FINAL INVESTIGATION REPORT ON AIR TURN BACK INCIDENT TO M/s AIR INDIA LTD AIRBUS A320-251N AIRCRAFT VT-EXM ON 19/05/2022 AT MUMBAI

GOVERNMENT OF INDIA
O/o DIRECTOR AIR SAFETY, WESTERN REGION,
NEW INTEGRATED OPERATIONAL OFFICE COMPLEX,
SAHAR ROAD, VILE PARLE (EAST), MUMBAI-400099

FOREWARD

This investigation is performed in accordance with The Aircraft (Investigation of Accidents and Incidents) Rules 2017 of India. The sole objective of this investigation is to prevent aircraft accidents and incidents. It is not the purpose of this investigation to apportion blame or liability.

This document has been prepared based upon the evidences collected during the investigation, opinion obtained from the experts and laboratory examination of various components. Consequently, the use of this report for any purpose other than for the prevention of accidents or incidents could lead to erroneous interpretations.

CONTENTS

ABBREVIATIONS

A/c	Aircraft
ADF	Automatic Direction Finder
Aircraft	Incident aircraft
AME	Aircraft Maintenance Engineer
AMM	Aircraft Maintenance Manual
AMP	Aircraft Maintenance Programme
AMSL	Above Mean Seal Level
APU	Auxiliary Power Unit
ARC	Airworthiness Review Certificate
ASDA	Accelerate Distance Available
ATC	Air Traffic Control
ATPL	Air Transport Pilot's License
BLR	Bangalore Airport
BOM	Mumbai Airport
BSI	Boroscope Inspection
CPL	Commercial Pilot's License
CSMIA	Chhatrapati Shivaji Maharaj International Airport
CSN	Cycles Since New
CSV	Cycle Since Shop Visit
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder

DGCA	Director General of Civil Aviation, India
DME	Distance Measuring Equipment
DVOR	Directional Very high frequency Omni Range
EBC	Environmental Barrier Coating
ECAM	Electronic Centralized Aircraft Monitor
ECTM	Engine Condition Trend Monitoring
EDTO	Extended Diversion Time Operations
EGT	Exhaust Gas Temperature
ELT	Emergency Locator Transmitter
FCOM	Flight Crew Operating Manual
FDTL	Flight and Duty Time Limitations
FL	Flight Level
FO	Co-Pilot/ First Officer
FRTO	Flight Radio Telephone Operator
GPS	Global Positioning System
HPT	High Pressure Turbine
HPTR	High Pressure Turbine Rotor
HZ	Haze
IATA	International Air Traffic Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules

IFSD	In-Flight Shutdown
ILS	Instrument Landing System
IR	Instrument Rating
LDA	Landing Distance Available
LH	Left Hand
LPT	Low Pressure Turbine
MCT	Maximum Continuous Thrust
MEL	Minimum Equipment List
MENA	Middle East North Africa
NGV	Nozzle Guide Vane
NOSIG	Non-significant
OEM	Original Equipment Manufacturer
Operator	AOP holder of the incident aircraft
PDR	Pilot Defect Report
PFR	Post Flight Report
PIC	Pilot in Command
PPC	Pilot Proficiency Check
QNH	Pressure setting to indicate elevation
QRH	Quick Response Handbook
RADAR	Radio Detection and Ranging
RESA	Runway End Safety Area
RH	Right Hand

SCT	Scattered
SER	Service Evaluation Request
TCAS	Traffic Collision Avoidance System
TBC	Thermal Barrier Coating
TODA	Take-off Distance Available
TORA	Take-off Run Available
TSN	Time Since New
TSV	Time Since Shop Visit
UTC	Coordinated Universal Time
VABB	Mumbai Airport
VFR	Visual Flight Rules
VOBL	Bangalore Airport
VOR	Very high-frequency Omni Range

FINAL INVESTIGATION REPORT ON AIR TURN BACK INCIDENT TO M/s AIR INDIA LTD AIRBUS A320-251N AIRCRAFT VT-EXM ON 19/05/2022 AT MUMBAI

1.	**Aircraft**	**Type**	Airbus A320-251N
2.		**Nationality**	Indian
3.		**Registration**	VT-EXM
4.	**Owner**		M/s Alafco Irish Aircraft Leasing Eight Ltd 2 Grand Canal Square, Grand Canal Harbour, Dublin 2, Ireland
5.	**Operator**		M/s Air India Ltd
6.	**Pilot In- Command**		Airline Transport Pilot's License Holder
7.	**Extent of Injuries**		Nil
8.	**Date and Time of Incident**		19/05/2022 04:18hrs
9.	**Place of Incident**		Mumbai
10.	**Geographical location of site of Occurrence (Lat. Long.)**		Enroute
11.	**Last point of Departure**		Mumbai, India
12.	**Intended Place of Landing**		Bengaluru, India
13.	**No. of Passengers On-Board**		158
14.	**Type of Operation**		Schedule, Passenger
15.	**Phase of Operation**		Climb
16.	**Type of Incident**		Air Turn Back due to Eng# 2 IFSD

All timings in this report are in UTC.

SYNOPSIS

On 19th May 2022, M/s Air India Ltd Airbus A320-251N aircraft VT-EXM was involved in air turn back incident due to In-Flight Shutdown of Engine# 2 during climb while operating flight AI-639 (VABB-VOBL).

Aircraft was released under MEL 36-11-01A for 'ENG2 Bleed Air Supply System' to operate flight AI-639 as a non-EDTO sector. Both engines were started normally and the taxi was also normal. The aircraft got airborne at 04:14hrs from Runway 27. While climbing passing FL112 at 04:18hrs, the crew heard a loud bang noise which was followed by ECAM caution Eng# 2 Stall. Immediately after Eng# 2 stall, ECAM warning for Eng# 2 EGT overlimit was also triggered followed by Eng#2 Vibration advisory. As part of QRH abnormal and emergency procedures throttle lever of Eng#2 was brought to idle and the throttle lever of Eng# 1 was moved forward to MCT. Subsequently, on noticing the abnormal engine parameters, the crew shut down Eng# 2 by putting the master to OFF as required by QRH procedures. The maximum EGT of Eng# 2 was recorded as 1166˚C and the maximum vibration of N1 & N2 was recorded as 10. PIC declared MAYDAY and requested descent immediately for landing back to Mumbai. Subsequently, with the co-ordination of ATC, the aircraft landed with a single engine on Runway 27 uneventfully. The aircraft was taxied with a single engine and parked at Bay K1 at 04:47hrs. Full emergency was declared at Mumbai airport due to the arrival of aircraft VT-EXM. No human injury was reported in the incident.

The Director General of Civil Aviation ordered the investigation of the incident by appointing Investigator In-charge vide order no. DGCA-15018(01)/27/2022-DAS dated 30.05.2022 under Rule 13(1) of The Aircraft (Investigation of Accidents and Incidents) Rules 2017. The most probable cause of the incident is liberation of the aft catenary arm from the HPT rotor interstage seal (mid-seal) due to inadequate peen coverage/ intensity and visible turning lines (re-machined surface) in the aft rabbet fillet.

1. FACTUAL INFORMATION:

1.1 History of Flight:

M/s Air India Ltd Airbus A320-251N aircraft VT-EXM, was scheduled to operate flight no. AI-639 (sector Mumbai - Bangaluru) on 19th May 2022 at 04:00hrs with 165 persons on board including 02 cockpit crew and 05 cabin crew. The aircraft was under the command of PIC (ATPL holder). PIC was the pilot flying and First Officer was the pilot monitoring. It was the first flight of the day for PIC whereas First Officer operated incoming flight AI-640 (VOBL-VABB) of 19.05.2022 on VT-EXM with other PIC.

While operating incoming flight AI-640, 'AIR ENG2 BLEED ABNORMAL PR' ECAM message came during the taxi at VOBL. The flight was continued after

performing RESET followed by MEL 36-11-01A operational procedures which requires associated engine bleed push button switch is set to OFF and cross bleed selector is set to OPEN. Subsequent flight was uneventful and aircraft arrived to Mumbai at 03:04hrs. Defect was recorded in the PDR section for the sector VOBL-VABB.

On arrival at Mumbai, MEL 36-11-01A Cat 'B' for 'ENG2 Bleed Air Supply System' was invoked by the AME in order to address the 'AIR ENG2 BLEED ABNORMAL PR' snag of incoming flight. Further, a transit check was carried out and no abnormality was observed on Eng# 2. Subsequently, AME released the aircraft for departure of the flight AI-639 (VABB-VOBL) for the non-EDTO route at 03:34hrs. Refueling was not carried out at Mumbai.

PIC reported for flight duty at 03:07hrs for flight AI-639 and completed preflight external checks wherein no abnormality was observed. PIC accepted the aircraft at 03:35hrs. APU was started while the aircraft was getting ready for the departure. The aircraft pushed back on time and both the engines were started normally with the help of APU bleed. No abnormalities were observed during taxi and engine parameters were observed normal during taxi and take-off.

Aircraft got airborne at 04:14hrs from Runway 27. At around 04:18hrs during climb, crew heard loud bang noise followed by ECAM caution Eng 2 Stall. As part of QRH abnormal and emergency procedures throttle lever of Eng# 2 was brought to idle and throttle lever Eng# 1 was moved forward to MCT. Meanwhile, the ECAM warning for Eng# 2 EGT overlimit was also triggered and crew noticed that EGT of Eng# 2 EGT was at maximum value on the gauge. Eng# 2 was shut down by putting master OFF as required by QRH abnormal and emergency procedures. Eng#2 Vibration advisory also triggered as N1 and N2 vibrations of Eng# 2 had reached to its maximum value 10. Thereafter, no buffet/sound/smell was perceived by the crew.

Subsequent to the Eng# 2 shut down, the aircraft was leveled off at FL117, and MAYDAY was declared by the PIC at 04:19hrs. PIC requested ATC for immediate descent for landing back to Mumbai. Subsequently, the abnormal procedures were reviewed and completed. Later, APU was also started and kept ON throughout the flight.

On being asked by ATC, PIC informed that Eng# 2 failure was the reason of declaring MAYDAY. Subsequently, crew once again reviewed the checklist for Eng# 2 shut down and made a cabin announcement to inform passengers about inflight turn back due to technical problem.

Later with co-ordination of ATC, aircraft made ILS approach and landed with single engine on Runway 27 uneventfully at 04:33hrs. Upon landing, aircraft reported to

ATC that all operations were normal and no assistance required. Aircraft taxied on its own power with single engine and parked at bay K1 at 04:47hrs. Full emergency was declared by ATC at Mumbai airport at 04:22hrs due to the arrival aircraft VT-EXM and withdrawn at 04:47hrs. Aircraft landing weight was within the maximum landing weight. No human injury was reported in the incident. Later, PIC and First Officer operated flight AI-639 in aircraft VT-EXQ.

Pre-flight briefing, Before Start Procedure, Engine Start Procedure, After Start Procedure, Before Taxi Procedure, Line up Procedure, final brief & review of Go Around Procedure, Approach Procedure, Landing Procedure, After Landing Procedure, Engine Shutdown Procedure and Parking Procedure were carried out in incident flight as per FCOM.

1.2 Injuries to Persons:

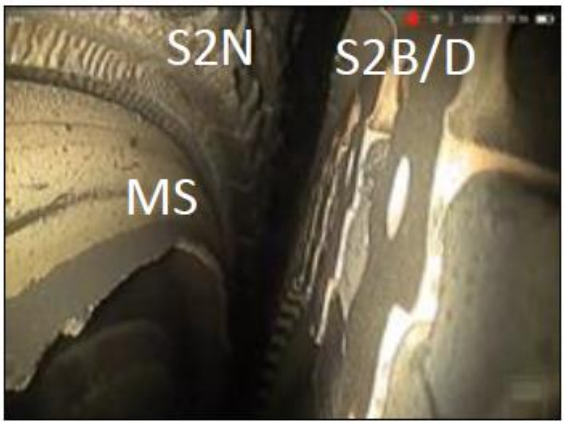
Injuries	Crew	Passengers	Others
Fatal	0	0	0
Serious	0	0	0
Minor/ None	0/7	0/158	0

1.3 Damage to Aircraft:

On arrival at Mumbai, aircraft VT-EXM was inspected by the AME. During inspection, Engine # 2 last two stages of LPT & LPT NGVs found damaged/ missing material. Boroscope inspection of the engine revealed liberation of aft catenary arm from the HPT rotor interstage seal (mid-seal). Consequential damage to HPT and LPT blades downstream was also seen in the boroscope inspection as per images depicted below:

Image# 1 Damage to Eng# 2 LPT blades

Image# 2 HPT Stage1 blade trailing edge & liberated material



Image# 3 Damaged HPT rotor interstage seal (Mid-seal)

Image# 4 HPT Stage2 blade leading edge

Image# 5 HPT Stage2 blade trailing edge

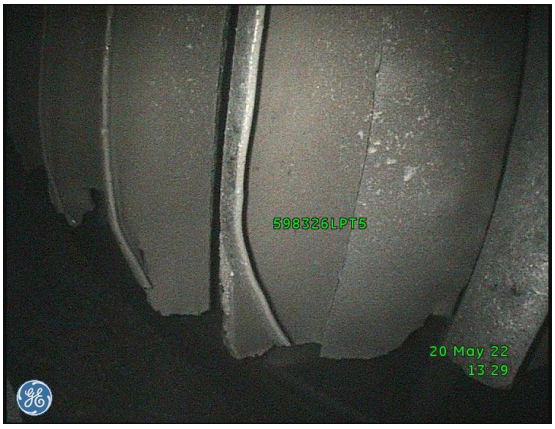
Image# 6 LPT Stage1

Image# 7 LPT Stage2

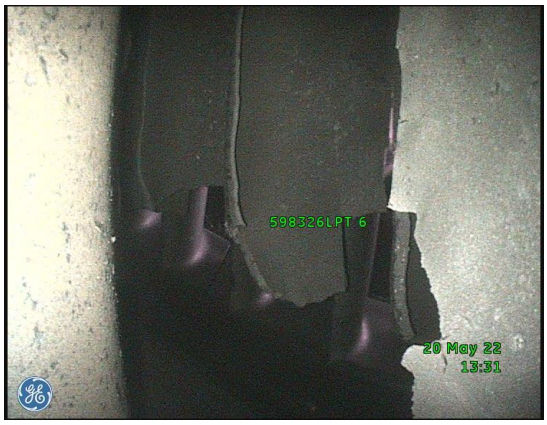
Image# 8 LPT Stage2

Image# 9 LPT Stage3

Image# 10 LPT Stage4



Image# 11 LPT Stage5



Image# 12 LPT Stage6

Image# 13 LPT Stage7

1.4 Other Damage: There was no other damage.

1.5 Personnel Information:

Pilot- In-Command:

Age	45 years 01 month Male
License	ATPL
Date of Issue	07/10/2011
Valid up to	28/09/2025
Category	Aeroplane
Date of Class I Medical Exam	11/10/2021
Class I Medical Valid up to	25/10/2022
Date of Issue of FRTO Licence	12/11/1997
FRTO Licence Valid up to	16/04/2026
Date of IR/ PPC	12//03/2022
Total Flying Experience	15780hrs (Approx.)
Total Flying Experience on Type	13300hrs (Approx.)
Total Flying Experience as PIC on Type	8983hrs (Approx.)
Total Flying Experience in last 1 year	653hrs (Approx.)
Total Flying Experience in last 6 months	392hrs (Approx.)
Total Flying Experience in last 30 days	69:40hrs (Approx.)
Total Flying Experience in last 7 days	20:30hrs
Total Flying Experience in last 24 hours	05:48hrs
Duty Time last 24 hours	08:10hrs
Rest before the incident flight	15:20hrs (Approx.)
Ratings	PIC: Cessna 172, Cessna 152A, Airbus A320 family FO: Boeing 737-200

First Officer:

Age	42years Male
License	CPL
Date of Issue	22/03/2012
Valid up to	21/03/2027
Category	Aeroplane
Date of Class I Medical Exam	15/03/2022
Class I Medical Valid up to	25/03/2023
Date of Issue of FRTO Licence	22/03/2012
FRTO Licence Valid up to	21/03/2027
Date of IR/ PPC	09/12/2021
Total Flying Experience	1267hrs (Approx.)
Total Flying Experience on Type	1050hrs (Approx.)
Total Flying Experience in last 1 year	380hrs (Approx.)
Total Flying Experience in last 6 months	190hrs (Approx.)
Total Flying Experience in last 30 days	27hrs (Approx.)
Total Flying Experience in last 7 days	05hrs (Approx.)
Total Flying Experience in last 24 hours	00:00hrs
Duty Time last 24 hours	06hrs (Standby duty)
Rest before the incident flight duty period	16hrs (Approx.)
Ratings	PIC: Cessna 152, Cessna 310, FO: Airbus A320

PIC was examined for consumption of alcohol at Mumbai at 03:08hrs on 19/05/2022 before operating incident sector (flight no. AI-639) and found fit for flying.

First Officer was examined for consumption of alcohol at Bengaluru at 00:58hrs on 19/05/2022 before operating sector VOBL-VABB (flight no. AI-640) and found fit for flying.

PIC and First Officer had adequate rest before they operated flight on 19th May 2022. Upon scrutiny of the records, PIC and First Officer were found to be within limits of FDTL.

Performance of PIC and First Officer was found satisfactory during IR/PPC checks carried out in last one year. No adverse remarks were found to be recorded in their respective assessment forms. They did not have any past incident history with the operator.

1.6 Aircraft Information:

1.6.1 Aircraft details:

The details provided below are as of prior to the incident flight.

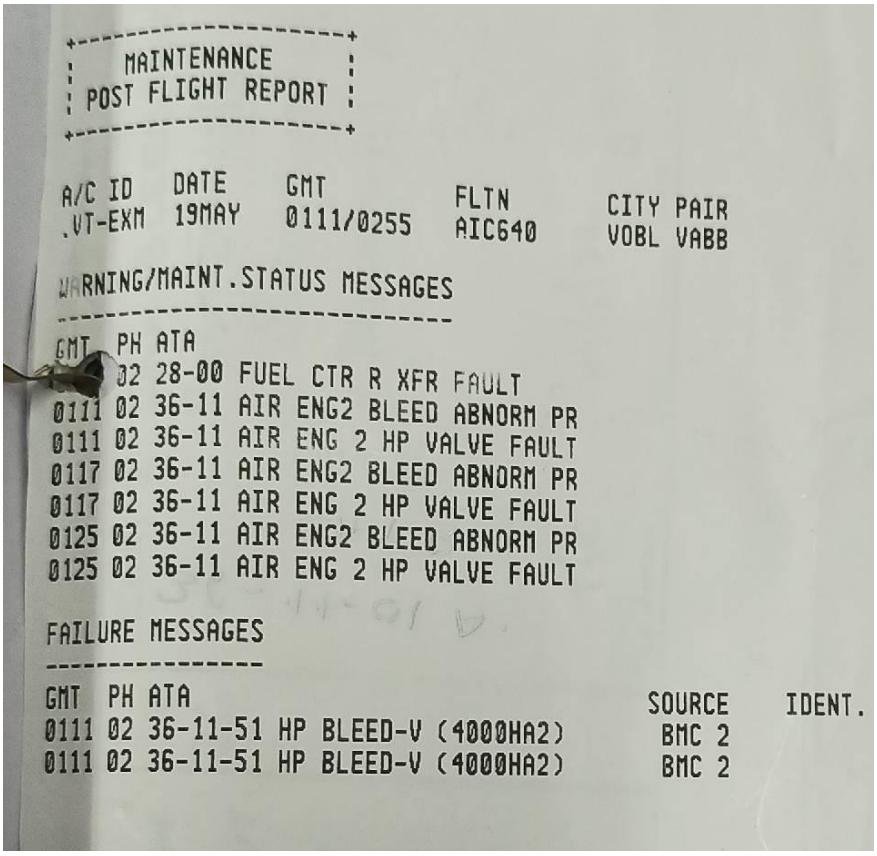
Aircraft Registration	VT-EXM
Type of Aircraft	Airbus A320-251N
Aircraft Serial No.	8056
State of Manufacturing	France
Manufacturing year	2018
Owner	M/s Alafco Irish Aircraft Leasing Eight Limited 2 Grand Canal Square, Grand Canal Harbour Dublin 2, Ireland
Operator	M/s Air India Ltd
Certificate of Airworthiness number and issue date	6980 dated 16/02/2018
ARC number and Validity	AI/ENGG/NR/ARC/2021/13 Valid up to 16/01/2023
A/c TSN / CSN	13,351:38hrs/ 6,880
Minimum crew necessary	Two
Engine Type	# 1 (LH): Leap 1A26 # 2 (RH): Leap 1A26

Engine Serial No.	598187	598326
Engine TSN / CSN	12,712:11hrs/ 6,390	12,612:45hrs/ 6,596
Engine TSV / CSV	2,125hrs/ 1,105	6,059hrs/ 3,242
HPT rotor interstage seal Make	Paradigm	
HPT rotor interstage seal	P/N: 2466M68P02	S/N: WESF3568
HPT rotor interstage seal CSN	6,596	
Last major check carried out	4A+P1.5 check on 17/05/2022 at 13,340:05hrs A/c TSN/ 6,871 A/c CSN	
Next schedule maintenance due at (A Check)	At 14,090:05hrs A/c TSN or 7,471 A/c CSN or 15/08/2022 whichever earlier	
Maximum All Up Weight authorized	79,000kg	
Aircraft Take-off Weight	64,926kg	
Aircraft Landing Weight	64,301kg	
Maximum Landing Weight	67,400kg	
Fuel On-board before Flight	6,400kg	
Centre of Gravity	Within limits	
AMP compliance	Satisfactory	

1.6.2 Previous flight AI-640 (VOBL-VABB):

Aircraft had encountered a defect with regard to Eng# 2 bleed system in the previous sector (AI-640) during taxi out wherein crew had carried out operational procedure for 'MEL 36-11-01A - Engine Bleed Air Supply System (non- EDTO flights)' and continued flight. Subsequently, no abnormalities were observed in incoming flight AI-640. Crew reported in Pilot Defect Report that- 'AIR ENG2 BLEED ABNORMAL PR ECAM DURING TAXI IN BLR. RESET CARRIED OUT. MEL 36-11-01A OPS PROC CARRIED OUT'.

Maintenance Post Flight Report (PFR) of AI-640 of 19/05/2022 reflected following warning/ maintenance status messages:



MAINTENANCE
POST FLIGHT REPORT

A/C ID	DATE	GMT	FLTN	CITY PAIR
VT-EXM	19MAY	0111/0255	AIC640	VOBL VABB

WARNING/MAINT.STATUS MESSAGES

GMT	PH	ATA	
	02	28-00	FUEL CTR R XFR FAULT
0111	02	36-11	AIR ENG2 BLEED ABNORM PR
0111	02	36-11	AIR ENG 2 HP VALVE FAULT
0117	02	36-11	AIR ENG2 BLEED ABNORM PR
0117	02	36-11	AIR ENG 2 HP VALVE FAULT
0125	02	36-11	AIR ENG2 BLEED ABNORM PR
0125	02	36-11	AIR ENG 2 HP VALVE FAULT

FAILURE MESSAGES

GMT	PH	ATA		SOURCE	IDENT.
0111	02	36-11-51	HP BLEED-V (4000HA2)	BMC 2	
0111	02	36-11-51	HP BLEED-V (4000HA2)	BMC 2	

Image# 14 Maintenance Post Flight Report (PFR) of AI-640 of 19/05/2022

As part of rectification, AME invoked MEL 36-11-01A Cat 'B' for 'ENG2 Bleed Air Supply System' at Mumbai.

Further, maintenance records of VT-EXM revealed that MEL 28-26-1B Cat 'C' for Center Tank Right Transfer Valve was invoked on 18/05/2022 at Delhi.

Hence, two MELs were active when the aircraft was released to service for AI-639, i.e. MEL 28-26-1B Cat 'C' for Center Tank Right Transfer Valve and MEL 36-11-01A Cat 'B' for 'ENG2 Bleed Air Supply System'. No relevant snag was open for rectification when the aircraft was released from Mumbai for AI-639 on 19.05.2022. All the warning/ maintenance status messages recorded during incoming flight AI-640 were addressed.

1.6.3 Incident flight AI-639 (VABB- VOBL):

Before operating flight AI-639 on 19/05/2022, transit check was carried out and the same was found satisfactory. No abnormal observations pertaining to engines were made during transit inspection.

While operating AI-639, aircraft made air turn back to Mumbai due to Eng# 2 in flight shut down due to stall and EGT overlimit warning during climb. Maintenance Post Flight Report (PFR) of incident flight was as follows:

```
A/C ID    DATE    GMT    FLTN       CITY PAIR
.VT-EXM   19MAY   0723   AIC639     VABB VABB


+--------------------+
:    MAINTENANCE     :
: POST FLIGHT REPORT :
+--------------------+

A/C ID   DATE    GMT         FLTN       CITY PAIR
.VT-EXM  19MAY   0405/0436   AIC639     VABB VABB

WARNING/MAINT.STATUS MESSAGES
-----------------------------
GMT  PH ATA
0406 02 28-00 FUEL CTR R XFR FAULT
0406 02 36-00 AIR BLEED
0418 06 77-00 ENG 2 STALL
0418 06 77-00 ENG 2 EGT OVER LIMIT
0418 06 78-00 ENG 2 HIGH VIBRATION
0419 06 77-00 ENG 2 SHUT DOWN
0419 06 78-00 ENG 2 HIGH VIBRATION
0419 06 22-00 AUTO FLT A/THR OFF
0423 06 21-61 AIR PACK 2 REGUL FAULT
0433 08 77-00 ENG 2 FADEC
0433 08 78-00 ENG 2 FADEC SYS FAULT

FAILURE MESSAGES
----------------
GMT  PH ATA                                SOURCE    IDENT.
0406 02 36-11-51 HP BLEED-V (4000HA2)       BMC 2
0418 06 72-00-00 ENG2D-0350-STALL           EIU2FADEC
0419 06 72-00-00 ENG2D-0151-EGT RED LIMIT   EIU2FADEC
0419 06 72-00-00 ENG2D-0436-N2 VIB EXCEED   EIU2FADEC
0419 06 72-00-00 ENG2D-0434-N1 VIB EXCEED   EIU2FADEC
0419 06 72-00-00 ENG2D-0525-N2 VIB EXCEED   EIU2FADEC
                 SUBIDLE
0419 06 24-22-55 AFS:28V PWR 11XU1          AFS 1
0423 06 21-51-51 P2 FLOW CONT VALVE(24HB)   TEMP CTL
0423 06 21-51-51 P2 FLOW CONT VALVE         TEMP CTL
                   PRESSURE FAULT(24HB)
0433 09 73-21-00 ENG2D-0502-EOS BIT TEST    EIU2FADEC
                 SKIP
0433 09 73-21-00 ENG2B-0536-EOS SHUTDOWN    EIU2FADEC
                 TEST SKIP
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Image# 15 Maintenance Post Flight Report (PFR) of AI-639 of 19/05/2022

Pilot Defect Report of the incident flight was as follows:

'Eng# 2 stall. Eng# 2 EGT overlimit. Eng# 2 shut down. Returned back to Mumbai'.

During physical inspection by AME (Cat 'B1' license holder) on arrival, it was observed that last two stages of LPT & LPT NGVs found damaged/ missing material. Boroscope inspection was carried out the incident involved engine as per M/s CFM International (Engine OEM) recommendations and the results were shared with M/s CFM International. Visual evidence of HPT rotor interstage seal material loss of the aft catenary arm was confirmed from the inspection reports.

Subsequently, the involved engine was removed for further investigation and a serviceable engine (Sl. No.: 599055) was installed on the aircraft on 09.06.2022. Inspection after a major engine failure was carried out on VT-EXM as per the advice of M/s Airbus. SSCVR and SSFDR were also replaced and the aircraft was released to service on 10.06.2022. The aircraft VT-EXM operated AI- 627 (Mumbai- Nagpur) on 10.06.2022 after completing the rectification action.

1.6.4 History of Engine# 2 (Sl. No. 598326):

The involved engine was repaired and released to service by M/s Safran Aircraft Engine Services shop at Belgium on 18.11.2019 at TSN- 6553:20hrs and CSN- 3354. Subsequently, the engine was installed on VT-EXM at no. 2 position on 10.12.2019.

Service Evaluation Request (SER) 72-0002 was issued on 26th August 2019 for the evaluation of newly introduced HPT stage 01 shrouds with improved Environmental Barrier Coating (EBC) coating. This SER requested that the HPT Stage 01 shrouds be inspected using a borescope and send BSI videos to CFM. The subject engine was subjected to boroscope inspection as required by SER 72-0002 on 27.04.2022 and following observations were made:

1. Blade tip rub marks observed on some of the shrouds, within AMM limits.
2. TBC loss observed at Qty.2 locations on LE and at Qty.1 location on TE.

Furthermore, CFM did not provide any recommendation on these findings.

The last boroscope inspection of Engine# 2 was performed during 4A check on 17.05.2022 (at Eng# 2 TSN- 12601:09hrs and CSN- 6586) at Delhi wherein the combustion section, fuel nozzles and turbine section were inspected. No abnormality was noticed during this inspection.

Further, no defect was observed on Engine# 2 since its last shop visit and hence no unscheduled maintenance was carried out since its last shop visit. ECTM report of the engine indicates that there was no abnormal deviation of engine parameters since its last shop visit.

While being in service the engine was subjected to inspections and monitoring as required by OEM guidelines and approved maintenance programme. The HPT rotor

interstage seal is a life limited part. The life of HPT rotor interstage seal as prescribed by OEM is 11,100 cycles. The HPT rotor interstage seal of incident involved engine had completed 6596 cycles during the incident flight. There was no schedule inspection requirement on HPT rotor interstage seal by OEM as of the date of incident.

1.7 Meteorological Information:

Meteorological information is provided by Indian Meteorological Department in every 30 minutes. The weather at Mumbai, as per Indian Meteorological Department, was reported as follows:

Time	04:00hrs	04:30hrs	05:00hrs
Wind	280º / 04knots	260º / 05knots	260º / 08knots
Visibility	3500meter	3500meter	3500meter
Clouds	SCT020 SCT 100	SCT020 SCT 100	SCT020 SCT 100
Weather	HZ	HZ	HZ
Temperature	30ºC	32ºC	31ºC
Dew Point	24ºC	24ºC	24ºC
QNH	1007hPa	1007hPa	1007hPa
Trend	NOSIG	NOSIG	NOSIG

Aircraft take-off and landing was performed on Runway 27 of CSMIA airport, Mumbai. The actual weather conveyed to crew while giving takeoff clearance at 04:13hrs was Winds: 230º 05knots; and while giving landing clearance at 04:29hrs was Winds: 220º 03knots.

1.8 Aids to Navigation:

Aircraft is equipped with navigation aids such as ADF, ILS, GPS, VOR, DME, ATC Transponder Mode S and Weather Radar, Radio Altimeter, TCAS & ELT. All navigational aids were reported to be available.

Runway 27 at CSMIA Mumbai, is equipped with CAT-II ILS (DME collocated with glide path) and DVOR. It also has a secondary surveillance RADAR for providing route navigation services.

There were no known navigation aid difficulties reported by the crew.

1.9 Communication:

Aircraft is equipped with Very High Frequency transmitter & receiver set, High Frequency transmitter & receiver set and Satellite transmitter & receiver set. There was always two-way communication established between the ATC and aircraft.

The crew promptly declared MAYDAY through radiotelephony while dealing with the Eng# 2 In Flight Shut Down situation. Aerodrome full emergency was declared by ATC at 04:22hrs and withdrawn at 04:47hrs.

1.10 Aerodrome Information:

The Chhatrapati Shivaji Maharaj International Airport (CSMIA) (Reference point 19° 05' 30" N 072° 51' 58" E) is a licensed airport both for IFR and VFR traffic with IATA location Identifier code as BOM and ICAO location Indicator code as VABB. CSMIA is being operated, managed and developed by Mumbai International Airport Limited. The Airports Authority of India controls the ATC. The airport is equipped with Advanced Surface Movement Guidance and Control System.

The elevation (AMSL) is 12.13m (40 ft). The airport has two cross runways made of Asphalt. The details of these runways are as given below: -

- RWY 27 - 3448m x 60m
- RWY 09 - 3188m x 60m
- RWY 14/32 - 2871m x 45m

As per the electronic Aeronautical Information Publication (e-AIP) of CSMIA Airport, declared distances for Runway27 are as under:

Runway	TORA (m)	TODA (m)	ASDA (m)	LDA (m)	RESA (m)
27	3448	3448	3448	2965	240 x 120

Aerodrome category for rescue & firefighting is CAT-10.

1.11 Flight Recorders:

1.11.1 CVR:

The CVR readout starts from the previous sector AI-640 BLR- BOM. Recording of flight AI- 639 operating BOM- BLR, involved in the said incident starts from the succeeding 41 minutes of the readout.

AI-639 departure clearance was issued by ATC at 03:34 and asked crew to report when ready. ATIS information was also monitored by the crew. Subsequently, PIC reviewed active MELs with respect to Center Tank R Transfer Valve & Engine Bleed Air Supply System; and operational procedures for MEL 36-11-01A Engine Bleed Air Supply System were read by PIC. Compliance to the active MELs was reviewed with respect to completed actions and required actions. Subsequently, First Officer gave take off briefing on being asked by PIC.

APU was started in co-ordination with the ground and subsequently, cockpit preparation checklist was completed in challenge and response manner.

Push back commenced at 04:06 after approval from ATC. Before Start checklist was completed in the challenge & response manner and subsequently Eng# 2 was started followed by Eng# 1. Crew followed the after start operational procedure for the snag under MEL and did the After Start checklist. Crew performed the Flight Controls checks. Auto Brakes selected MAX. Crew commenced taxi after taking clearance from ATC and carried out taxi checks. After carrying out Line Up checklist, crew took off at 04:14 on clearance from ATC. Passing FL 100, crew did the 10000ft checklist.

At 1 hour 25 mins 55 seconds of the CVR readout/ 04 minutes after take-off, a "THUD" noise was recorded followed by MASTER CAUTION (2). Immediately Eng# 2 stall was announced by the First Officer and PIC is heard carrying out ECAM actions--- Thrust Lever 2 to IDLE. PIC continued with ECAM action and asked First Officer to put Engine Master 2 OFF. First Officer put Engine Master 2 OFF after confirmation from PIC. Subsequently, First Officer announced N2 high Vibrations--- Engine 2 SHUT DOWN--- Engine Mode Selector Ignition.

Immediately after shutting down Eng# 2, PIC declared MAYDAY to the ATC requesting descend immediately for landing R/Wy 27. MAYDAY was acknowledged by ATC immediately and descend permission was given to AI-639.

Subsequently, crew continued with the ECAM actions wherein they carried out Engine shut down checklist. Crew continued to review affected systems on the STATUS PAGE and all related System Pages and put on APU subsequently.

ATC asked AI-639 reason for MAYDAY and any assistance required to which PIC replied Engine 2 FAIL. While, ATC continued to vector AI-639 for Runway 27 approach, PIC made an announcement to inform passengers & cabin crew about the turn back & landing back into Mumbai due to technical issue. PIC also informed company dispatch about Engine 2 failure and landing back.

At 04:29, ATC cleared AI-639 for landing, subsequent to which crew reviewed the final brief & Go Around procedure. Approach and landing checklist was carried out & aircraft landed uneventfully. Subsequent to the landing, aircraft reported to ATC that all operations normal and no assistance required. Aircraft taxied on single engine and parked at bay K1 as per instructions of the ATC. Engine# 1 shut down & Parking Checklist was carried out.

1.11.2 DFDR:

Following are the salient observations made from FDR readout of AI-639:

- AI-639 had a normal start on both engines in sequence with the help of APU bleed. Eng# 2 was started at time 04:02:15hrs. During Eng# 2 start Max EGT= 684°C, Max Vibrations= 0.8 units. After Eng# 2 was stabilized, Eng# 1 was started at 04:03:03hrs. During Eng# 1 start, Max EGT= 686°C, Max Vibrations= 0.9 units. During both engine start cycles, all other engine parameters like Qil quantity, Oil pressure and Oil temperature recorded were within normal range. APU bleed put to OFF at 04:05:01hrs after starting both engines.
- During Taxi all standard flight parameters were manifested within normal range. AI-639 lined up Runway 27 (indicative of heading). At time 04:13:33hrs Thrust Levers were moved to FLEX detent. Aircraft got airborne at time 04:14:04hrs. Packs OFF take off was performed. During Takeoff Eng# 2 Max EGT= 846°C, Max N2 Vibrations= 0.8 units.
- At 04:14:25hrs, Pack Control Valve P/B put ON resulted in opening of Eng#1 PRV to feed Pack# 1. FDR does not record the position of cross bleed valve.
- Passing 800 feet at 04:14:22hrs, Thrust Levers were brought back to CLIMB detent. Thereafter, the aircraft continued a normal climb with all parameters in standard range. Eng# 2 EGT stabilized around 881°C.
- During climb passing FL 112, at time 04:18:49hrs, N1 & N2 started reducing and EGT suddenly spiked from 880°C to 1046°C and continued to increase with increase in vibration. At time 04:18:53hrs, passing FL 113 a Master Caution was triggered. This corresponds with the ENG 2 STALL Warning recorded in the Post Flight Report (PFR).
- At 04:18:55hrs an EGT OVRLMT was recorded and stayed up to 04:19:04hrs. This corresponds with ENG 2 EGT OVERLMT recorded in the PFR. Simultaneously Eng# 2 vibrations continued to increase. Max. EGT for Eng# 2 recorded was 1166°C at 04:18:58hrs.
- In approximately 4 seconds after the EGT Overlimit Warning was triggered, i.e. at 04:18:59hrs, Eng# 2 Thrust Lever was brought back to IDLE & Eng# 1 Thrust Lever was moved to MCT (Max Continuous Thrust). Consequently Eng# 2 EGT started decreasing immediately. After 5 seconds of setting the Thrust Lever to IDLE, Eng# 2 Master Switch was OFF at 04:19:04hrs.

- At time 04:19:06hrs Eng# 2 vibration Advisory was triggered for one second wherein Max N1 & N2 Vibrations were recorded as 10 units and subsequently Eng# 2 vibrations started reducing. The flight segment before the occurrence of this event recorded stable Eng# 2 N2 vibrations at around 1.1 units.
- During this segment of the flight other parameters associated with Eng# 2 viz: N1, N2, Oil quantity, Oil Pressure & Oil Temperature were constant and within normal range of each parameter. Status of the High-Pressure Valve (HPV), Pressure Relief Valve (PRV) and Bleeds of both the engines throughout the flight was in accordance with the phases & dispatch condition of the flight. Eng# 1 was feeding the bleed to Pack# 1 for the entire flight. APU was put ON after Eng# 2 shut down.
- AI-639 leveled off at FL 117. Changes to the heading thereafter are indicative of vectors for approach into BOM. At time 04:20:4hrs (Top of Descend Alt. 11948ft), the aircraft commenced descend for the approach. Gross weight of the aircraft at TOD recorded 64.3 tons.
- At 04:21:54hrs the P/B for Pack# 2 control was put to ON and later put to OFF at 04:22:00hrs.
- During descend and approach phases all standard flight parameters were manifested within normal range. AI- 639 touched down on Runway 27 at BOM at time 04:33:30hrs with 1.31g normal acceleration. After touchdown Single Engine Taxi was carried through up to the bay.

1.12 Wreckage and impact information: Nil.

1.13 Medical and pathological information:

Both the crew had undergone a Pre-flight medical examination before operating the incident flight and tested negative for consumption of alcohol.

1.14 Fire: There was no fire before or after the incident.

1.15 Survival Aspects: No human injuries were reported in the incident.

1.16 Tests and research:

The affected engine Sl no. 598326 was removed from VT-EXM and sent to M/s CFM International (OEM) for investigation purposes. After carrying out an investigation, OEM had concluded the most probable root cause for the IFSD of the subject engine, however potential secondary/ aggravating factors considering India region operations are still under investigation with OEM. The teardown inspection findings and investigation report received from OEM are attached as Annexure to this report.

While the OEM is still investigating potential secondary/ aggravating factors considering India region operations, the following corrective actions have been taken/ planned by the OEM as of the date of writing of this report:

(a) OEM has opined that inadequate peen coverage results in debited low cycle fatigue capability but supports Ch 05 life, i.e. 11,100 cycles.

(b) The following is the status of corrective action taken/ under process by OEM:
- Paradigm fleet: CAT 2A SB 72-0478 (issued 28/07/2022)- Status Completed.
  - Removes 8 Paradigm mid-seal from service for inspection based on a list of optimized parameters (manufacturing and operating proximity).
- Entire fleet: CAT 4B SB 72-0512 (issued 29/06/2023)
  - Based on the subject incident, Ultrasonic Inspection was developed to scan the axial face and fillet regions of the aft catenary arm at the module level.
  - Module-level UT inspection at shops for engines with HPTR exposure >4000 cycles.
  - Identification of cracks and provides additional information for the current database of inspection for root cause.
- Paradigm India/MENA sub fleet: CAT 2A SB 72-0516 (Issued 30/06/2023)
  - Prevent any possible Paradigm re-pairing in the India/MENA region.
  - India/MENA Region defined by departures.

(c) As 85% of the Paradigm (WES) parts have been inspected with inadequate peen coverage, OEM has planned the following corrective action:
- To issue CAT 2B Service Bulletin 72-0525 recommending removal of all Paradigm mid seals (serial numbers starting with "WES") from service.

(d) Work ongoing for additional surface condition characterization of other suppliers along with understanding of India operation contribution.

1.17 Organizational and Management Information:

Air India is a scheduled airline owned by Tata Group. Air India operates its flights on domestic and international sectors. Air India operates its flights on domestic and international destinations with a fleet of Boeing 777, Boeing 787, Airbus 319, Airbus 320 and Airbus 321 aircraft. M/s Air India Limited is headquartered at New Delhi. Air India is the largest international carrier of India. Over 40 international destinations are served by Air India spanning cities in Europe, USA, UK, Africa, the Gulf, Asia and Australia. The airline became the member of Star Alliance on 11 July 2014.

1.18 Additional Information:

1.18.1 MEL 36-11-01A Engine Bleed Air Supply System (non- EDTO flights):

A319/A320/A321 MINIMUM EQUIPMENT LIST	MEL ITEMS PNEUMATIC ENGINE BLEED AIR SUPPLY SYSTEM

36-11-01	Engine Bleed Air Supply System

Applicable to: VT-PPA, VT-PPB,VT-PPD,VT-PPE,VT-PPF,VT-PPG,VT-PPH,VT-PPI,VT-PPJ, VT-PPK,VT-PPL,VT-PPM,VT-PPN, VT-PPO,VT-PPQ,VT-PPT, VT-PPU,VT-PPV,VT-PPW,VT-PPX , VT-EDC, VT-EDD, VT-EDE,VT-EDF, VT-EXA,VT-EXB,VT-EXC,VT-EXD,VT-EXE, VT-EXF, VT-EXG, VT-EXH, VT-EXI, VT-EXJ ,VT-EXK, VT-EXL, VT-EXM ,VT-EXN,VT-EXO, VT-EXP,VT-EXQ,VT-EXR,VT-EXS,VT-EXT,VT-EXU,VT-EXV , VT-CID,VT-CIE VT-CIF, VT-CIG, VT-CIH, VT-CIM, VT-CIN, VT-CIO, VT-CIP, VT-CIQ

Note: *The HP ground connection is near the engine 1 hazardous area. If the bleed air supply system 2 is inoperative, it is better to use the APU bleed for engine start. If the APU bleed is not available, a ground cart can be used as long as the pneumatic pipe is kept out of the hazardous area.*

36-11-01A Non EDTO flight - no FL limitation

Repair interval	Nbr installed	Nbr required	Placard
B	2	1	Yes

(o) One may be inoperative provided that:
1) EDTO is not conducted, and
2) The associated ENG BLEED pb-sw is set to OFF, and
3) The X-BLEED selector is set to OPEN, and
4) The speedbrakes are operative.

Reference(s)

(o) *Refer to OpsProc 36-11-01A Engine Bleed Air Supply System (non-EDTO flights)*

Image# 16 MEL 36-11-01A excerpts

1.18.2 MEL 36-11-01A Engine Bleed Air Supply System (non- EDTO flights) operational procedures:

A319/A320/A321 MINIMUM EQUIPMENT LIST	MEL OPERATIONAL PROCEDURES 36 - PNEUMATIC 36-11 - Engine Bleed Air Supply System

36-11-01A 36-11-01C 36-11-01E 36-11-01G	Engine Bleed Air Supply System (non- EDTO flights)

Applicable to: VT-EXF, VT-EXG, VT-EXH , VT-EXI ,VT-EXJ, VT-EXK, VT-EXL, VT-EXM, VT-EXN,VT-EXO,VT-EXP ,VT-EXQ,VT-EXR,VT-EXS,VT-EXT, VT-EXU, VT-EXV ,VT-OID, VT-OIE , VT-OIF, VT-OIG, VT-OIH, VT-OII, VT-OIN, VT-OIO, VT-OIP, VT-OIQ

FLIGHT PREPARATION/LIMITATIONS

The flight crew should take into account the severity of forecast icing conditions. The wing anti-ice will be lost if the remaining engine bleed air supply system becomes inoperative.

- **If the cargo heating is switched off:**
  For live animal transportation, use the Live Animal Transportation Calculation Tool.

AFTER ENGINE START

- ENG BLEED (AFFECTED) pb-sw.....OFF
- AFT CARGO HOT AIR pb-sw.....OFF

- **If both PACKs are operative:**

  PACK (AFFECTED) pb-sw.....OFF

  X BLEED rotary selector.....OPEN

AFTER TAKEOFF

- **If the APU has been used to supply the air conditioning during the take-off:**
  APU BLEED pb-sw.....Off

IN FLIGHT

- **In the case of failure of the remaining engine bleed air supply system, or in the case of failure of the associated engine:**

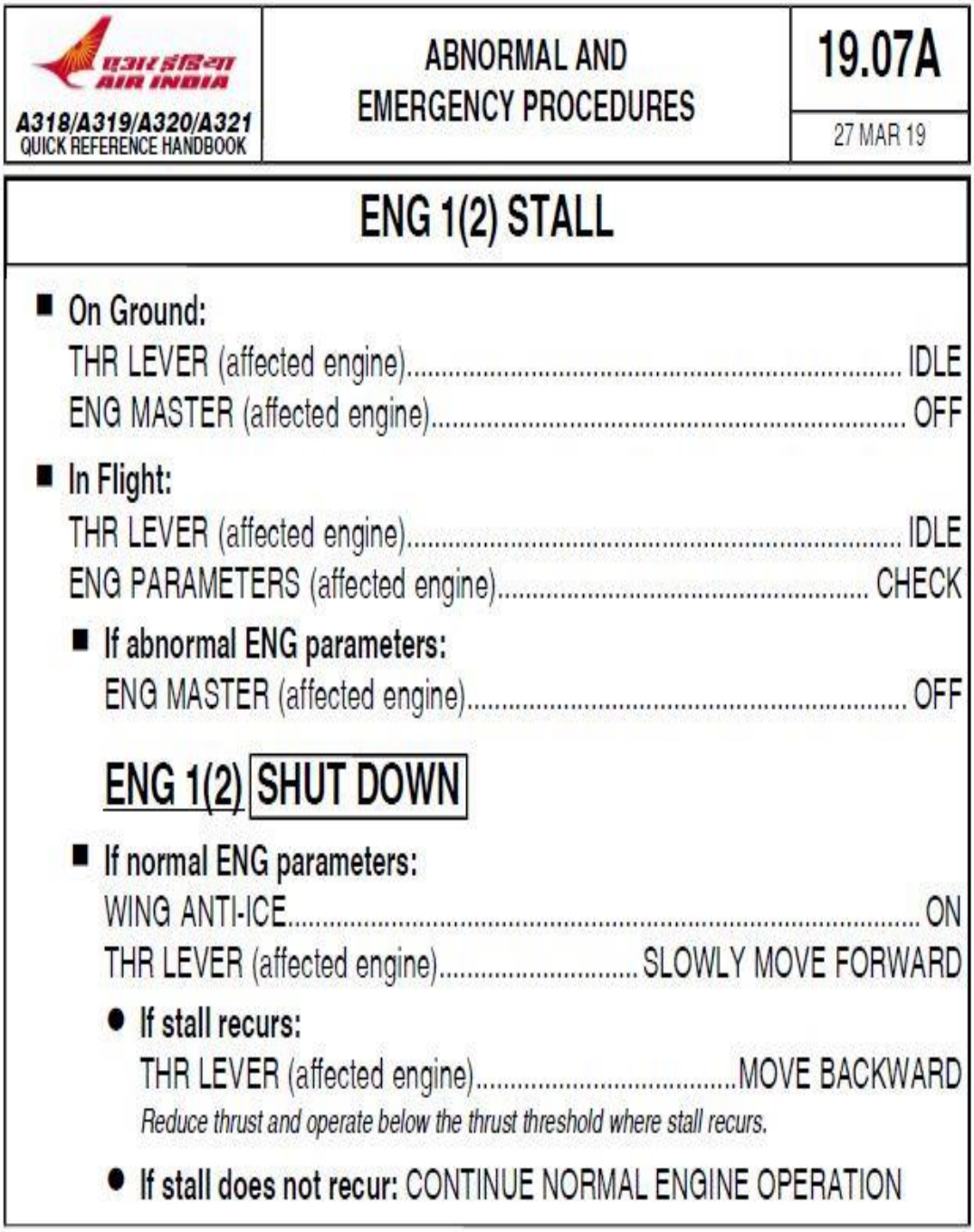
  - *Apply the AIR ENG 1+2 BLEED FAULT ECAM procedure.*

CAUTION	Reset ENG BLEED pb-sw as requested by ECAM procedure even if the ENG BLEED pb-sw is placarded inoperative as per MEL 36-11-01.

- **In the case of failure of the opposite PACK:**
  PACK (AFFECTED)pb-sw.....ON

Image# 17 MEL 36-11-01A Operational procedures

1.18.3 QRH Abnormal and Emergency Procedures for Engine Stall:



AIR INDIA

A318/A319/A320/A321
QUICK REFERENCE HANDBOOK

ABNORMAL AND
EMERGENCY PROCEDURES

19.07A

27 MAR 19

ENG 1(2) STALL

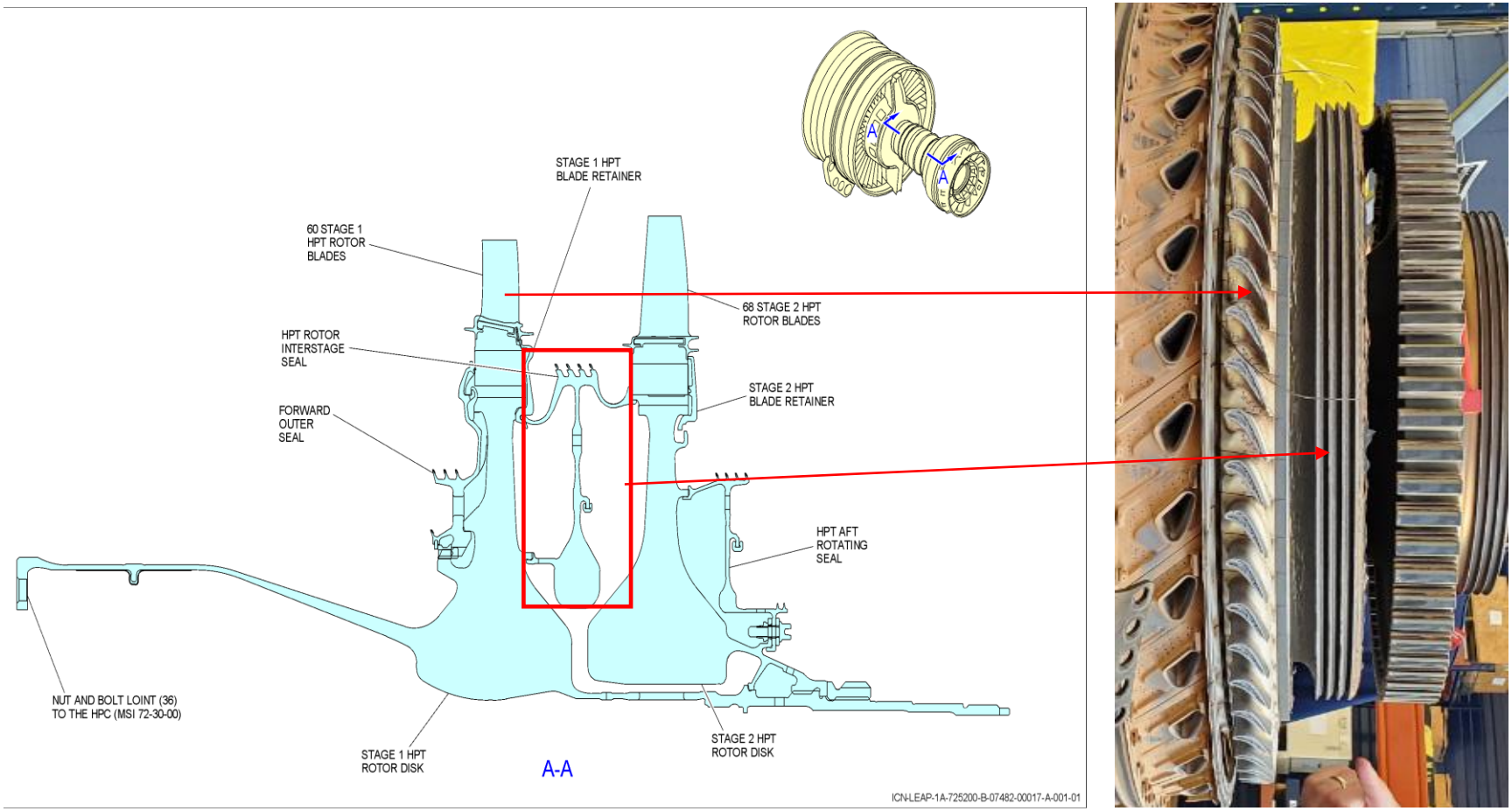
- **On Ground:**
  THR LEVER (affected engine)..... IDLE
  ENG MASTER (affected engine)..... OFF
- **In Flight:**
  THR LEVER (affected engine)..... IDLE
  ENG PARAMETERS (affected engine)..... CHECK
  - **If abnormal ENG parameters:**
    ENG MASTER (affected engine)..... OFF

    ENG 1(2) SHUT DOWN
  - **If normal ENG parameters:**
    WING ANTI-ICE..... ON
    THR LEVER (affected engine)..... SLOWLY MOVE FORWARD
    - **If stall recurs:**
      THR LEVER (affected engine).....MOVE BACKWARD
      Reduce thrust and operate below the thrust threshold where stall recurs.
    - **If stall does not recur:** CONTINUE NORMAL ENGINE OPERATION

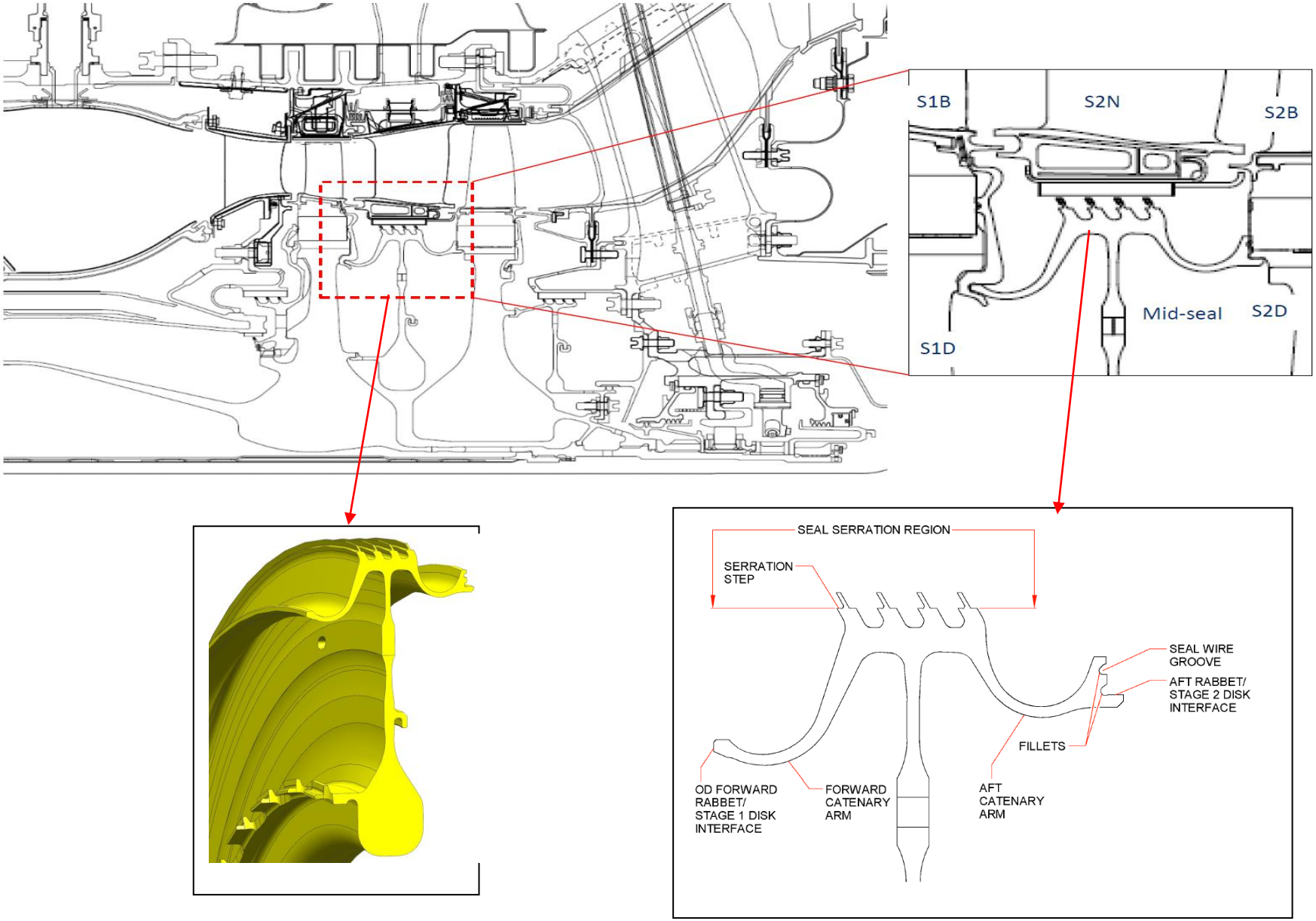
Image# 18 Engine stall abnormal procedures as per QRH

1.18.4 HPT rotor interstage seal (mid-seal):

The HPT rotor interstage seal is a life limited part which is used to prevent air from leaking around the stage 2 HPT stator nozzle.



Image# 19A HPT rotor interstage seal (mid-seal) description



Image# 19B HPT rotor interstage seal (mid-seal) description

1.19 Useful or Effective Investigation Techniques: None.

2. ANALYSIS:

2.1 Investigation on the incident involved engine (Sl. no.: 598326):

The incident involved engine (Sl. no.: 598326) was subjected to several boroscope inspections at Mumbai under advice and guidance from M/s CFM International (OEM). Clear visual evidence of HPT mid-seal material loss of the aft catenary arm was seen during these boroscope inspections and subsequently the engine was removed from aircraft VT-EXM and sent to OEM facility for further investigation.

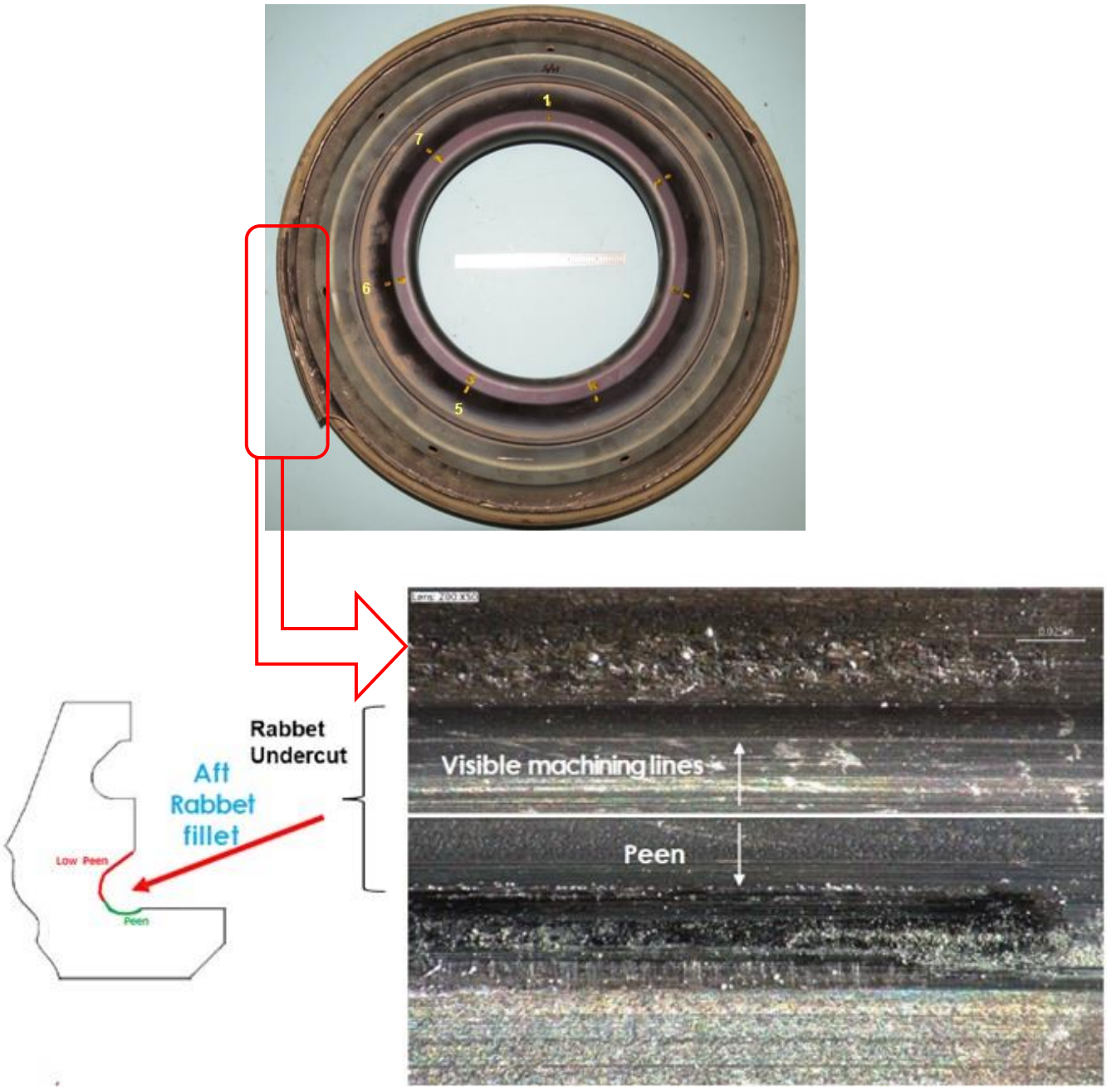
The teardown inspection carried out by the OEM revealed following salient observations (refer the annexure for complete details with photographs):

- No unusual distress at Fan blades or external to fan module.
- Combustor found in good condition, with sooting on fuel nozzle aft heat shield.
- HPT Stage 1 nozzles found in good condition.
- HPT stage 1 blades in good condition, minor missing TBC, tip condition good (minimal rub).
- HPT rotor interstage seal (Mid-seal):
  - Forward arm in-tact, no evidence of creep or thermal distress.
  - ~320deg portion of aft arm of HPT mid-seal fractured.
  - All fracture features on mid-seal are consistent with overstress (instantaneous fracture) with no propagation to seal rack or web.
  - Ligament remaining under aft rabbet consistent with final fracture regions.
  - Mid-seal squeeze differences noted in areas where aft arm missing.
  - Forward arm found intact. Few minor missing material areas at teeth.
  - Axial position of HPT stage 2 blades as expected in mid-seal intact aft arm.
- HPT Stage 2 blades damage across all airfoils. Tip damage & TE cracks at outer span.
- No evidence of case punctures. The event was found contained.
- LPT stage 1 row missing above platform, debris found mostly at 6:00 – M10 rotating seal teeth in typical condition.
- EGT probe 7 with minor impact damage – 3 probes found with creep deformation.
- Impact damage noticed on LPT Stage 1 nozzles.

OEM conducted investigation on the event engine HPT rotor interstage seal as well as other HPT rotor interstage seals of interest (proximity by manufacturing and operation) to support an understanding of the root cause. OEM concluded during the investigation that the HPT rotor interstage seal aft catenary arm liberation had led to the IFSD of Engine# 2 (Sl no.: 598326) during flight AI-639 on 19.05.2022. No evidence of

creep or overtemperature exposure (verified dimensionally) on the HPT rotor interstage seal was confirmed. Investigation on the remaining aft catenary arm ligament revealed that Rabbet fillet has a less visible shot-peened area with visible machining lines. Based on the investigation, the most probable root cause for the liberation of the HPT rotor interstage seal aft catenary arm was concluded by OEM as follows:

- Non-design intent surface condition in aft rabbet fillet.
- Inadequate peen coverage or intensity and visible turning lines (re-machined surface) in rabbet fillet resulting in debited low cycle fatigue capability.



Image# 20A HPT rotor interstage seal (mid-seal) investigation findings

Image# 20B HPT rotor interstage seal (mid-seal) investigation findings

Apart from the probable root cause, potential secondary/ aggravating factors considering India region operations is still under investigation with OEM.

2.2 Engineering aspects:

Airworthiness Review Certificate of the aircraft was valid up to 16/01/2023. Last major maintenance, i.e., 4A+P1.5 check, was accomplished on 17/05/2022 at 13,340:05hrs A/c TSN/ 6,871 A/c CSN and next A check was due at 14,090:05hrs A/c TSN. Aircraft Load & Trim sheet was prepared. Take-off weight, landing weight and Centre of Gravity were found within limits. Aircraft was departed with valid Certificate of Release to Service on 19/05/2022.

Defect with regard to Eng# 2 bleed system, encountered in the previous sector (AI-640) during taxi-out, was considered appropriately addressed by cockpit crew as there is no maintenance procedure for the said MEL and the remaining flight was conducted without any abnormalities. Further, during transit at Mumbai, no abnormal observations pertaining to engines were made by the AME and he invoked MEL 36-11-01A Cat 'B' for 'ENG2 Bleed Air Supply System'. All the warning/ maintenance status messages recorded during incoming flight AI-640 were found appropriately addressed and the aircraft was released from Mumbai for AI-639. Therefore, the MELs or MEL invocation procedures are not considered contributory to the incident.

The warning/ maintenance status or failure messages recorded during incident flight are either pertaining to active MELs or consequence of the Engine# 2 malfunction. The PFR does not reflect any technical issue pertaining to any other systems/ components.

Involved engine had completed 12,612:45hrs/ 6,596 cycles since new and 6,059hrs/ 3,242 cycles since last shop visit. The engine was found to have been maintained in accordance with the OEM guidelines and approved maintenance programme. The last boroscope inspection of Engine# 2 was performed on combustion section, fuel nozzles and turbine section wherein no abnormality was noticed. Since its last shop visit, Engine# 2 was not subjected to any unscheduled maintenance as there was no defect observed on it. ECTM report of the engine also did not indicate any abnormal deviation of engine parameters till the incident flight.

The HPT rotor interstage seal of incident involved engine had completed 6596 cycles during the incident flight against its life of 11,100 cycles and there was no schedule inspection requirement on HPT rotor interstage seal by OEM as of the date of incident.

In view of the above discussion, the aircraft was considered airworthy before the incident flight and the maintenance of the aircraft is not a contributory factor to the incident.

2.3 Operational aspects:

Both the crew members were medically fit, had valid license, had adequate rest and found to be within FDTL limits before they operated flight on 19/05/2022. Medical fitness & FDTL of the crew was not a factor to this incident.

It was first flight of the day for the PIC whereas First Officer operated previous flight AI-640 in the same aircraft. PIC reported for flight duty in time and accepted the aircraft after satisfactory completion of preflight external checks. Appropriate briefing was carried out by cockpit crew while preparing the aircraft for sector AI-639. No abnormalities were observed by the crew while starting both the engines from the APU bleed and engine parameters were observed normal during taxi and take-off.

While passing FL112, crew heard thud sound followed by MASTER CAUTION for the Engine# 2 stall, Engine# 2 EGT overlimit and Engine# 2 high vibration. The malfunction of the engine was promptly handled by both PIC and First Officer by carrying out appropriate QRH abnormal and emergency procedures wherein Engine# 2 was shut down. Thereafter, no buffet/sound/smell was perceived by the crew.

Subsequent to the Engine# 2 shut down, the crew levelled the aircraft, declared MAYDAY and requested ATC for immediate descent for landing back to Mumbai. Subsequently, the abnormal procedures were reviewed and completed. APU was also started subsequent to shutting down Engine# 2 so as to ensure additional electrical source is available. Crew once again reviewed the checklist for Engine# 2 shut down and made cabin announcement about inflight turn back due to technical problem.

Later, while the aircraft was cleared to land, crew carried out final briefing and reviewed Go Around procedure. The aircraft landed uneventfully with single engine on Runway 27 and taxied to bay with single engine.

Status of the High-Pressure Valve (HPV), Pressure Relief Valve (PRV) and Bleeds of both the engines throughout the flight was in accordance with the phases & dispatch condition of the flight. Engine# 1 was feeding the bleed to Pack# 1 for the entire flight. Although, the DFDR reflected that P/B for Pack# 2 control was put to ON for 06 seconds while descent, however the same does not have any contribution to the incident or adverse effect on the flight. It could be ascertained from CVR and DFDR analysis that the crew action during the flight, including handling emergency, was prompt and appropriate. Crew actions are not a contributory factor to the incident.

Pre-flight briefing, Engine Starting Procedures, MEL operational Procedure, Taxi Procedure, Line up Procedure, final brief & review of Go Around Procedure, Approach

Procedure, Landing Procedure, After Landing Procedure, Engine Shutdown Procedure and Parking Procedure were carried out in incident flight as per FCOM.

3. CONCLUSION:

3.1 Findings:

- Airworthiness Review Certificate of the aircraft was valid up to 16/01/2023. Take-off weight, landing weight and Centre of Gravity were found within limits. Aircraft was departed with valid Certificate of Release to Service on 19/05/2022.
- Both crew members had valid licenses while operating incident flight. Medical fitness & FDTL was not a factor to this incident.
- Weather was not a factor in this incident.
- The MELs or associated invocation procedures were not contributory to the incident.
- The PFR does not reflect any technical issue pertaining to any other systems/ components except the consequential messages associated with MEL and Engine# 2 IFSD.
- The engine was maintained in accordance with the OEM guidelines and approved maintenance programme. ECTM report of the engine also did not indicate any abnormal deviation of engine parameters till the incident flight.
- The aircraft was considered airworthy before the incident flight and the maintenance of the aircraft is not a contributory factor to the incident.
- No abnormalities were observed by the crew while starting both the engines from the APU bleed and engine parameters were normal during taxi and take-off.
- While climbing, crew encountered abnormalities with Engine# 2 with associated ECAM caution/ warnings of Engine# 2 stall, Engine# 2 EGT overlimit and Engine# 2 high vibration.
- The malfunction of the engine was promptly and appropriately handled by the crew by declaring MAYDAY and carrying out appropriate QRH abnormal and emergency procedures requiring IFSD. Crew actions were not a factor in the incident.
- The aircraft landed uneventfully with single operating engine on Runway 27 and taxied to bay on its own power.
- Normal standard procedures for all the phases of flight were also carried out by cockpit crew as per FCOM.
- OEM has concluded during the investigation that HPT rotor interstage seal aft catenary arm liberation had led to IFSD of Engine# 2 (Sl no.: 598326) during flight AI-639.
- The HPT rotor interstage seal of incident involved engine had fractured within its stipulated life. There was no scheduled inspection requirement on the HPT rotor interstage seal by OEM as of the date of the incident.

- No evidence of creep or overtemperature exposure on the HPT rotor interstage seal could be established (verified dimensionally).
- Non-design intent surface condition in aft rabbet fillet (inadequate peen coverage or intensity and visible turning lines (re-machined surface)) was concluded as the most probable root cause by OEM for fracture and liberation of aft catenary arm of HPT rotor interstage seal.
- OEM determined that non-design intent surface condition in the aft rabbet fillet had led to a reduction in low cycle fatigue capability of the HPT rotor interstage seal (mid-seal) resulting in its fracture and liberation of aft catenary arm.
- Potential secondary/ aggravating factors considering India region operations are still under investigation with OEM.

3.2 Causes:

The most probable cause of the incident is liberation of the aft catenary arm from the HPT rotor interstage seal (mid-seal) due to inadequate peen coverage/ intensity and visible turning lines (re-machined surface) in the aft rabbet fillet.

4. SAFETY RECOMMENDATIONS:

4.1 DGCA Hqrs may follow up with OEM w.r.t. potential secondary/ aggravating factors considering India region operations under investigation with OEM.

4.2 DGCA Hqrs may examine/ review the corrective action taken/ under process by the OEM.

4.3 Amy other necessary action as deemed fit by DGCA Hqrs.

(Pathik Vaghela)
Investigator-In-Charge, VT- EXM

Date: 24.11.2023
Place: Mumbai

------END OF REPORT-----

The Power of Flight

598-326 Root Cause Investigation Teardown Virtual Table Review

Root Cause Investigation Team

Presentation includes:

Technical Data: (select all that apply)

- ☐ License Required (Lic. No. ___)
- ☒ No License Required (ECCN _____)
- ☐ No Technical Information

Proprietary Information: (select all that apply)

- ☐ CFM Proprietary – CFM Internal Use only
- ☒ CFM Proprietary - Acceptable for External Use
- ☐ Non-Proprietary

Audience Includes:

- ☐ CFM Only
- ☒ Non-CFM

June 27th 2022

Agenda

- Team introductions
- Engine Config & Background
- 598-326 Teardown Observations
- Next Steps

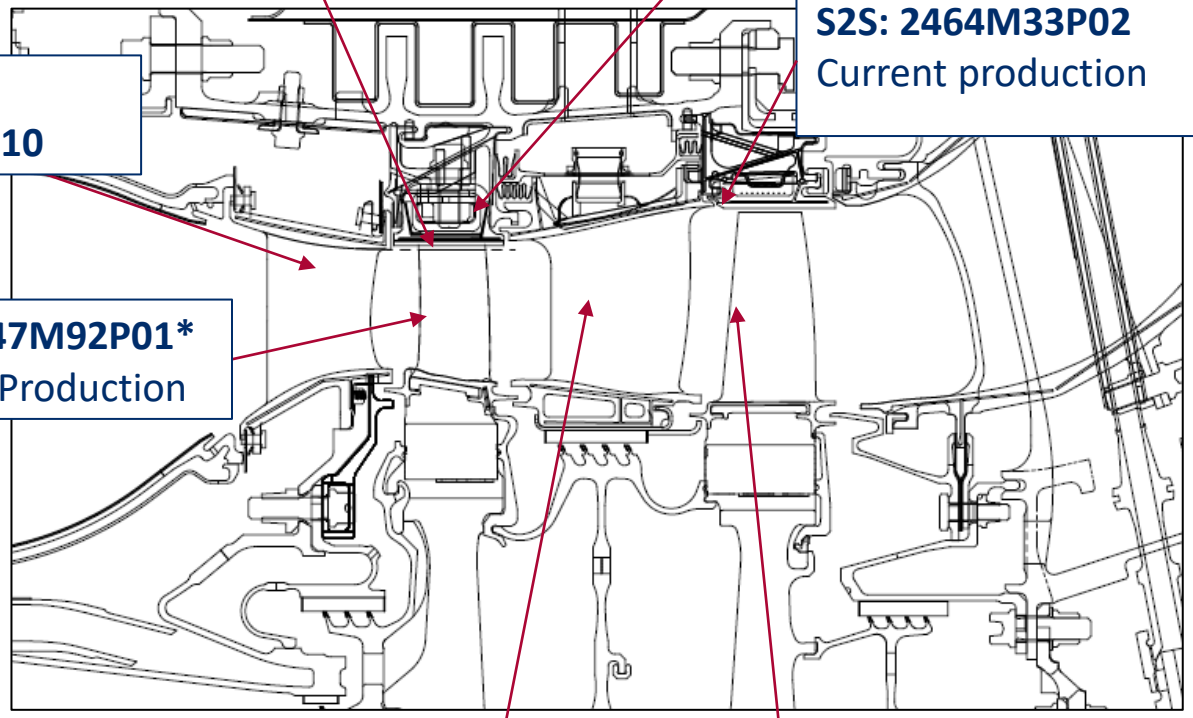
Engine Background & HPT Pedigree

Airline	TAIL	Eng Pos	ESN
Air India (AIC)	VT-EXM	#2	598326

- IFSD 598-326 (event on May 19th 2022)
- CSN = 6,559, TSN = 12,569
- Thrust rating: 1A26

Background

- Air India A320neo aircraft VT-EXM operating flight AI-639 (BOM-BLR) of today was involved in air turn back with #2 engine IFSD at Mumbai due to ENG STALL, EGT OVERLIMIT & N2 vibe exceedance message; Several LPT last stages blades seen broken.
- HPT Flowpath inspected per MPD during A/C A-check 2 days prior to event and found serviceable



**** = hardware installed new at SV @ 3340 cycles***

598-326 Teardown – Fan & Booster Modules

No unusual distress at Fan blades or external to fan module

598-326 Teardown – Fan & Booster Modules

ALF

Minor deposits at IGV

598-326 Teardown – Low Pressure Turbine Module

LPTB1 row missing above platform, debris found mostly at 6:00 – M10 rotating seal teeth in typical condition

598-326 Teardown – High Pressure Compressor Module

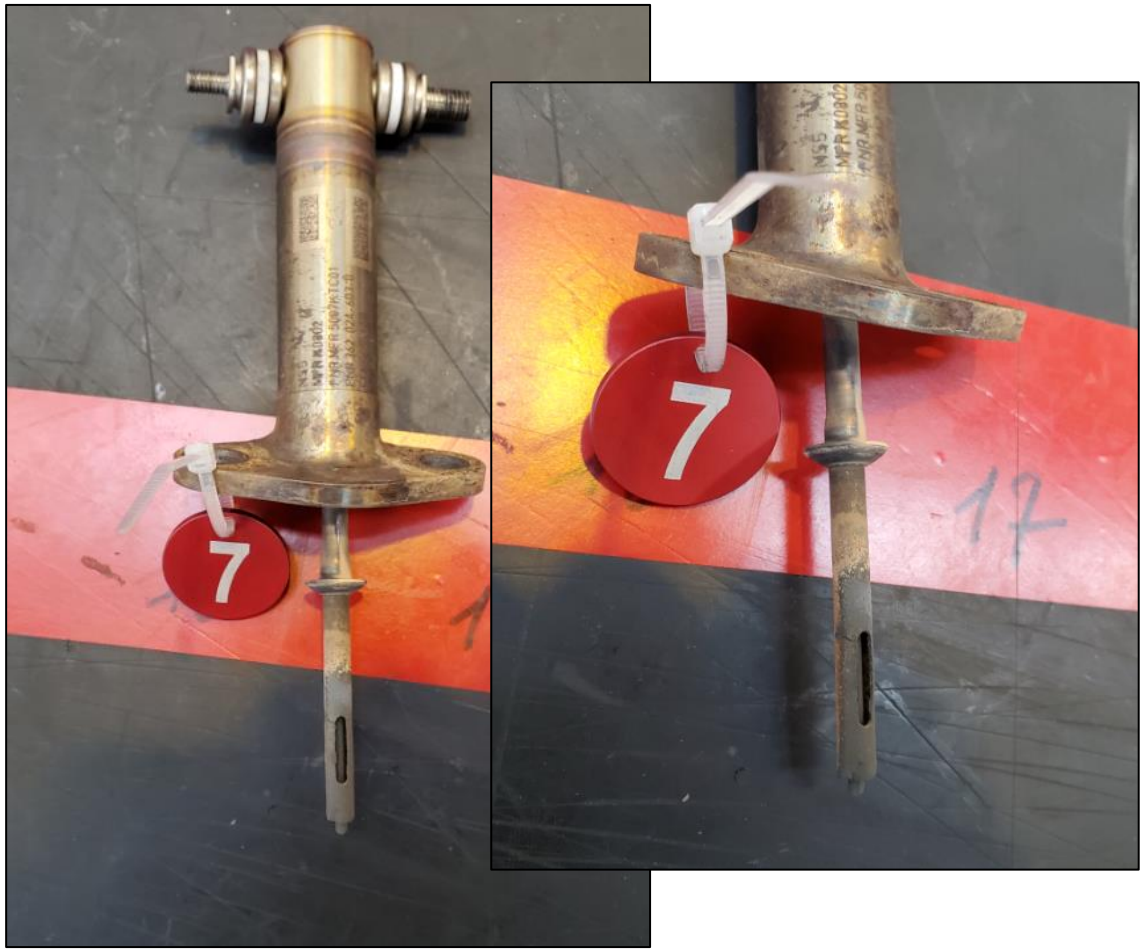
FLA

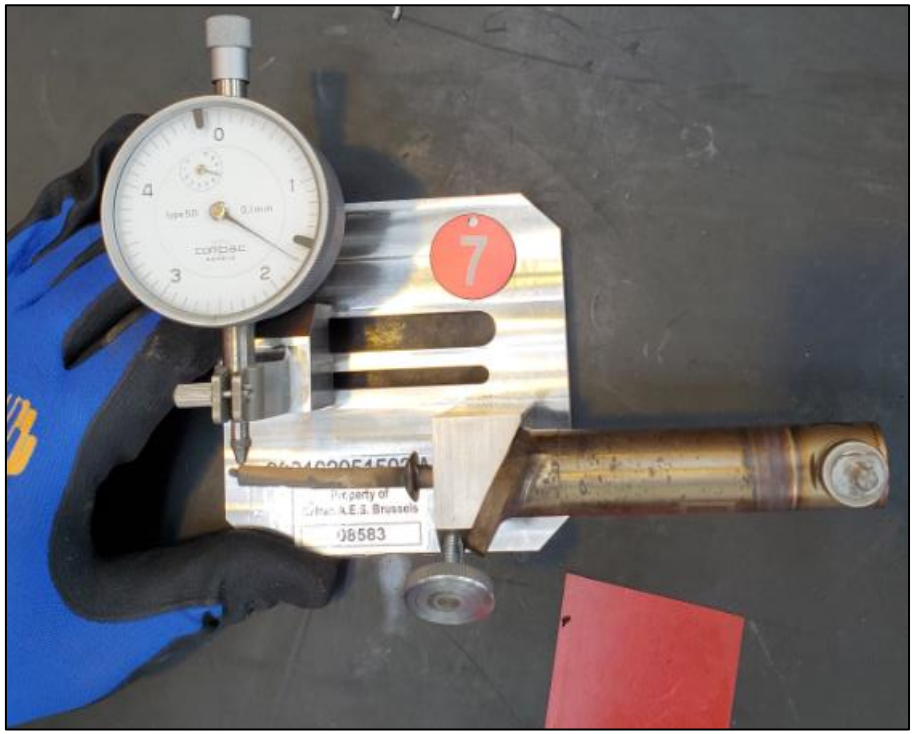
HPC Fwd Case heavy rub

Airfoil deposits on S1 Blisk

- Additional BSI inspection to be performed of HPC airfoils – *June 27th*

598-326 Teardown – EGT Probes



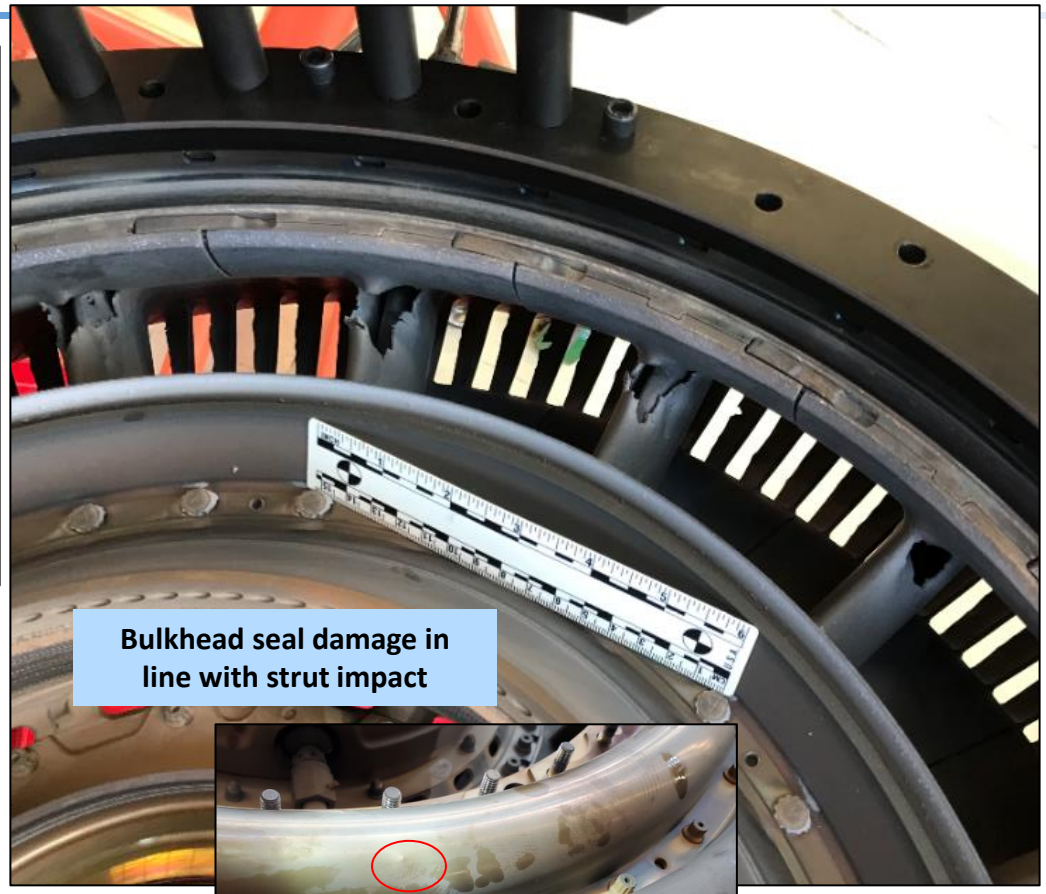


EGT probe 7 with minor impact damage – 3 probes with creep deformation (consistent with field observations)

598-326 Teardown – Core Removal

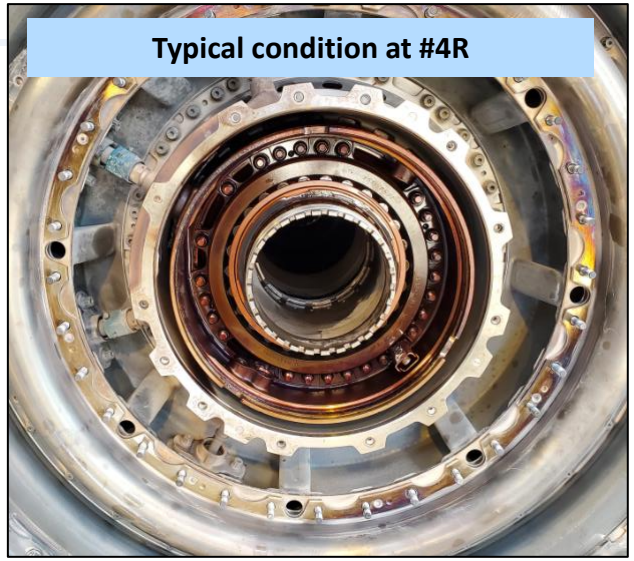
598-326 Teardown – Turbine Center Frame Module

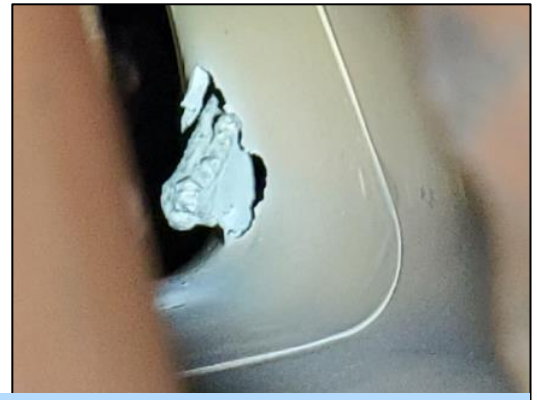
LPT S1N impact damage



Bulkhead seal damage in line with strut impact

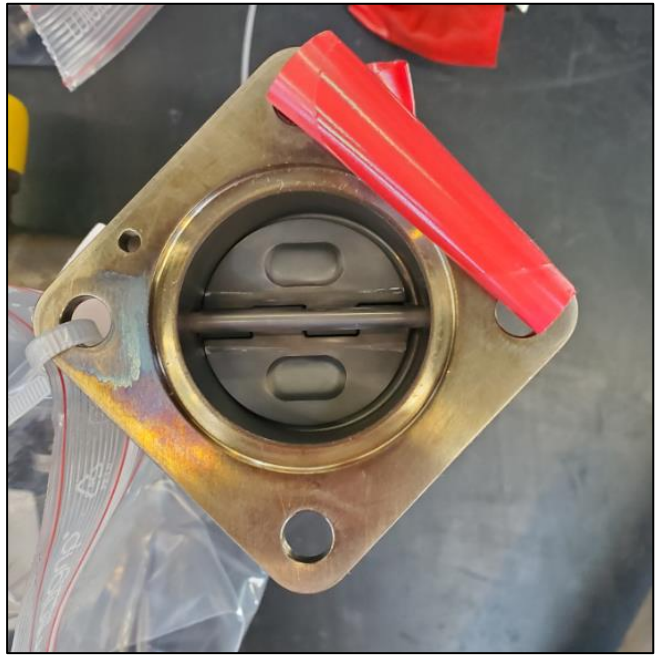
Typical condition at #4R

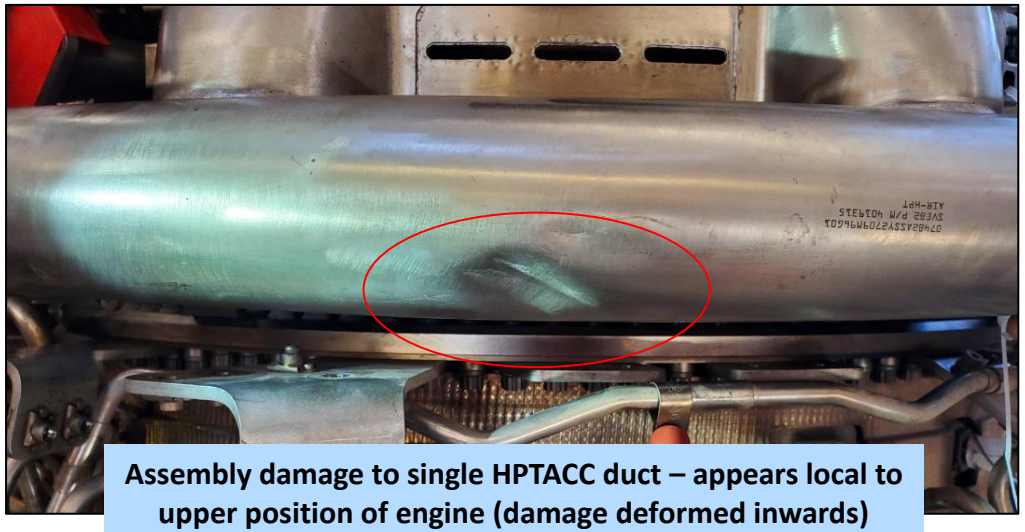




MS aft-arm fragment in TCF fairing

598-326 Teardown – Externals (HPC Stage 7 Bleed Pipe, HPTACC duct)



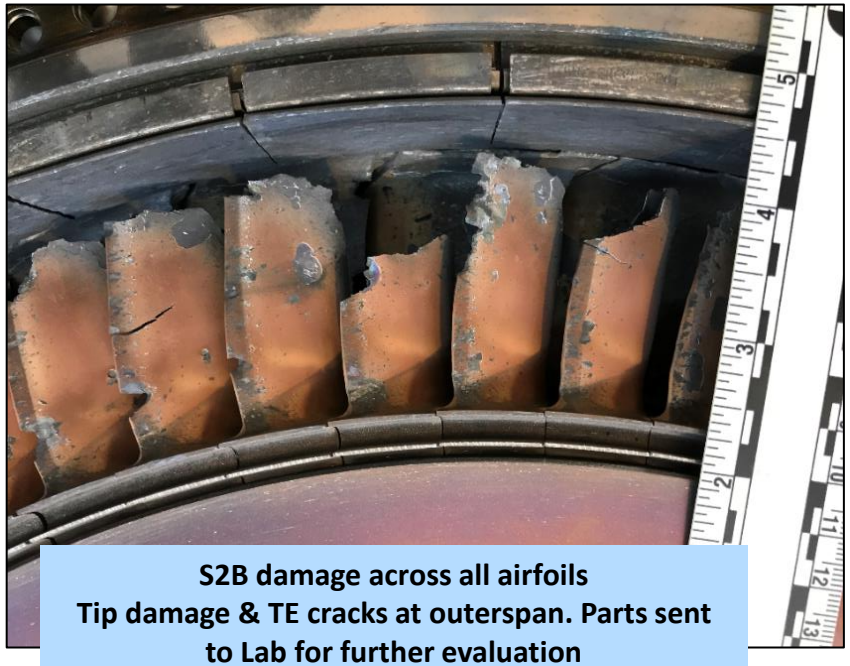


Assembly damage to single HPTACC duct – appears local to upper position of engine (damage deformed inwards)

Internal (BSI) and external visual of S7 domestic bleed pipes OK – flapper valve function as expected

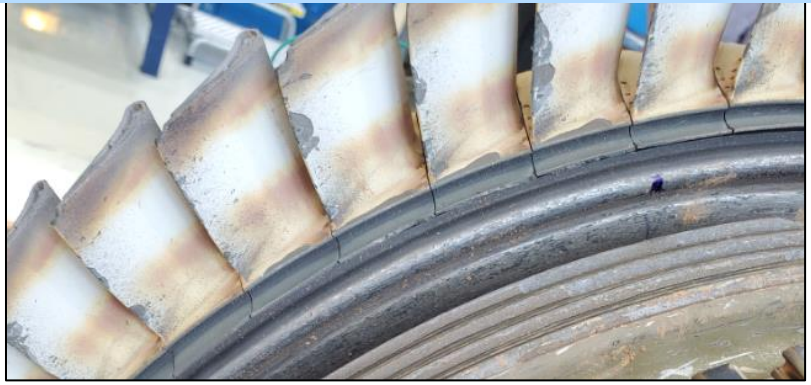
598-326 Teardown – High Pressure Turbine Rotor Assembly

S1B/S2B

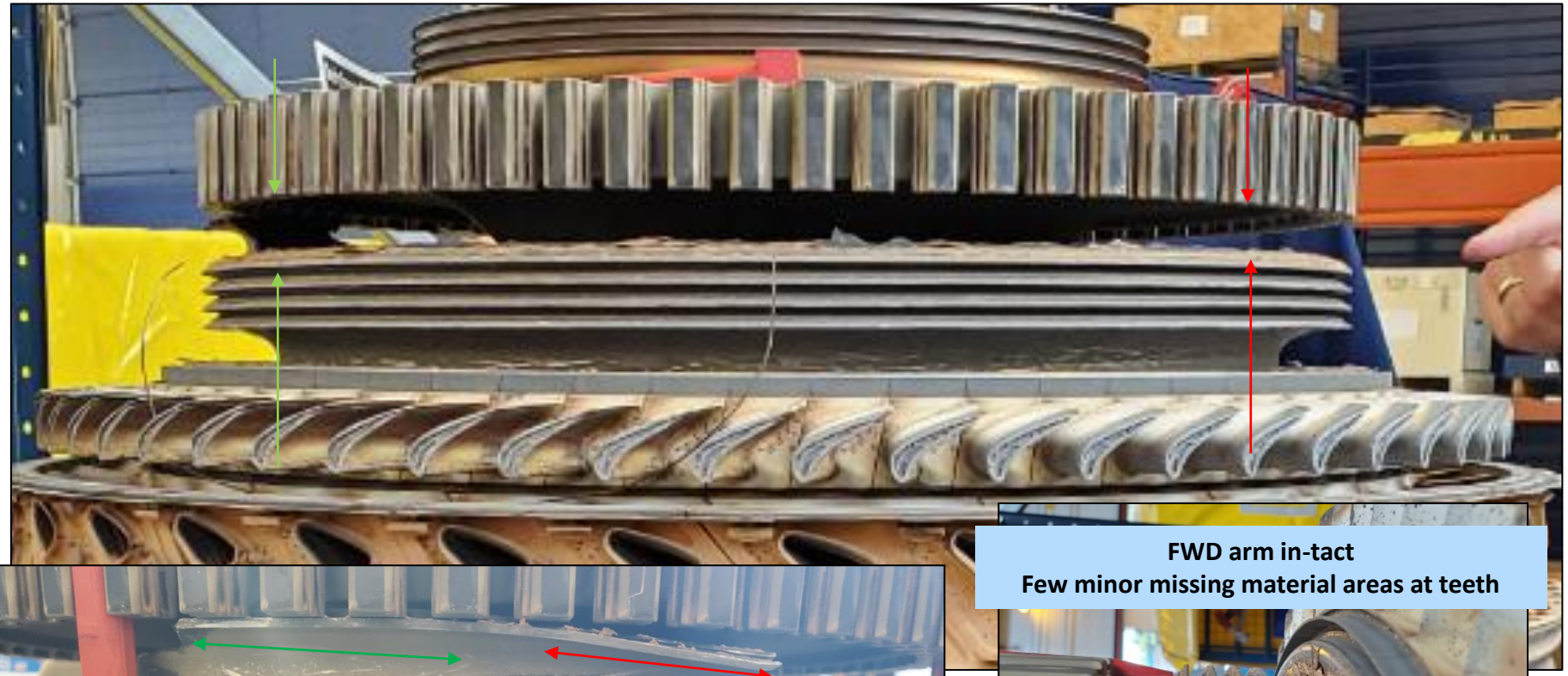


S2B damage across all airfoils
Tip damage & TE cracks at outerspan. Parts sent to Lab for further evaluation

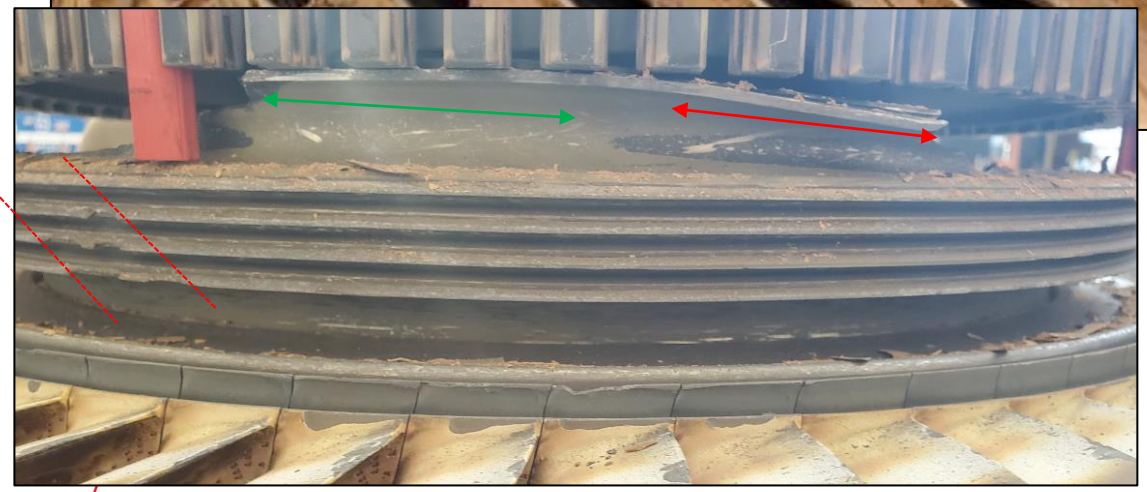
S1B in good condition , minor missing TBC, tip condition good (minimal rub)



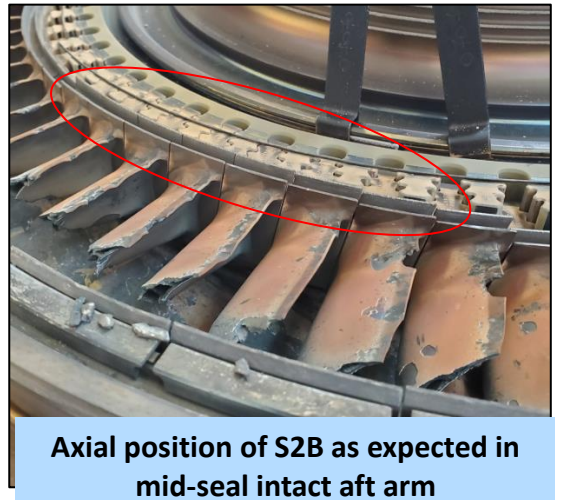
598-326 Teardown – High Pressure Turbine Rotor Assembly



- **Mid-seal squeeze differences noted in areas where aft arm missing**



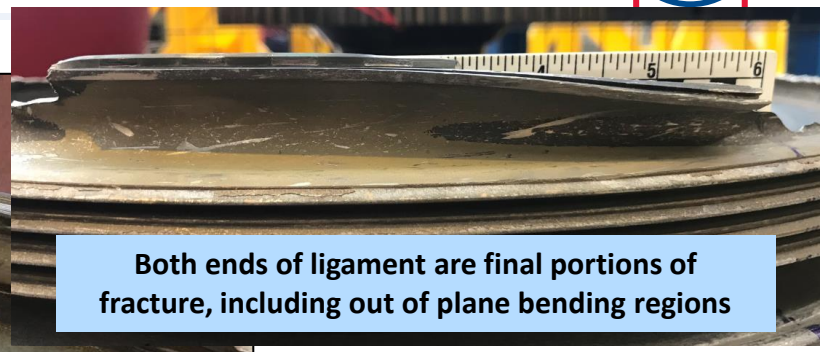
FWD arm in-tact
Few minor missing material areas at teeth



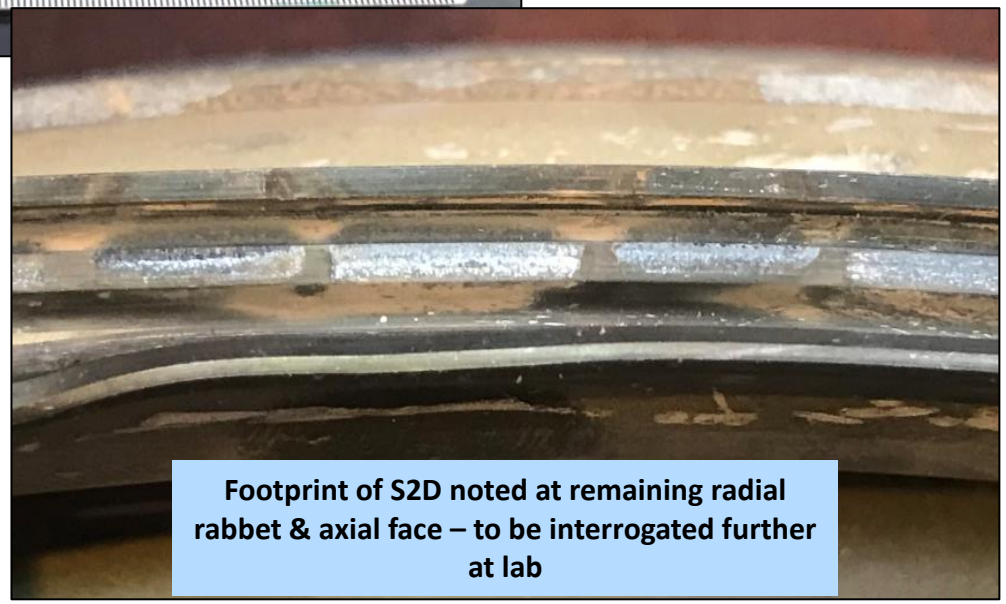
Axial position of S2B as expected in mid-seal intact aft arm

598-326 Teardown – High Pressure Turbine Rotor Assembly

All fracture features consistent with over-stress



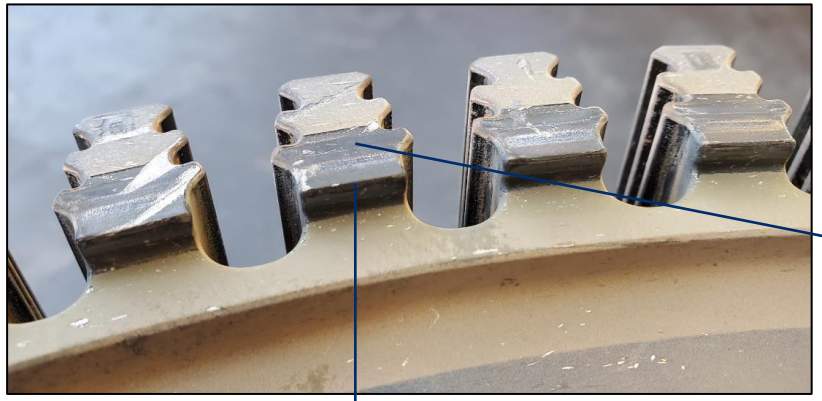
Both ends of ligament are final portions of fracture, including out of plane bending regions



Footprint of S2D noted at remaining radial rabbet & axial face – to be interrogated further at lab

598-326 Teardown – High Pressure Turbine Rotor Assembly

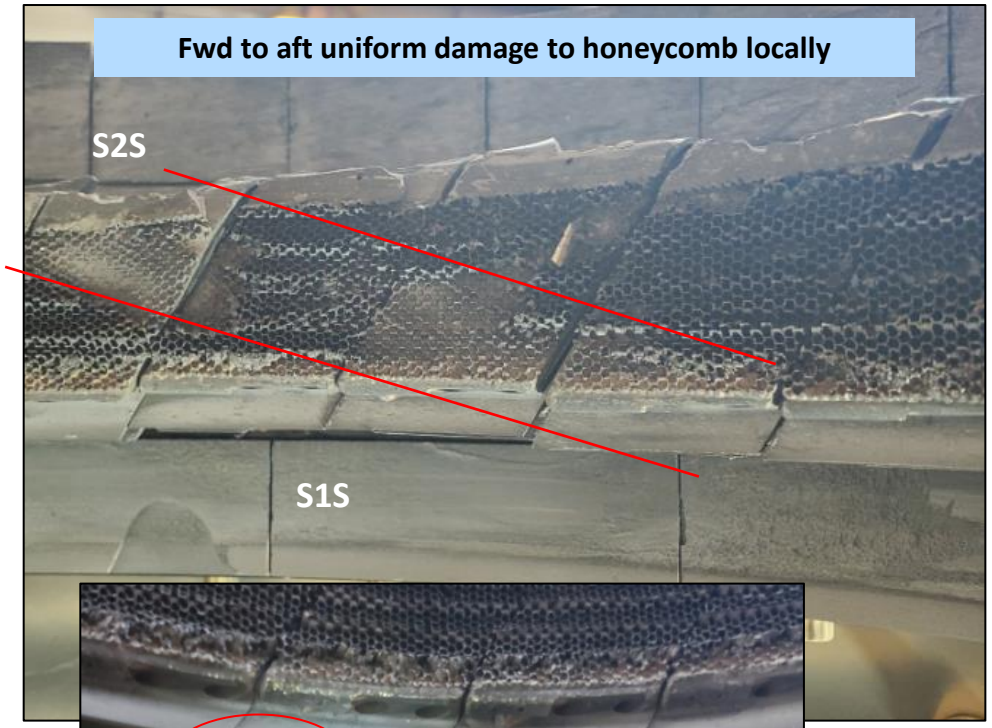
S2D

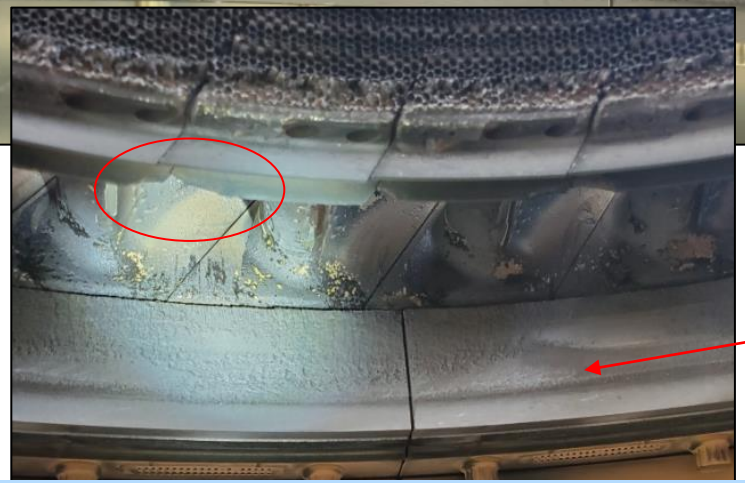


S2D face impression from MS aft axial face consistent with other field disks

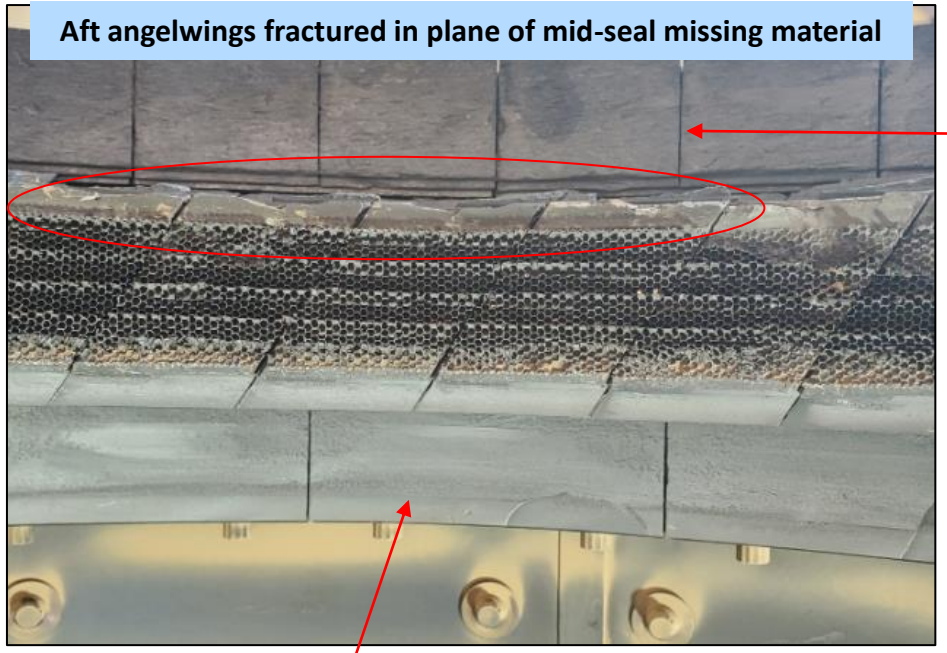
Rabbet area to be investigated in lab

598-326 Teardown – High Pressure Turbine Stage 2 Nozzle Assembly



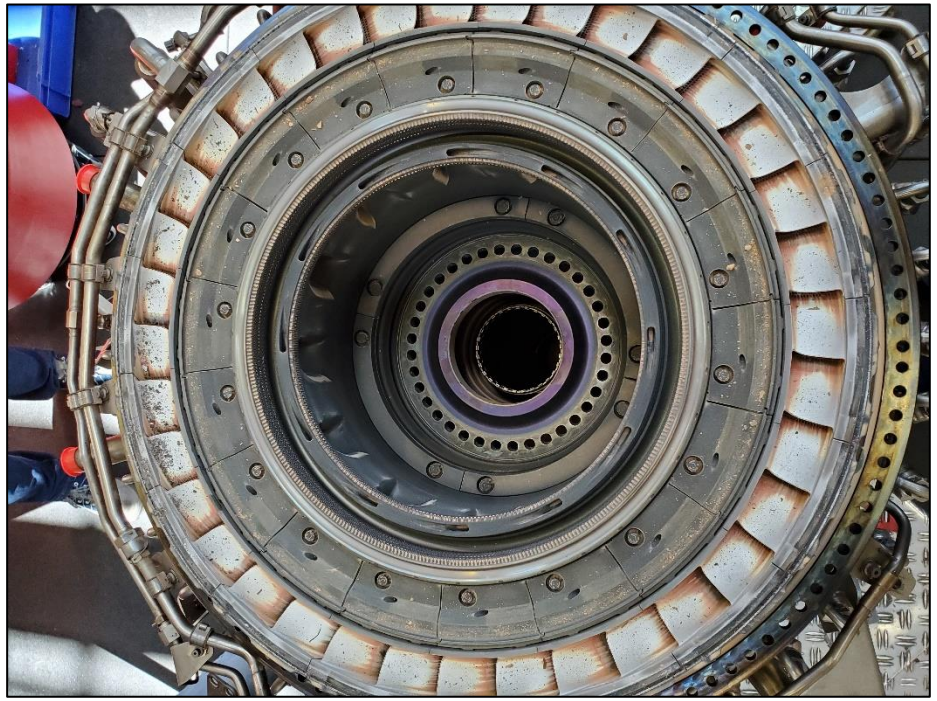


4 grooves in honeycomb, in general good condition
FWD S2N purge holes clear of obstruction
Aft purge holes clear where present

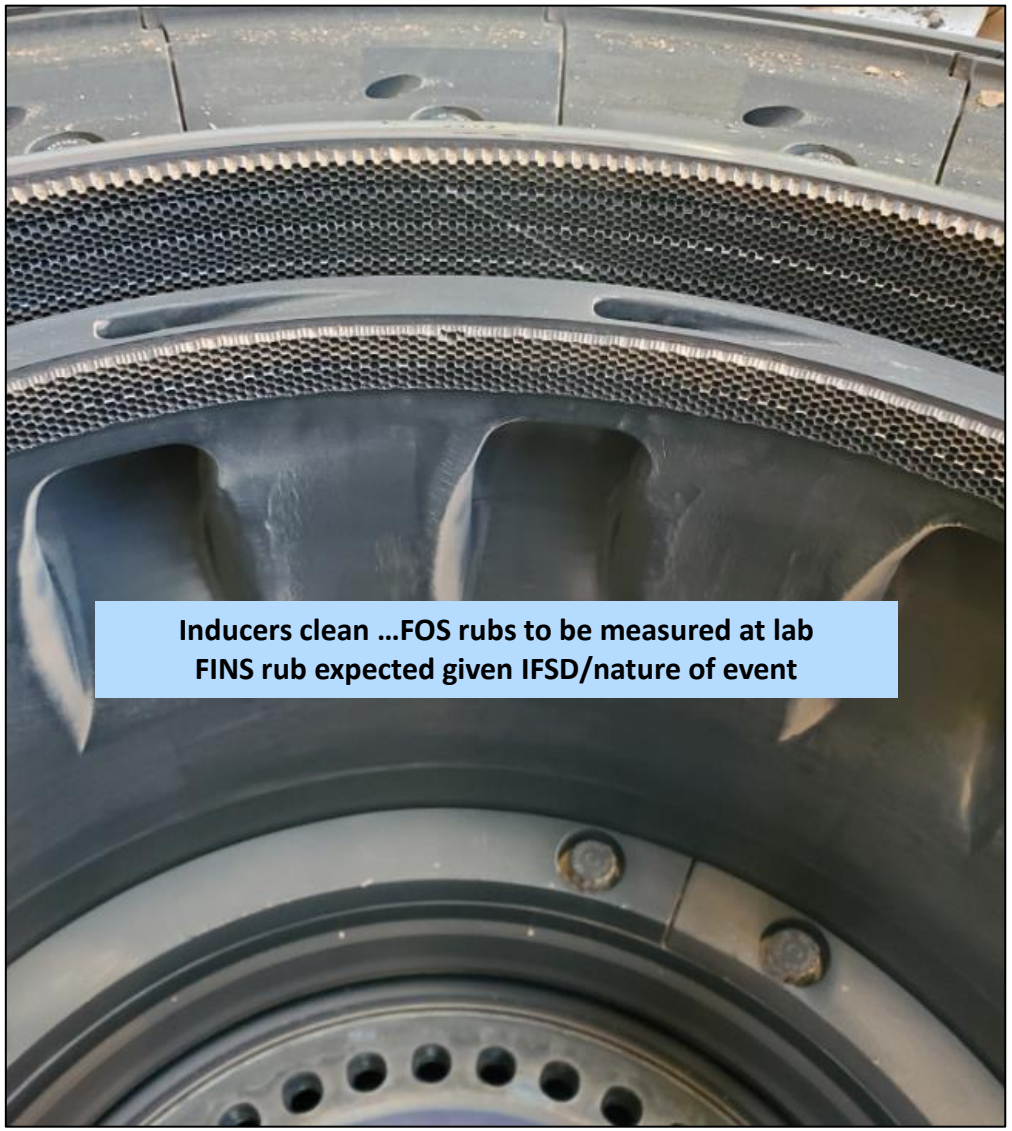


S1S with minor missing EBC coating, heavy sooting on flowpath

598-326 Teardown – High Pressure Turbine Stage 1 Nozzle Assembly

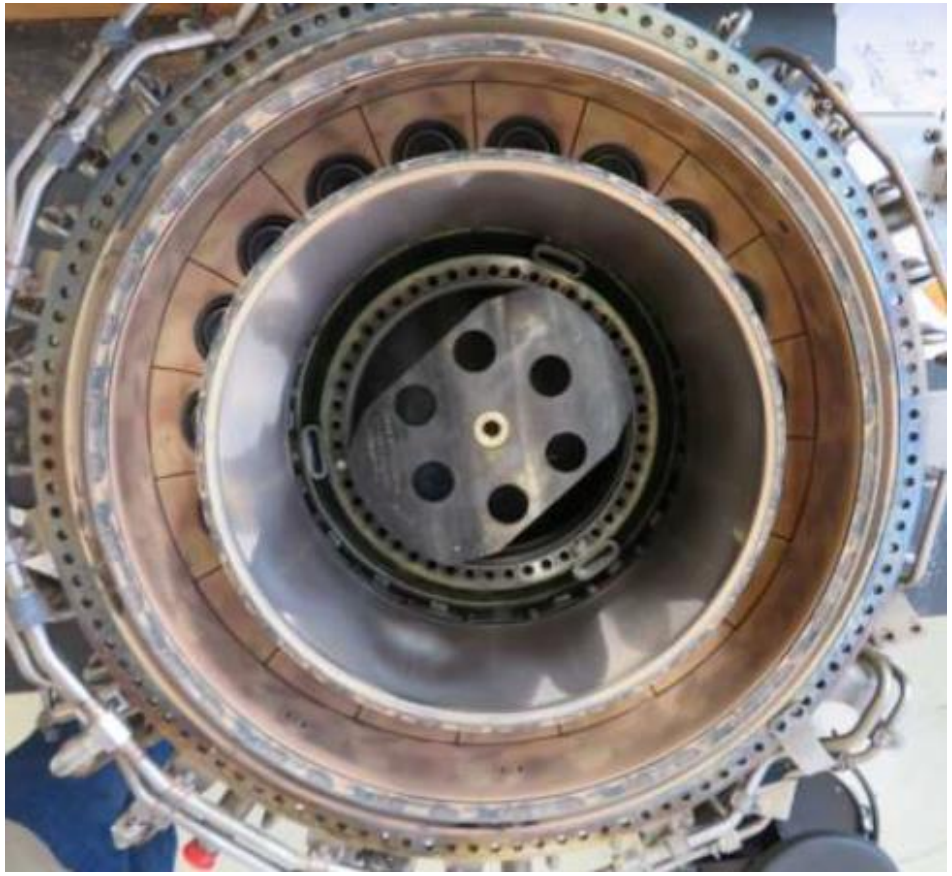


S1N in good condition – 1 segment with convex panel crack



Inducers clean …FOS rubs to be measured at lab
FINS rub expected given IFSD/nature of event

598-326 Teardown – Combustor Assembly



Combustor in good condition, with sooting on FN aft heat shield

598-326 Teardown – High Pressure Turbine Rotor Piece Parts

Evidence of dust buildup on FOS, less than MENA experience

Further investigation of S1 disk aft rabbet to S1R collet at lab

Summary of Observations

- No evidence of case punctures & minimal impact to containment carcass (S2N outerband,S2S) → event contained
- HPT Mid-seal:
  - Fwd arm in-tact, no evidence of creep or thermal distress
  - ~320deg portion of aft arm of HPT mid-seal fractured
  - All features consistent with overstress (instantaneous)
  - Ligament remaining under aft rabbet consistent with final fracture regions
- S2N Assembly:
  - 4 grooves present in S2N honeycomb, intact in general, as expected
  - Mid-seal purge circuit free from blockage
- S2B's showed varying distress (LE tip damage & TE cracks and outerspan)
  - Many regions of impact damage, additional evaluations planned
- #4 bearing looks OK – as expected

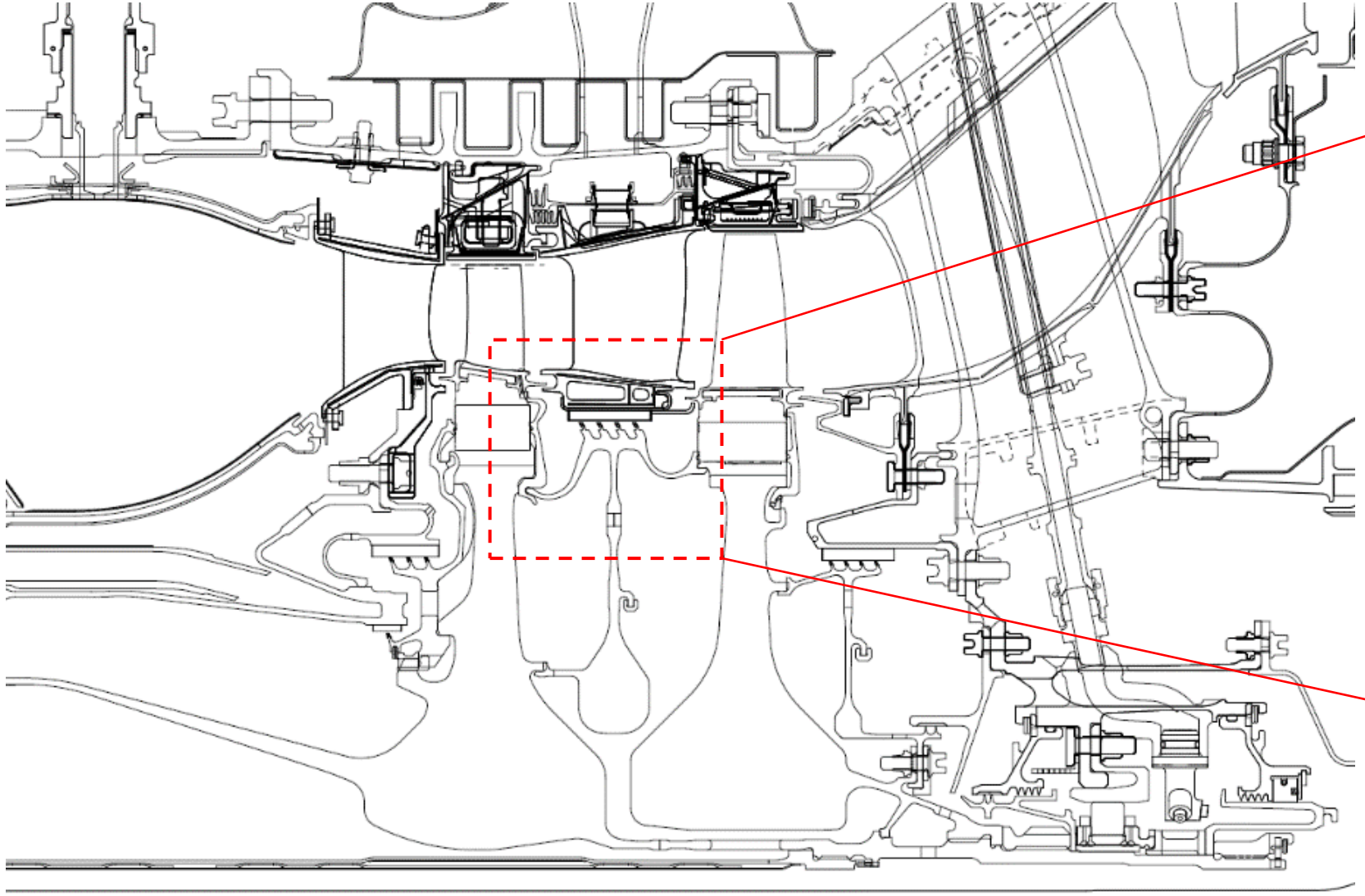
Next Steps

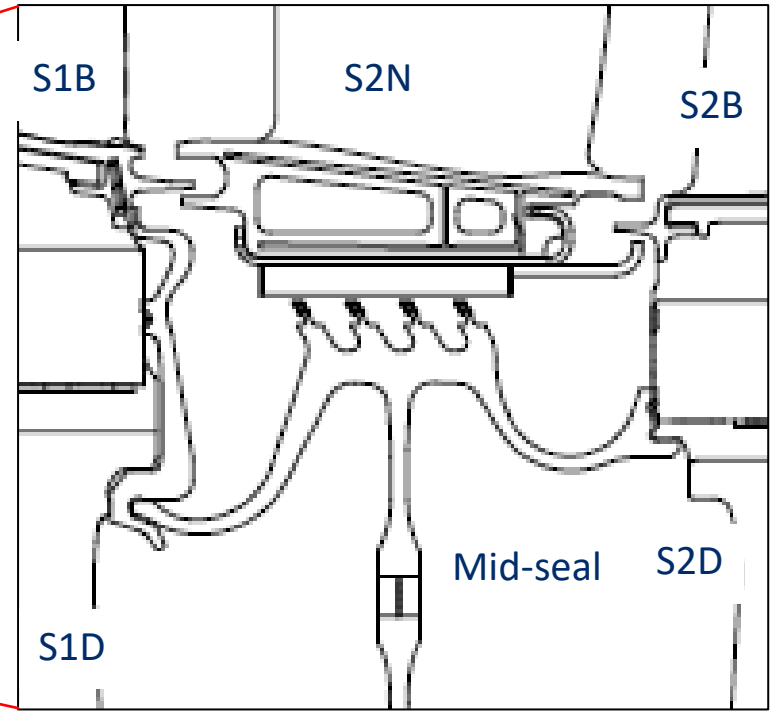
598-326 Milestones

- Ship out HPT investigation hardware to Failure analysis lab for detailed root cause investigation ***June 27 PM***
  - SM53 (Stage 2 Nozzle Assembly) to be shipped to GE for further module level non-destructive evaluation & subsequent teardown
- CFM will provide updates as investigation matures
  - Team is in close contact with EASA and FAA & will ensure DGCA is updated accordingly with investigation milestones

Backup

High Pressure Turbine - Cross-Section





AIR INDIA 598326 IFSD
HPT Mid-seal Investigation/SB Status

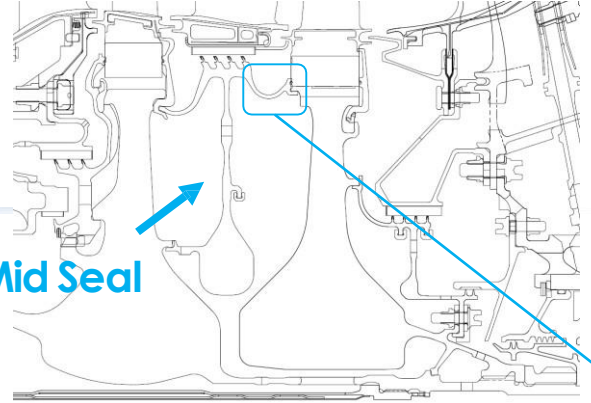
Executive Summary

Background

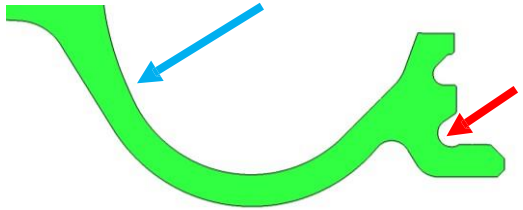
- LEAP-1A ESN 598326 experienced IFSD caused by N2 vibe exceedance & EGT overtemp as a result of HPT mid seal aft catenary arm liberation:
  - 598-326 (6,559/12,569 ECSN/ETSN)
- Teardown investigation confirmed large section HPT Mid Seal AFT catenary arm fracture … FWD arm fully in-tact
  - Observations of mid-seal damage are inconsistent with findings from HPT mid-seal high vibe event that led to SB 72-0426 and SB 72-0460 actions
- No damage observed to HPT case & limited impact to outer flow path

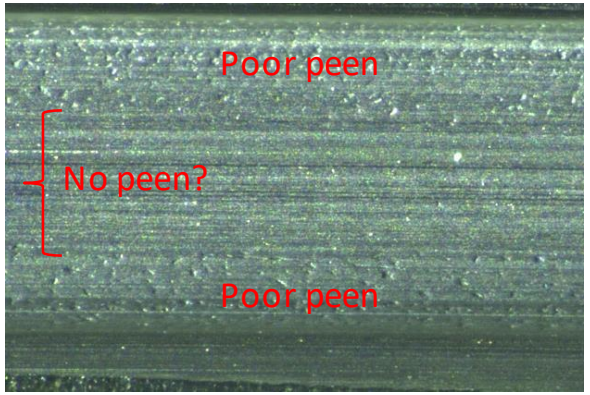
Key Conclusions

- Non-design intent surface condition in aft rabbet fillet
- Inadequate peen coverage or intensity and visible turning lines resulting in debited low cycle fatigue capability
- India region operation is under investigation as a potential secondary/aggravating factor



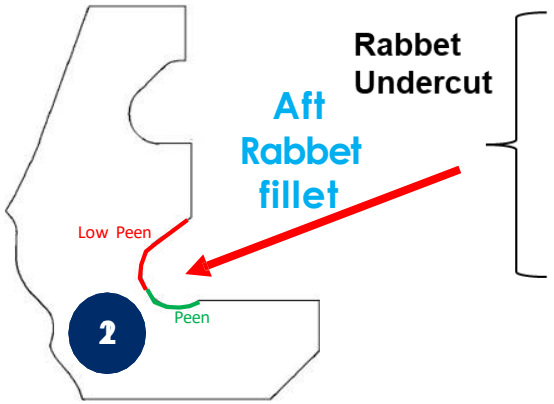
Approximate location of catenary arm fracture

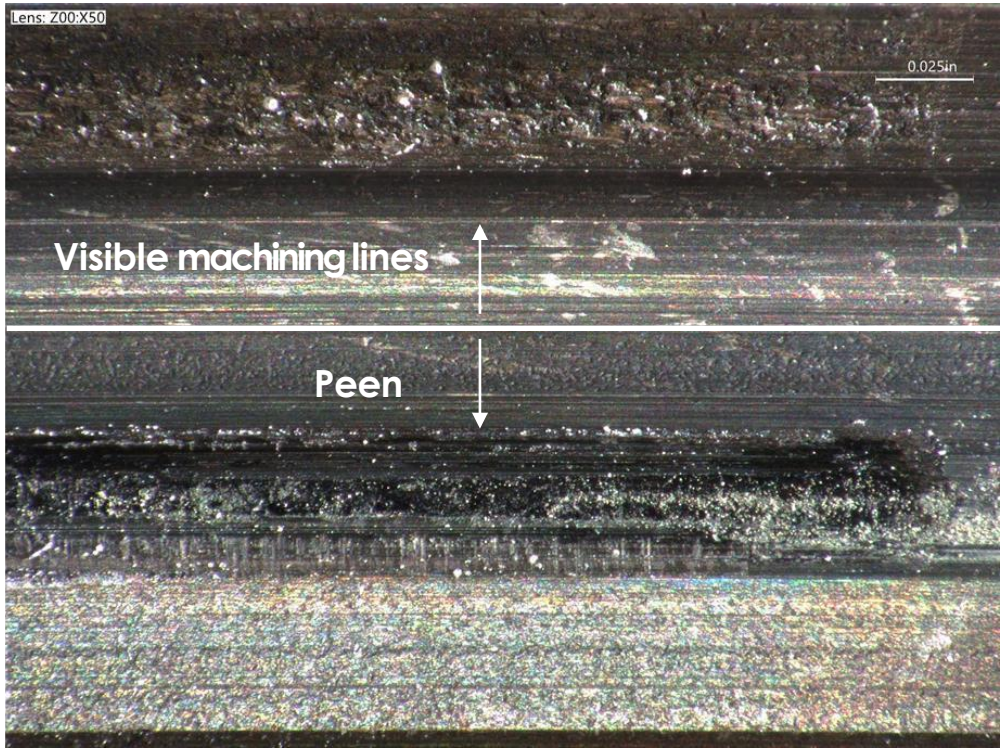


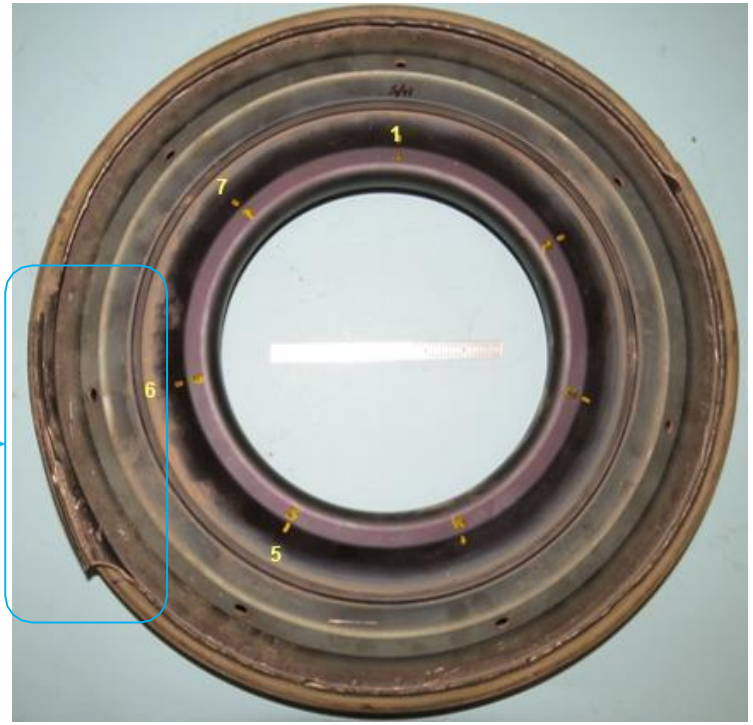


598-326 Mid Seal Metallurgical Evaluation

- No evidence of creep or overtemperature exposure (verified dimensionally)
- In remaining aft catenary arm ligament:
  1. Rabbet fillet has less visible shot-peened area with visible machining lines







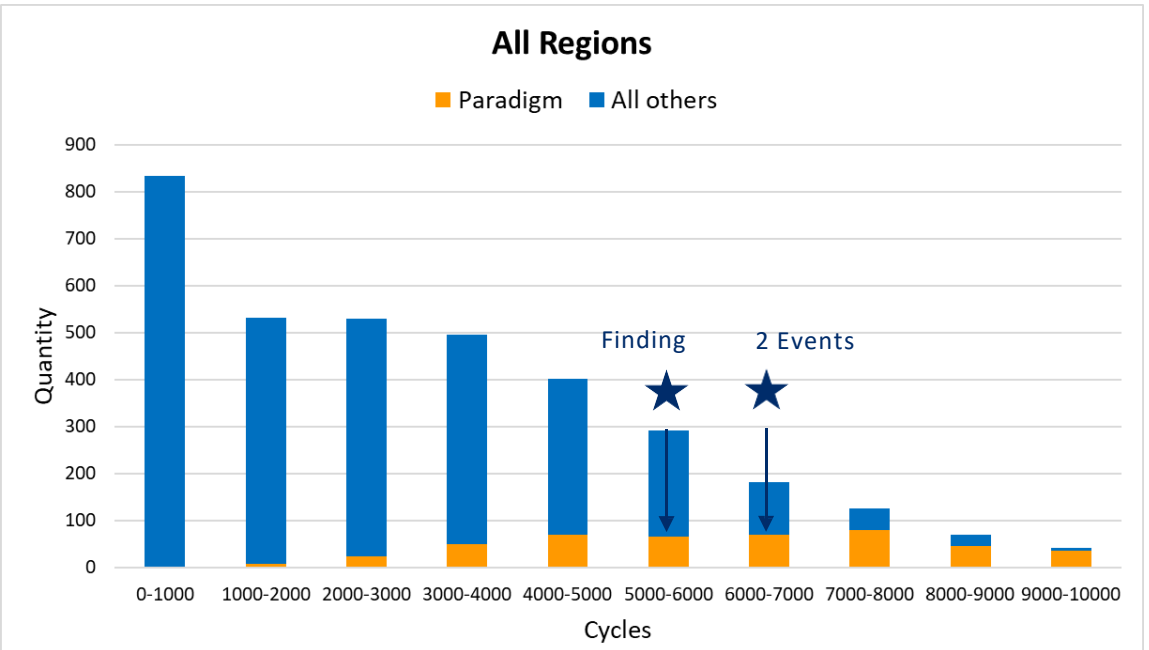
Commonalties

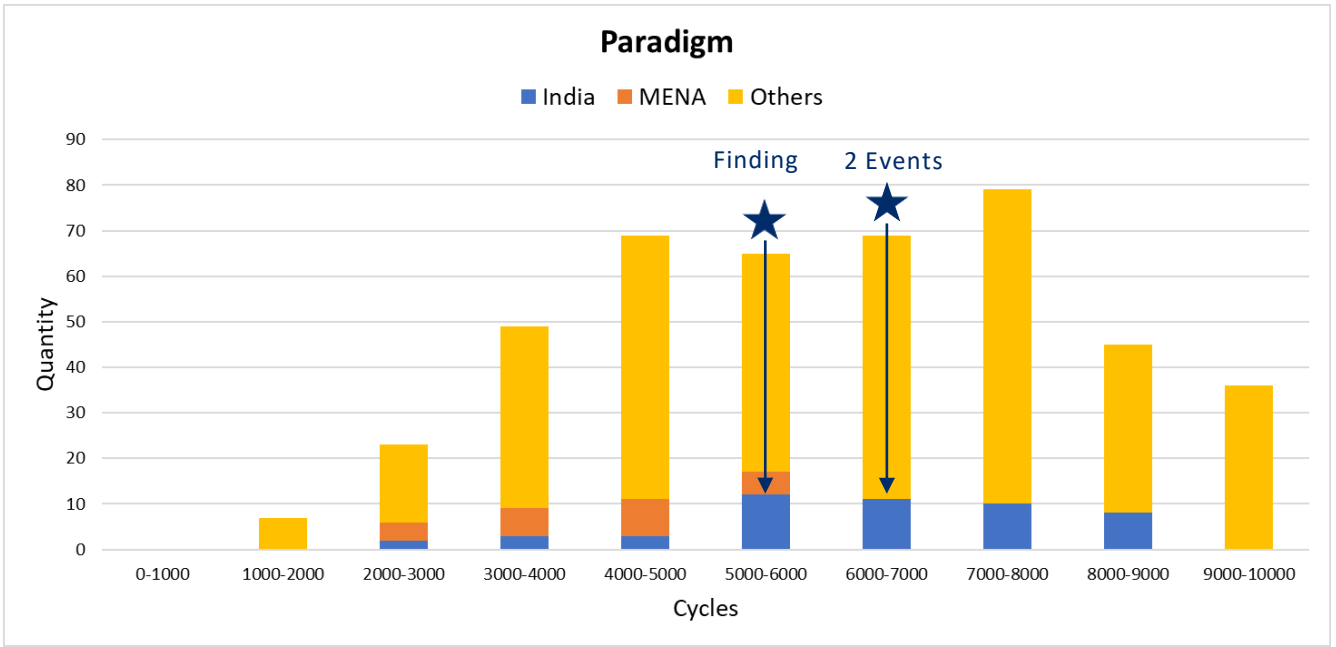
Similar findings on ESN 598-271 IFSD and ESN 598-317 inspected in shop.

All three events/findings

- Relatively high time parts, but not highest
  - Failure at ~6500 – 6800 CSN
  - -317 finding extrapolated to fail at ~6500 CSN
- Manufactured by same supplier (Paradigm)

Model	Date	ESN	CSN/TSN	CSSV/TSSV
1A26	May 19th, 2022	598-326	6,559/12,569	3,219/6,030
1A26	Shop - Jan 2023	598-317	5,589/9,643	3,320/5,458
1A26	May 10, 2023	598-271	6,756/11,989	3,329/5,695

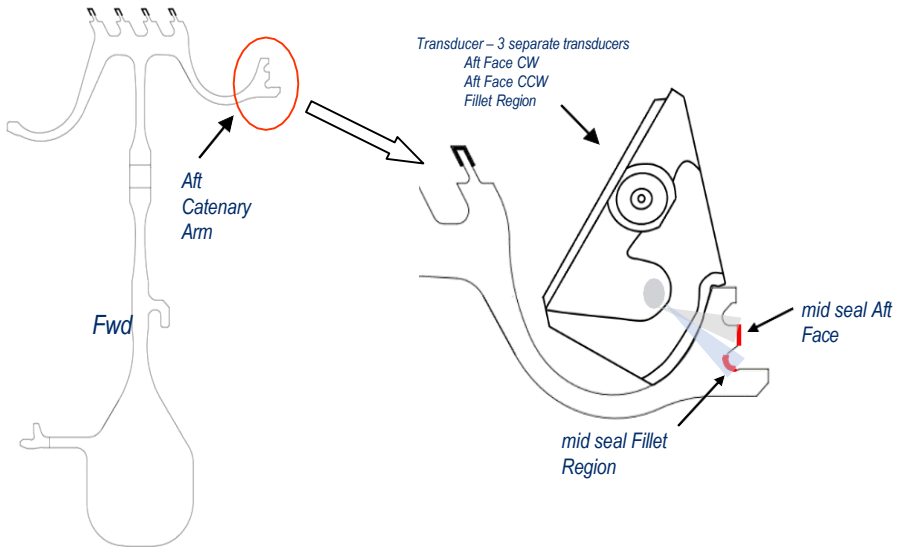




All three mid seals manufactured from same supplier “Paradigm” and operated in India region

Field Plan Overview

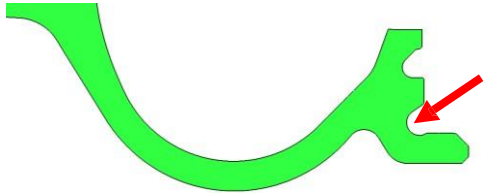
- **Paradigm fleet: CAT 2A SB 72-0478 (issued 7/28/2022) – Completed**
  - Removes 8 Paradigm mid seal from service for inspection based on a list of optimized parameters (manufacturing and operating proximity)
- **Entire fleet: CAT 4B SB 72-0512 (issued 6/29/2023)**
  - Based on 598-326 event, Ultrasonic Inspection developed to scan axial face and fillet regions of aft catenary arm at module level
  - Module level UT inspection at shops for engines with HPTR exposure >4000 cycles
  - Identification of cracks and provides additional information for current data base of inspection for root cause
- **Paradigm India/MENA sub-fleet: CAT 2A SB 72-0516 (Issued 6/30/2023)**
  - Prevent any possible Paradigm re-pairing in India/MENA region
  - India/MENA Region defined by departures



Ultrasonic Inspection of Aft arm

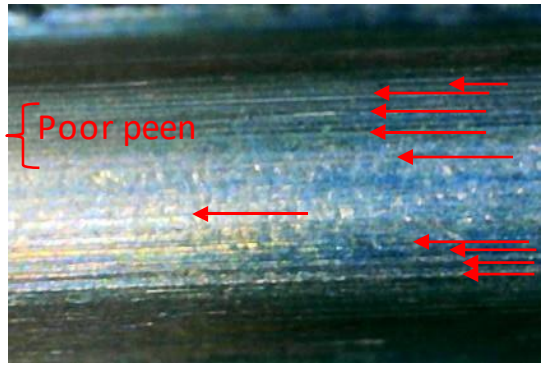
Proposed field plan for Paradigm Mid Seals

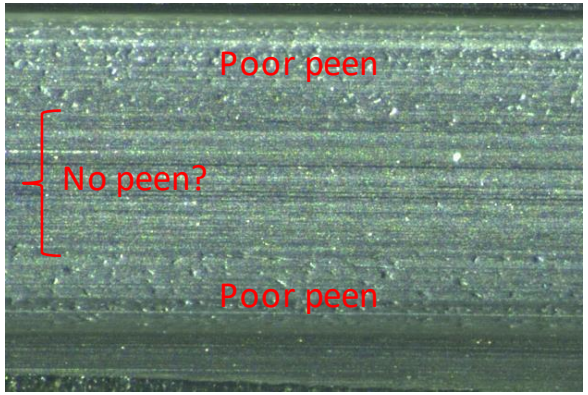
- One of the most probable root cause is inadequate peen coverage and visible turning lines on the fillet
- Inadequate peen coverage results in debited LCF capability but supports Ch 05 life (11.1 k cycles for Commercial and 9.7k cycles for corporate)
- 85% of the Paradigm (WES) parts inspected with inadequate peen coverage
- **CFM plans to issue CAT 2B Service Bulletin 72-0525 recommending removal of all Paradigm mid-seals (serial numbers starting with "WES") from service**
- Work ongoing for additional surface condition characterization of other suppliers along with understanding of India operation contribution
- CFM will provide updates on the investigation through Customer Connection Calls

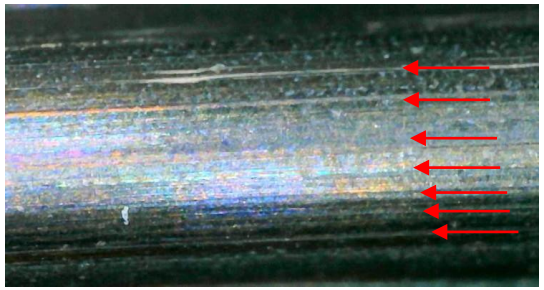


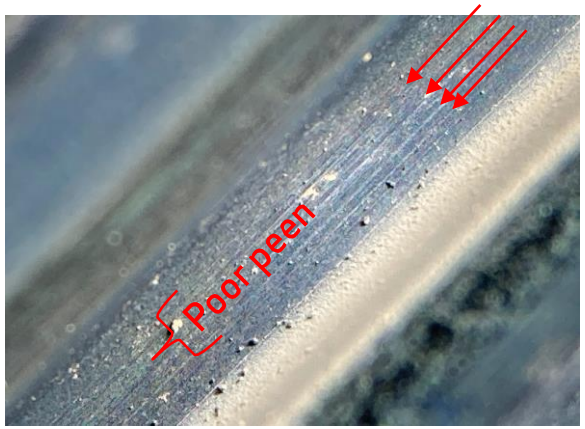
Fillet of Interest
Aft Rabbet Fillet

Photo-Standard Examples of Fillet Surface Condition









Proposed SB structure 72-0525

- **Category 2**
  - **India/MENA*** – Remove & discard the mid seal by 11.1 k cycles for commercial and 9.7k cycles for corporate or at next shop visit including quick turns, whichever comes first
  - **All other regions** - Remove & discard the mid seal by 11.1 k cycles for commercial and 9.7k cycles for corporate or at next piece-part exposure , whichever comes first
- **Impact B** - This recommendation is to address a condition that may result in an increased rate of In-Flight Shutdowns (IFSD), Take-Off Aborts (TOA), Air Turn Backs (ATB) or Diversion (DIV).

*Operating in the India/MENA region means having the majority of departures (more than 50 percent) occurring in the India/MENA region.