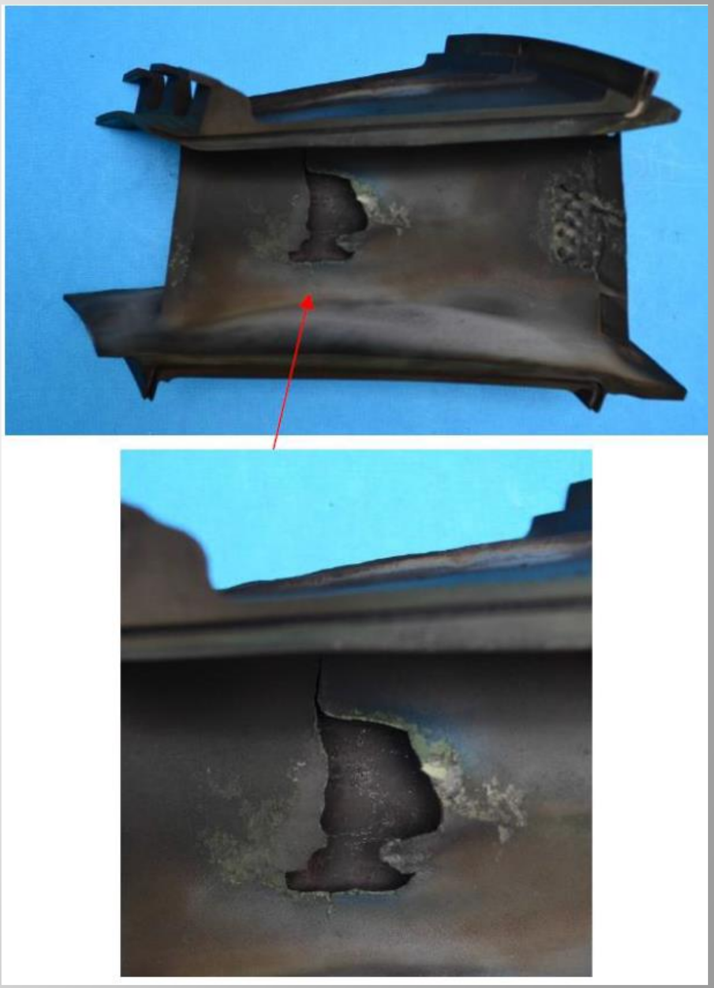
- Fractographic analysis concluded that the fatigue/fracture was not initiated by an impact mark or surface defect

- However, it is possible that the liberated portion of blade (not recovered) could have been impacted causing damage/distortion to the airfoil resulting in abnormal aerodynamic excitation leading to fatigue

Upstream Airflow Disturbance → IP NGV airfoil breach causing once-per-revolution excitation

- The airfoil breach was significant enough to have plausibly caused a once-per-revolution impulse to the IP Turbine Blades due to airflow disturbance

- Further analysis was suggested to the customer to explore this possibility further (modal analysis of the GT IP Turbine Blade)



Blade Design Limitation → OEM Design Limitation

- The subject set of IP Turbine Blades were original to the engine which had accumulated ~75,000 hours
- Siemens Service Bulletin 191 states a Life Limitation of 43,000 hours for RB211-GT (SAC) IP Turbine Blades
- Any extension beyond 43,000 hours requires Siemens to review engine operating characteristics, destructive analysis of Qty 1 exemplar blade from the engine set and the results of the RN5021 assessment for IPT Blade outer shroud condition
- It is possible that the subject IPT Blades had exceeded their design limitations (the Blades had not been through the life extension exercise during a previous 3rd party overhaul)

Issue Index: *2020 #66*

Leaks from Fuel Metering Valves

Original: UGM 2018, CAT-1 issue (2018 #66 | 2019 #66)

Reported by Users

“Leaks from fuel metering valves”

Leaks from FMV's

Issue Index: 66

- Customers are reporting Leaks from the Fuel Metering Valves

- Two recent OEM documents relating to the FMV's released by Siemens:
  - PIB 01-0001-01 (UPDATED GAS FUEL METERING VALVES) – Nov 2016
  - PAB 01-0001-02 (MEGGITT GAS FUEL METERING VALVE STEM SEAL FAILURES) – Mar 2019

  - Any Update in 2020 from Customers?

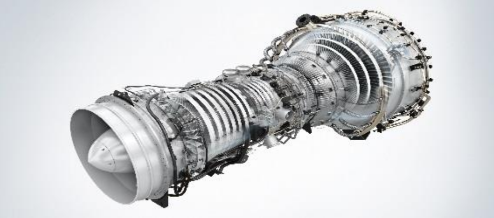
Table 1 – Valve Part Numbers

Part	Size	Legacy Manufacturer Part Number	Legacy Siemens Part Number	Current Standard
Gas metering valve	1.5 inch Moog Actuated	C422855		C521405-1 RRE072210
		C422855-1	RRE007968	
		C422855-2	RRE033711	
		C422855-3	RRE010169	
	2.0 inch Moog Actuated	C422485	E02G169002	C521395-1 RRE072209
		C422485-1	RRE006818	
		C422485-2	RRE006818	

Table 2 – GFMV Improvements

Design/build change	Improvement
Actuator with ceramic bearings	Improved bearing life within the actuator
Valve stem to actuator alignment	Reduced bearing side load leading to longer bearing life within the actuator
Compressible mechanical stop	Prevents the valve from becoming stuck fully open when driven more than 100% open
Threaded valve seat	Prevents the valve seat being pulled out of the valve body by the valve plug due to a tight fit
Improved balance port	Removes issues relating to a crushed diaphragm

PIB 01-0001-01 (UPDATED GAS FUEL METERING VALVES) – Nov 2016



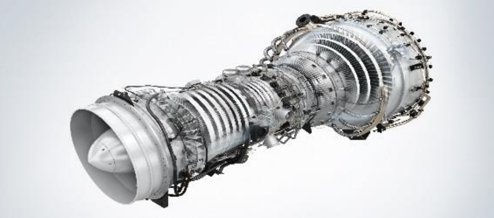

RB211-GT and GT-DLE Component Life Limitations (SB 191)

TABLE 5 - CLEARED CYCLIC LIVES FOR RB211-24G-T GAS GENERATORS

COMPONENT	PART NO.	MOD NO.	CLEARED SERVICE LIFE	
			CYCLES	HOURS
02 MODULE - IP COMPRESSOR				
STAGE 1-5 ROTOR DISC	LW17384	1193	3100	100000
	LW17458	1193	3100	100000
STAGE 1 DISC	LW15286	959	6500	100000
	LW15287	959	6500	100000
STAGE 2-5 ROTOR ASSEMBLY	LW17381	1193	3100	100000
STAGE 6-7 ROTOR ASSEMBLY	UL37094	1255	4000	100000
03 MODULE - INTERMEDIATE CASE				
IPC REAR STUBSHAFT	LW16410	1157	4000	100000
IP THRUST BEARING	BED1231	899	-	62000
	LW13882	621	-	50000
	LW14982	899	-	50000
	LW20502	1550	-	150000
HP THRUST BEARING	LW19912	-	-	40500
04 MODULE - HP COMPRESSOR				
STAGE 1-4 HPC ASSEMBLY	FK32580	-	35600	75000
STAGE 5-6 HPC ASSEMBLY	LW18985	-	4000	100000
04 MODULE - HP TURBINE				
STUBSHAFT	LW16466	-	4000	50000*
DISC	UL29473	-	4000	100000
05 MODULE - IP TURBINE				
DISC ASSEMBLY	UL32380	1355	4000	100000
DISC	LW20229	1535	4000	100000
	UL32381	1355	4000	100000
SHAFT ASSEMBLY	LW20225	1535	7700	50000*
	LW16409	1157	7700	50000*
SHAFT	LW20226	1535	4000	50000*
	LW16280	1157	4000	50000*
04 & 05 MODULE- TURBINE BLADES				
04 HP TURBINE BLADE	FW21837	-	-	25000
05 IP TURBINE BLADE	LW19813	-	4000	43000*
	LW20507	-	4000	43000*

TABLE 6 - CLEARED CYCLIC LIVES FOR RB211-24G-T DLE GAS GENERATORS

COMPONENT	PART NO.	MOD NO.	CLEARED SERVICE LIFE	
			CYCLES	HOURS
02 MODULE - IP COMPRESSOR				
STAGE 1-5 ROTOR DISC	LW17384	1193	5250	100000
	LW17458	1193	5250	100000
STAGE 1 DISC	LW15286	959	5250	100000
	LW15287	959	5250	100000
STAGE 2-5 ROTOR ASSEMBLY	LW17381	1193	8000	100000
STAGE 6-7 ROTOR ASSEMBLY	UL37094	1255	11000	100000
03 MODULE - INTERMEDIATE CASE				
IPC REAR STUBSHAFT	LW16410	1157	50000	100000
IP THRUST BEARING	BED1231	899	-	62000
	LW13882	621	-	67000
	LW14982	899	-	67000
	LW20502	1550	-	150000
HP THRUST BEARING	LW17433	1183	-	25000
	LW17434	1183	-	25000
	LW19912	1368	-	40500*
04 MODULE - HP COMPRESSOR				
STAGE 1-4 HPC ASSEMBLY	FK26167	-	13800	50000
	FK32580	-	13800	90000
STAGE 5-6 HPC ASSEMBLY	LW18985	-	8000	100000
04 MODULE - HP TURBINE				
STUBSHAFT	LW16466	-	30000	-
DISC	UL29473	-	7000	100000
05 MODULE - IP TURBINE				
DISC ASSEMBLY	UL32376	1172	5000	-
	UL32378	1172	5000	-
	UL32380	1355	5000	100000
DISC	LW20229	1535	5000	100000
	UL32377	-	5000	-
	UL32379	-	5000	-
	UL32381	-	5000	100000
SHAFT ASSEMBLY	LW20225	1535	17500	-
	LW16409	1157	17500	-
SHAFT	LW20226	1535	17500	-
	LW16280	1157	17500	-
04 & 05 MODULE-TURBINE BLADES				
04 HP TURBINE BLADE	UL38291	-	4000	25000
	FW21837	-	4000	25000
05 IP TURBINE BLADE	LW18509	-	4000	75000
	LW19813	-	4000	75000
	LW20507	-	4000	75000




GT and GT-DLE Life Extension Program

- GT and GT-DLE engines have been approaching/exceeding component life limitations per Service Bulletin 191
- TCT has initiated a GT/GT-DLE life extension program with Siemens through the TLRF system
- For components to be candidates for life extension, the following information is required from the operator:
  - Engine Time Since New
  - Engine Cycles Since New
  - Logbooks to confirm Component S/N match Engine hours (or history if not)
  - Engine Operating Data
    - Average Power (MW)
    - Average Inlet Temperature
    - Average T455 (EGT) Temperature
    - Average N2 (HP) Speed
    - Duty Type (Power Gen, Compression)
    - Duty Schedule (Base Load, Peaking)

GT and GT-DLE Life Extension Program

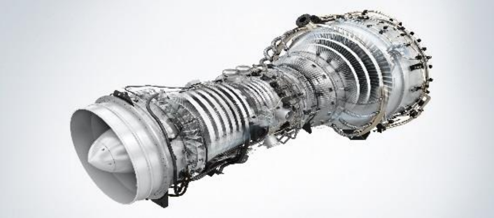
- HP Turbine Blades are still NOT candidates for life extension beyond 25,000 hours
- IP Turbine Blades – specific life extension requirements
  - Results of Repair Note RN5021 Assessment during Engine Strip (TCT action)
    - Assesses Blade Shroud Interlock Gaps and Blade Tip Axial Runout (Twist)
  - Results of Laboratory Blade Life Assessment (Repair Vendor action)
    - Destructive Analysis of Exemplar Blade from Set to assess Gamma Prime (γ’) microstructure
  - Engine Operation data shown in previous slide
- HP Thrust Bearing Life can be reset to “0” with major repair scope

GT and GT-DLE Life Extension Program

- Inconsistent Limits between GT and GT-DLE
  - Stage 1-4 HPC Drum
    - GT: 75,000 hours
    - GT-DLE: 90,000 hours
    - Per TLRF, limits can be followed as currently written
  - IP Turbine Blades
    - GT: 43,000 hours
    - GT-DLE: 75,000 hours (may decrease in next revision of Service Bulletin)
    - Per TLRF, limits are to be followed as currently written

GT and GT-DLE Life Extension Program

- Next revision of SB 191 will be in form of PSW (Product Safety Warning)
  - Expected to correct / clarify inconsistencies between all marks of RB211
  - Expected to revise some GT and GT-DLE Limits
  - Publication by Siemens currently delayed (expected Q2/Q3 2020)




Issue Index: *2020 #23.1*

Bearing Failure Mitigation

Original: ETN 2018, CAT-1 issue (2018 #11 | 2019 #11)

Reported by Users

The HP Thrust Bearing revealed extensive spalling affecting the ball bearings and Outer Raceway. It was also noted that the Bearing Cage had fractured at one ball pocket location.
Another issue reports front bearing case rivet broken

Bearing Issues

Issue Index: *2020 #23.1*

The Issue

Although each bearing event has unique elements, by far the most common sequence is:

1. Rolling element/raceway rolling contact fatigue (RCF).
2. Progression to macro spalling (flakes/debris on MCD's).
3. Cage pocket wear & fatigue damage to cage.
4. Cage/rivet failure leading to seizure, destruction of bearing, loss of rotor location.

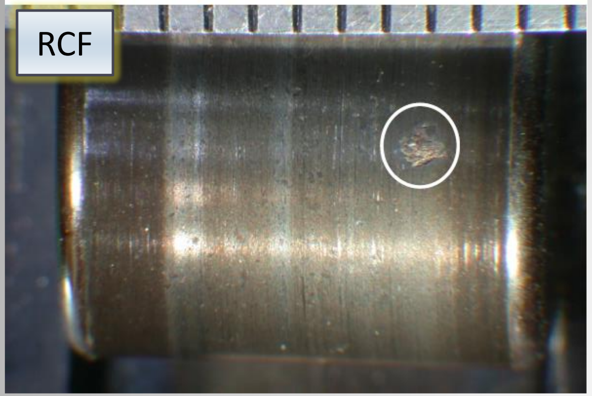
Note: Spalling, cage pocket wear/cracking and rivet failures are seldom the root cause.

Root Cause – Majority of bearing failures attributed to lubrication issues. Hard particle contamination or oil starvation. Other (less likely) root causes include excessive thrust loading, vibration loading, material defect, installation issue, transportation issue (brinelling or false brinelling).

Mitigation Measures

- Monitor oil quality (particulates, acidity water content etc).
- Check MCD's at regular intervals.
- Monitor vibration and oil system parameters for trends and step changes.
- Ensure package air filtration is effective.
- Ensure package oil system is properly flushed before engine is returned to service (if previous bearing failure experienced).

Issue Index: *2020 #23.1*



Centre Bearing Damage Progression

Issue Index: *2020 #23.1*

1) Onset Damage

Metal to metal contact resulted in repetitive sliding & scuffing contact between the raceways and rolling elements.

2) Damage Progression

1. Sliding Contact Fatigue (SCF) initiated surface cracking.
2. Cyclic stresses propagated the cracks resulting in progressive fatigue spallation and release of bearing chips/flakes.
3. Released debris caused hard particle indentations, resulting in elevated contact stresses and acceleration of the fatigue spallation.
4. Areas of fatigue spallation caused balls to hammer the cage pockets; imparting fatigue stresses to the cage with eventual initiation of a fatigue crack in the cage.

3) Final Engine Shutdown Event

The cage fatigue crack propagated to a through-crack, allowing cage to splay outwards and rub heavily against the outer race. Rapid generation of metallic debris resulted and consequent blockage of the L3 scavenge screen that resulted in the alarm and engine trip event.