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Final Investigation Report
on
Serious Incident involving M/s InterGlobe Aviation Limited, Airbus A320 Aircraft, VT-IFM on 28 October 2022

Government Of India
Ministry of Civil Aviation
Aircraft Accident Investigation Bureau

FOREWORD

In accordance with Annex 13 to the Convention on International Civil Aviation Organization (ICAO) and Rule 3 of Aircraft (Investigation of Accidents and Incidents), Rules 2025, the sole objective of the investigation of an Accident/Incident shall be the prevention of accidents and incidents and ***not to apportion blame or liability****. The investigation conducted in accordance with the provisions of the above said rules shall be separate from any judicial or administrative proceedings 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 future accidents or incidents could lead to erroneous interpretations.

Unless otherwise indicated, all times in this report are stated in Co-ordinated Universal Time (UTC). The relationship between IST and UTC is: IST = UTC + 5½ hours.

For reasons of data protection and simplification of the text, this report uses exclusively the generic masculine.

Note:

Figures used in this report are taken from different sources and are adjusted from the original for the sole purpose to improve the clarity of the Report. Modifications to images used in this report are limited to cropping, magnification or addition of text boxes, arrows or lines.

Contents

GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Aircraft Accident Investigation Bureau
AD	Airworthiness Directives
ALRC	Airline License Rating Check
AME	Aircraft Maintenance Engineer
AMM	Aircraft Maintenance Manual
AMP	Aircraft Maintenance Program
AMSL	Above Mean Sea Level
ARC	Airworthiness Review Certificate
ATPL	Airline Transport Pilot License
ATC	Air Traffic Control
BA	Breath Analyzer
CAMO	Continuing Airworthiness Management Organization
CEO	Current Engine Option
C.G	Centre of Gravity
C of A	Certificate of Airworthiness
C of R	Certificate of Registration
C.R. S	Certificate for Release to Service
CAR	Civil Aviation Requirements
CFT	Crash Fire Tender
CVR	Cockpit Voice Recorder
DFDR	Digital Flight Data Recorder
DGCA	Directorate General of Civil Aviation
ECAM	Electronic Centralized Aircraft Monitor
EEC	Electronic Engine Control
EPR	Engine Pressure Ratio
ESN	Engine Serial Number
FCOC	Fuel Cooled Oil Cooler
FCOM	Flight Crew Operation Manual
FLX/MCT	Flex/Maximum Continuous Thrust
FMU	Fuel Metering Unit
FRTOL	Flight Radio Telephone Operator License
FT/ft	Feet
HCF	High Cycle Fatigue
HPC	High Pressure Compressor
HPT	High Pressure Turbine
Hrs	Hours
IAE	International Aero Engines
IAS	Indicated Air Speed
Ibs	Pounds
ICAO	International Civil Aviation Organization
IIC	Investigator –In –Charge
IOD	Internal Object Damage
IR	Instrument Rating
Kg	Kilogram
KT/Kts	Knots
LH	Left Hand
LPC	Low Pressure Compressor

LPT	Low Pressure Turbine
MAC	Mean Aerodynamic Chord
M /m	Meter
METAR	Meteorological Aerodrome Report
MHz	Mega Hertz
MRO	Maintenance Repair Overhaul
MSN	Manufactures Serial Number
MTOW	Maximum Take-off Weight
N/A	Not Available
NM	Nautical Miles
OEM	Original Equipment Manufacturer
PIC	Pilot-In-Command
QNH	Nautical Height
RH	Right Hand
RTO	Rejected Take-Off
SB	Service Bulletin
SOP	Standard Operating Procedure
STA	Standard Time of Arrival
STD	Standard Time of Departure
DEL	IATA code for Delhi Airport
TSN	Time Since New
TSLSV	Time Since Last Shop Visit
TSO	Time Since Overhaul
USA	United States of America
UTC	Coordinated Universal Time
VHF	Very High Frequency
VSVs	Variable Stator Vanes
VIGVs	Variable Inlet Guide Vanes

SUMMARY

Aircraft and Serious Incident details of Airbus A320 Aircraft VT-IFM on 28 October 2022.			
1	**Aircraft**	**Type**	Airbus A-320-232 (CEO)
		Nationality	Indian
		Registration	VT – IFM
2	**Owner**		M/s Unicorn Leasing Limited, Ireland
3	**Operator**		M/s InterGlobe Aviation Limited, India
4	**Pilot – in –Command**		ATPL holder
5	**Co-Pilot**		ATPL holder
6	**No. Passengers on Board**		178
7	**Injuries**		Nil
8	**Place of Serious Incident**		Delhi Airport (VIDP)
9	**Date & Time of Serious Incident**		28 October 2022 at 1617 UTC
10	**Last point of Departure**		Delhi Airport (VIDP)
11	**Point of intended landing**		Bengaluru Airport (VOBL)
12	**Co-ordinates of Serious Incident Site**		Latitude: 28°34’07” N Longitude: 77°06’44” E.
13	**Type of operation**		Scheduled Operation
14	**Phase of Operation**		Take-off
15	**Type of Serious Incident**		System/Component Failure or Malfunction (Powerplant) (SCF-PP)

(All the timings in this report are in UTC unless otherwise specified)

SYNOPSIS

On 28 October 2022, M/s InterGlobe Aviation Limited's A320 aircraft, bearing registration VT-IFM, while operating a scheduled flight (6E-2131), Delhi to Bengaluru was involved in an engine failure occurrence.

On that day, Flight 6E-2131 was scheduled to operate from Delhi to Bengaluru. Flight 6E-2131 was under the command of an ATPL holder pilot, who was the Pilot Flying (PF). The Co-pilot was also an ATPL holder, the Pilot Monitoring (PM). There were 178 passengers and six crew members onboard. The preceding sector was operated by the same set of flight crew and nil snag was reported by them. At Delhi, Pre-flight Inspection was carried out by the PIC and nil abnormalities were found. As per aircraft records, nil snag was pending for rectification on engine no. 02 prior to departure.

When Flight 6E-2131 was ready for departure, flight crew obtained the necessary clearances from ATC, Delhi. Pushback, engine start-up and taxi were uneventful. Aircraft lined up on runway 28 for take-off. Subsequently, the ATC, Delhi cleared the aircraft for take-off. The aircraft started to rolling on runway 28. When the aircraft's speed reached around 46 kts (IAS), the flight crew heard a loud bang accompanied with a right yaw movement. Flight crew immediately rejected the take-off. Soon the aircraft came to halt on the runway 28. Meanwhile "*ENG 2 Fail*" ECAM message triggered. Subsequently, fire coming out of engine no. 02 was confirmed by few passengers and by an aircraft standing on the taxiway. The Flight crew followed the FCOM procedures of engine failure and secured the engine. Flight crew also apprised the ATC Delhi about engine no. 2 failure and the rejected take-off. In turn, ATC Delhi, alerted the emergency service and directed them towards the aircraft. Fire tender and other emergency service teams immediately, rushed toward the aircraft for assistance. Later, the aircraft taxied to the assigned bay under its own power and was parked. Passengers and crew members disembarked normally.

Post incident, in the initial inspection at Delhi airport, substantial damage in engine no. 2 was observed by the maintenance personnel and the damaged engine was replaced with a serviceable one.

The occurrence was classified as a Serious Incident and the Director General, AAIB ordered an investigation into the probable cause(s) of this Serious Incident, vide Order No. INV.12011/5/2022-AAIB dated 02nd Nov 2022 under Rule 11 (1) of Aircraft (Investigation of Accidents and Incidents), Rules 2017.

Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities of the State having the responsibility for the matters with which the recommendation is concerned.

1. FACTUAL INFORMATION

1.1 History of the flight

On 28 October 2022, prior to the serious incident sector, M/s Indigo's A320-232 aircraft bearing registration VT-IFM had operated 07 sectors viz. Kolkata–Delhi, Delhi–Jaipur, Jaipur–Chennai, Chennai–Bengaluru, Bengaluru–Chennai, Chennai–Hyderabad, and Hyderabad–Delhi uneventfully. During these preceding sectors, three different sets of flight crew were changed. On completion of the abovementioned sectors nil snag were reported by the respective flight crew.

The flight crew of the incident flight was the same set of flight crew, who had operated the two preceding sectors viz. Chennai - Hyderabad (flight no. 6E-6805) and Hyderabad–Delhi sector (flight no. 6E-2135). At 0956 UTC, according their duty roaster, flight crew reported for duty at Chennai airport. Subsequently, Flight crew's Pre-flight Breath Analyzer (B.A.) tests were conducted. The Pre-flight medical results for both flight crew were satisfactory. After completing the Pre-Flight inspection, PIC accepted the aircraft by signing in the aircraft technical logbook.

As per flight schedule, at 1112 UTC, aircraft took -off from Chennai airport and landed at Hyderabad airport at 1202 UTC. Later, at 1257 UTC, aircraft took -off from Hyderabad airport and landed at Delhi airport at 1457 UTC. Both sectors were uneventful and nil snag was reported by the flight crew.

On the same day, Flight no. 6E-2131, Delhi -Bengaluru was scheduled to depart at 1600 UTC (STD) and arrive in Bengaluru at 1845 UTC (STA). There were 178 passengers and six crew members onboard.

At 1553 UTC, flight crew contacted the Delhi Ground Controller and requested for push back and engine start up. At 1558 UTC, the Ground Controller approved the push back and engine start up request. After push back, flight crew started the engine no. 1.

At 1603 UTC, flight crew requested Ground Controller for taxi instructions. The Ground Controller gave the taxi instructions in a phased manner and directed the aircraft up to the holding point of runway 28. Meanwhile, the flight crew also started engine no. 2.

Later, as per Ground controller's instructions the flight crew switched over to Delhi Tower, Control. At 1614 UTC, Tower Controller gave the line Up clearance to the aircraft for runway 28. At 1615 UTC, aircraft entered the runway 28. At 1616 UTC, Tower Controller gave the take-off clearance and also passed the wind information as "…. Wind Calm". The Flight crew acknowledged the take-off clearance and initiated the take-off. Flight crew advanced the thrust level to FLX/MCT. Then both the engines spooled up normally and the aircraft started rolling on runway 28.

When the aircraft's speed reached around 46 kts (IAS), the flight crew heard a loud bang accompanied with a right yaw movement. Flight crew responded and immediately selected full thrust reversers and rejected the intended take-off. Soon the aircraft came to a halt on the runway 28. As per flight crew statements, initially "ENG 2 Fail" ECAM message triggered. But suddenly it changed to "ENG 2 Reverser unlocked" and in no time it again changed to "ENG 2 Fail" ECAM.

Meanwhile, another aircraft standing on nearby taxiway observed fire coming out of the aircraft VT-IFM's engine no. 2. Immediately, she reported the same to Delhi Tower control. Delhi Tower controller acted swiftly and contacted the aircraft VT-IFM. In response, the flight crew of the aircraft VT-IFM informed the Tower controller about the engine failure followed by the rejected take-off on runway 28. The flight crew followed the company's FCOM procedures and emergency checklists. As the Flight crew anticipated damage in engine No. 2 hence engine fire extinguisher was used and the affected engine was switched off. Meanwhile, the tower controller activated the emergency siren and alerted the airport emergency services. Subsequently, the Follow Me vehicle and the Crash Fire Tender reached near to the aircraft for assistance.

The flight crew first reviewed the prevailing situation and confirmed with the other aircraft that had reported seeing fire. The crew of that aircraft replied that the fire was visible earlier, but now it is not.

Meanwhile, the flight crew instructed the cabin crew to check for any visible fire in the right engine. The cabin crew reported to the flight deck that smoke was present, but no fire was observed. Thereafter, the flight crew requested Tower controller to re-check with the emergency services regarding any fire from the right engine. The emergency services also reported negative.

Finally, the flight crew requested Follow Me assistance for taxiing to nearest bay under single engine power. The Delhi Tower approved the request and provided Follow Me assistance to guide the aircraft to the nearest bay. Subsequently, the aircraft safely docked at the assigned bay.

All passengers and crew disembarked normally at bay. No injuries were reported among the passengers or crew.

During the initial inspection, maintenance personnel reported that engine no. 2's thrust reverser was in the deployed position, the fan could not be rotated by hand, and metal particles were visible in the exhaust. Subsequent inspections revealed substantial damage to engine no. 2.

1.2 Injuries to Persons

INJURIES	CREW	PASSENGERS	OTHERS
Fatal	Nil	Nil	Nil
Serious	Nil	Nil	Nil
~~Minor~~/None	06	178	Nil

1.3 Damage to Aircraft

There was no damage to the aircraft, except the substantial damage sustained by the engine no. 2. Details of damage observed by the maintenance personnel during the Boro Scope Inspection of the engine no. 2 are given below:

(a) Severe damages were observed in (Low Pressures Compressor) LPC 2.5 stage.

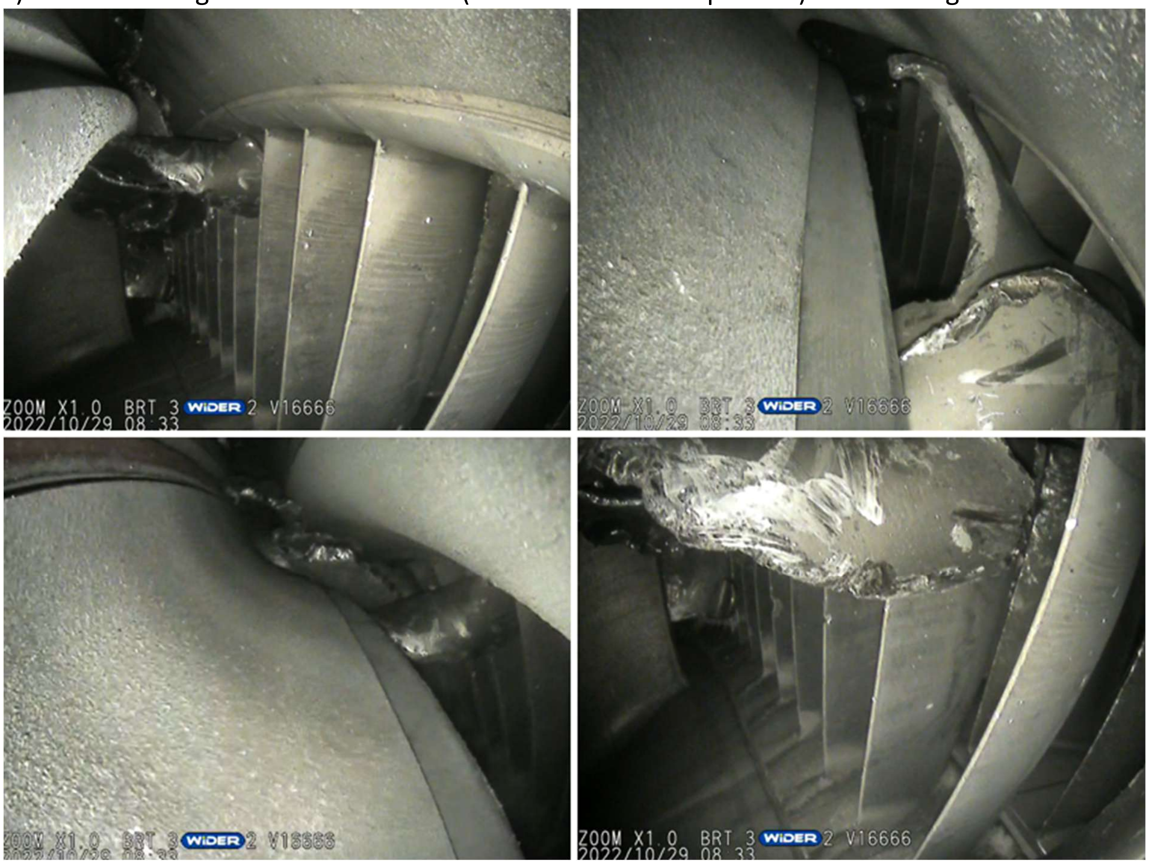

Figure 1: Damaged LPC 2.5

(b) Severe damages were observed in the (High Pressures Compressor) HPC 3 stage.

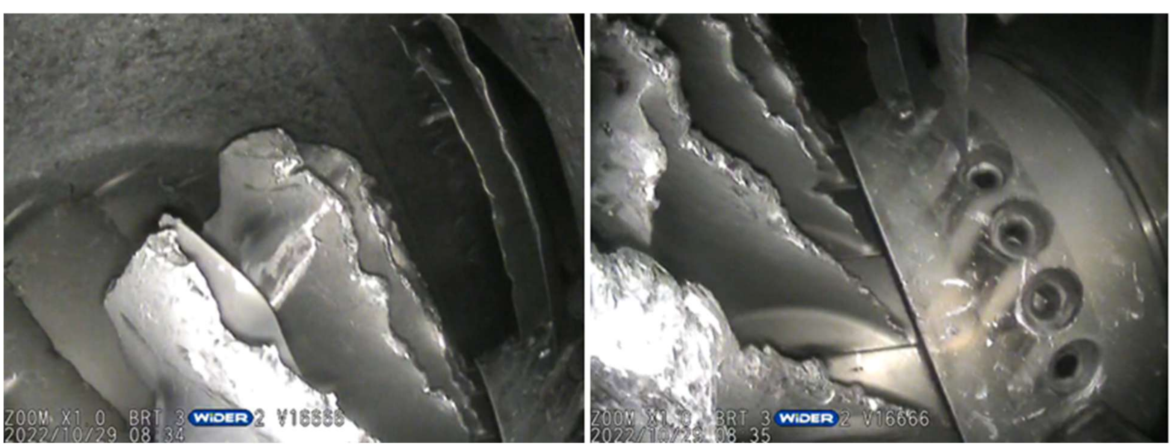

Figure 2: Damaged HPC 3rd Stage

(c) Severe damages were observed in the (High Pressures Compressor) HPC 6 stage.

Figure 3: Damaged HPC 6th Stage

(d) 2.5 and 7B bleed valve were found damaged due to IOD.

1.4 Other Damage

Nil

1.5 Personnel Information

1.5.1 Pilot- In- Command

The Pilot-in-Command (PIC) of flight 6E-2131 held an Airline Transport Pilot License (ATPL) and had accumulated more than 3,426 hours of total flying experience. At the time of the incident, the PIC's Class I Medical Certificate was valid. A summary of the PIC's credentials and flying experience as of the date of the incident is provided in the table below:

Nationality	Indian
Age	30 yrs.
License (Issue/valid till)	29/04/2019 - 28/04/2024
License Type	ATPL
Date of Class I Med. Exam.	23/06/2022
Class I Medical Valid up to	28/06/2023
Date of issue FRTOL License	09/05/2018
FRTO License Valid up to	08/05/2023
Endorsements as PIC	PA34, A320
Total flying experience	3426: 29 Hours
Total flying experience on type	A320- 3052:22 Hours
Last Flown on type	28/10/2022
Total flying experience during last 1 year	373.46 Hours
Total flying experience during last 6 Months	186.48 Hours

Total flying experience during last 30 days	50.58 Hours
Total flying experience during last 07 Days	04:45 Hours
Total flying experience during last 24 Hours	03:29 Hours
Rest period before flight	15:26 Hours
Whether involved in Accident/Incident earlier	No
Date of latest Flight Checks and Ground Classes	ALRC 11/06/2022, REF 27/10/2022

1.5.1 Co-Pilot

The Co-Pilot of flight 6E-2131 held an Airline Transport Pilot License (ATPL) and had accumulated more than 3240 hours of total flying experience. At the time of the incident, the Co-Pilot's Class I Medical Certificate was valid. A summary of the Co-Pilot's credentials and flying experience as of the date of the incident is provided in the table below:

Nationality	Indian
Age	34 yrs.
License (Issue/valid till)	24/11/2021 - 23/11/2026
License Type	ATPL
Date of Class I Med. Exam.	05/10/2022
Class I Medical Valid up to	08/10/2023
Date of issue FRTOL License	09/07/2022
FRTO License Valid up to	12/07/2032
Endorsements as PIC	C152, PA34, A320
Total flying experience	3240: 48 Hours
Total flying experience on type	A320- 2849:35 Hours, A321- 126:18 Hours
Last Flown on type	28/10/2022
Total flying experience during last 1 year	468.08 Hours
Total flying experience during last 6 Months	278.25 Hours
Total flying experience during last 30 days	43.25 Hours
Total flying experience during last 07 Days	16.17 Hours
Total flying experience during last 24 Hours	03:29 Hours
Rest period before flight	34:50 Hours
Whether involved in Accident/Incident earlier	No
Date of latest Flight Checks and Ground Classes	ALRC 26/05/2022; REF 16/09/2022

1.6 Aircraft Information

1.6.1 Brief Description of Airbus A-320

The Airbus A320 is a narrow-body (single-aisle) aircraft with a retractable tricycle landing gear and is powered by two wing pylon-mounted turbofan engines. The aircraft is powered by two IAE V2500 turbo fan engines designed for subsonic commercial airline service. Each engine is housed in a nacelle suspended from a pylon attached below the wing. The 3-view drawing taken from Airbus Manual (Airplane Flight Manual) is depicted below:

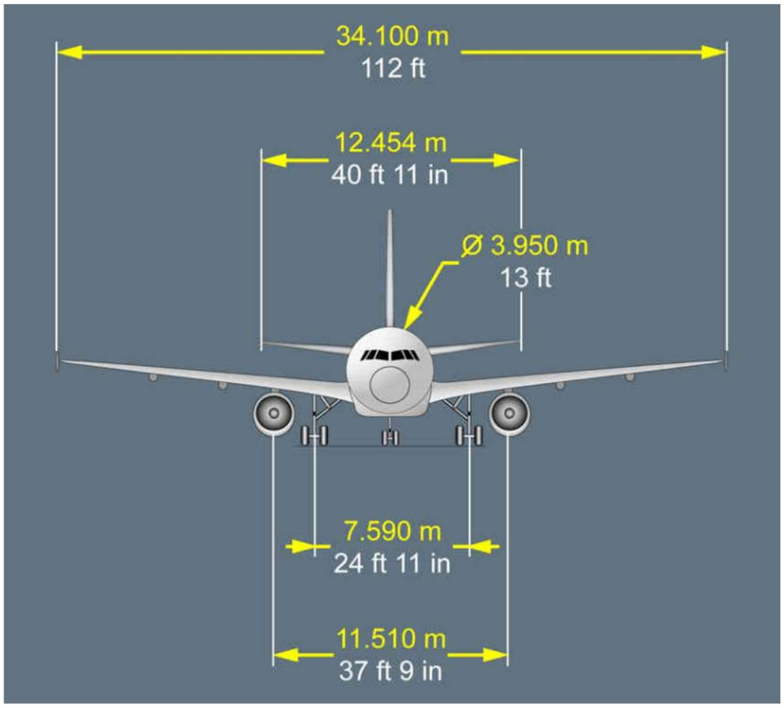

Figure 4: Three-dimensional view (Front view)

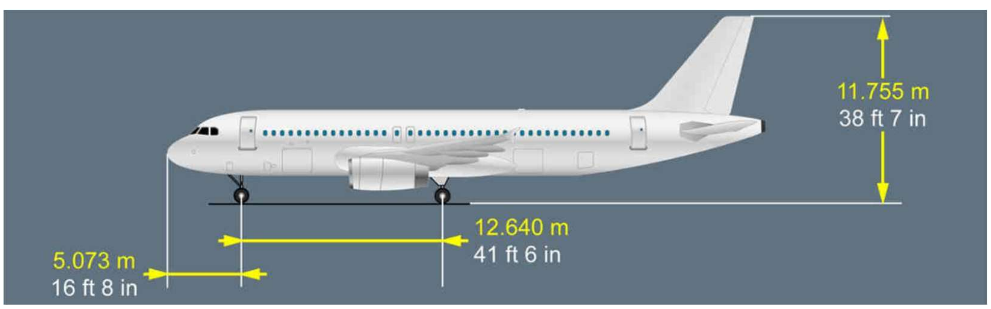

Figure 5: Three-dimensional view (Side view)

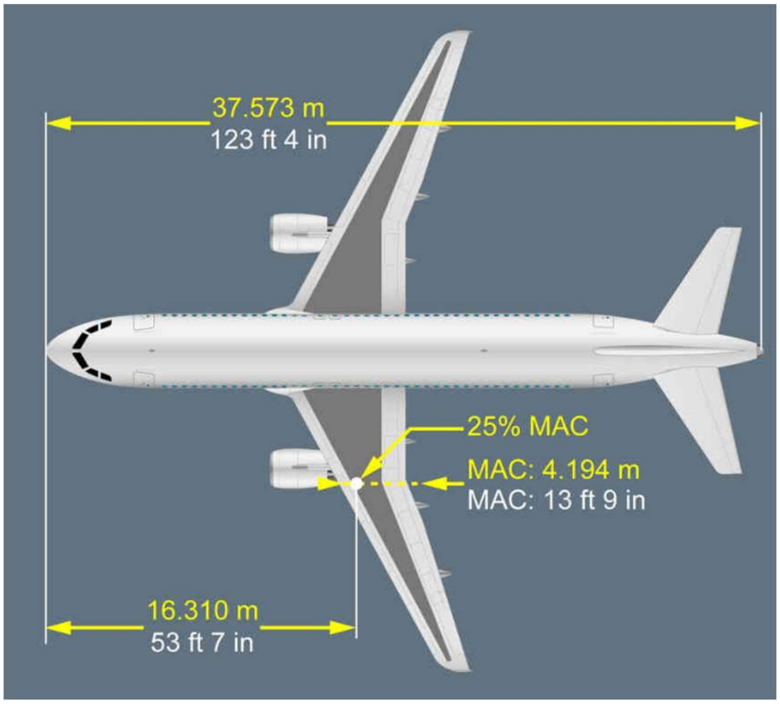

Figure 6: Three-dimensional view (Top view)

1.6.2 Aircraft (VT-IFM) Specific Information

Aircraft	Model	AIRBUS A320-232
	S. No.	5537
	Year of Manufacturer	10/04/2013
C of R		Valid
C of A Validity		Valid
A R C issued on		09/04/2022
ARC valid up to		09/04/2023
Aircraft Empty Weight		41204.70 kg
Maximum Takeoff weight		77000.00 kg
Date of Aircraft weighment		08/04/2019
Max Usable Fuel		19052.000kg
Max Payload with full fuel		15713.473 kg
Empty Weight C. G		26.982 % MAC
Next Weighing due		07/04/2024
Total Aircraft Hours		30839:41(As on 28/10/2022)
Last major inspection		Performed 3000FH/360 Days on 17/10/2022
Engine Type		IAE V2527-A5
Date of Manufacture LH		25/08/2013
Engine Sl. No. LH		V16945

Last major inspection (LH)	08/06/2018
Total Engine Hours/Cycles LH	24769:23 FH
Date of Manufacture RH	07/02/2013
Engine Sl. No. RH	V16666
Last major inspection (RH)	05/01/2022
Total Engine Hours/Cycles RH	29603:46 FH
Aero mobile License	L-14012/002/2015-RLO (NR)

1.6.3 V2500 Engine

1.6.3.1 Technical Description of Engine

The IAE V2500 turbo fan engine is a two spool, axial flow, high by-pass ratio turbo fan engine. The V2500 incorporates a Full Authority Digital Engine Control (FADEC).

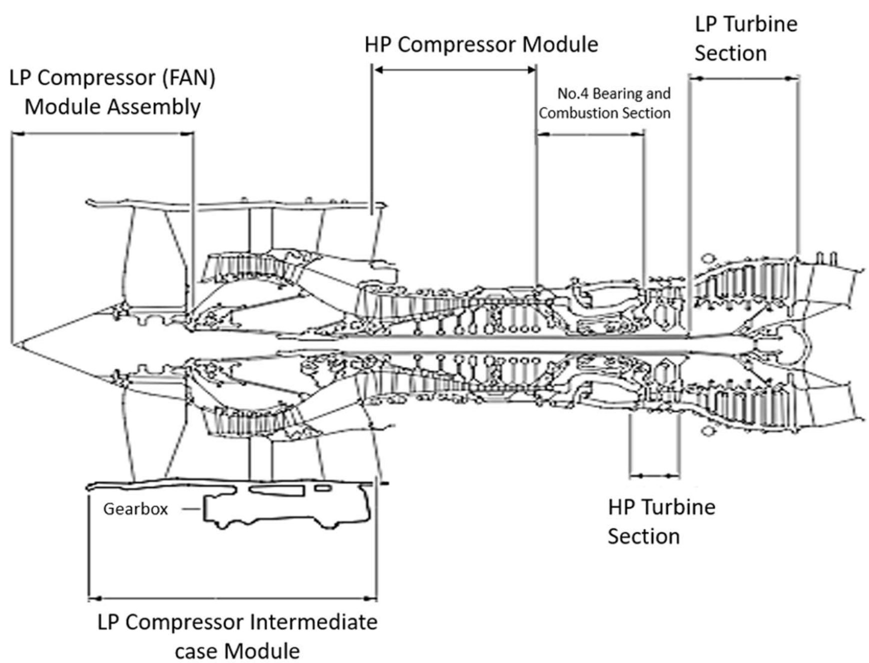

Figure 7: V2500 Engine Modules

The main modules of the engine are: the Low Pressure (LP) compressor (fan and booster) assembly, the LP compressor/intermediate case, the No. 4 bearing and combustion section, the High Pressure (HP) compressor, the HP turbine section, the LP turbine section and the accessory drives (gearbox).

Its compression system features a single stage fan, a four-stage booster, and a ten stage High Pressure Compressor (HPC). The Low-Pressure Compressor (LPC) is driven by a five stage Low Pressure Turbine (LPT) and the HPC by a two stage High Pressure Turbine (HPT). The HPT also drives a gearbox which, in turn, drives the engine and aircraft mounted accessories. The two shafts are supported by five main bearings. The engine incorporates a full authority digital Electronic Engine Control (EEC). The control system governs all engine functions, including power management. Reverse thrust for braking the aircraft after landing is supplied by an integrated system which acts on the fan discharge airflow. Borescope accesses are provided for inspection purposes.

Fuel system: The fuel system enables delivery of a fuel flow corresponding to the power required and compatible with engine limits. The system consists of two stage fuel pumps with low pressure and high-pressure elements, the Fuel Metering Unit (FMU), the engine Fuel Cooled Oil Cooler (FCOC), the Integrated Drive Generator (IDG), the fuel filter, the fuel distribution valve, the fuel flow meter, 20 fuel nozzles, the fuel diverter and return (to tank) valve.

Ignition system: The ignition system consists of two independent systems. Two high energy ignition exciters for which the energization is controlled by the EEC, two igniter plugs, and two coaxial shielded ignition leads. The purpose of the system is to produce an electrical spark to ignite the fuel air/mixture in the engine combustion chamber during the starting cycle on ground and in flight. to provide continuous ignition (manual or automatic selection) during take-off, landing and operation in adverse weather conditions. Continuous ignition will also be automatically selected when the EIU (Engine Interface Unit) is failed.

The air system includes primary, secondary (bypass) and parasitic (cooling and pressurizing) airflows and the systems used to control the airflow Engine Section

The airstream that flows through the engine supplies the propulsion airflow (secondary and primary airflow) or the ambient air to the air systems.

The nacelle section supplies cooling and ventilation air for engine accessories installed along the fan and core casing. The distribution and circulation of the air makes sure that the components do not exceed their temperature limits.

Engine control system: The throttle control system is fully electrical. The throttle control lever drives several position detectors. The position detectors are located under the cockpit center pedestal. Two of them are resolvers dedicated to the FADEC system. Each channel of the Electronic Engine Control receives the position signal from one resolver in the analog form.

The engine power management indicating is performed by means of:

-the ECAM system (upper and lower display units)

-the warning and caution systems.

The engine monitoring is carried out by means of:

-the EEC and the ECAM

- the vibration monitoring system with a display on the ECAM.

- the engine management main parameters (N1, EPR LIMIT, EPR THROTTLE, EPR MAX, EPR REF)

Each engine is equipped with a Reverser system which reverses cold fan air by means of translating sleeves and cascades, turning the engine airflow forward and providing a braking effect for the aircraft on the ground. Thrust reversers can be operated on the ground only.

The event engine was a V2527-A5 engine with Serial No. V16666.

1.6.3.2 High Pressure Compressor (HPC) Section:

The High-Pressure Compressor (HPC) in the IAE V2527-A5 series engine is a core component designed for high efficiency and reliability, featuring a 10-stage axial-flow design. The HPC is a key component of the V2527-A5, featuring 3D aerodynamics to improve handling, increase efficiency, and reduce core temperatures. The HPC features a drum construction for stages 3 to 8. The system includes 4 stages of variable stator vanes (VSVs) to improve starting and high-speed handling.

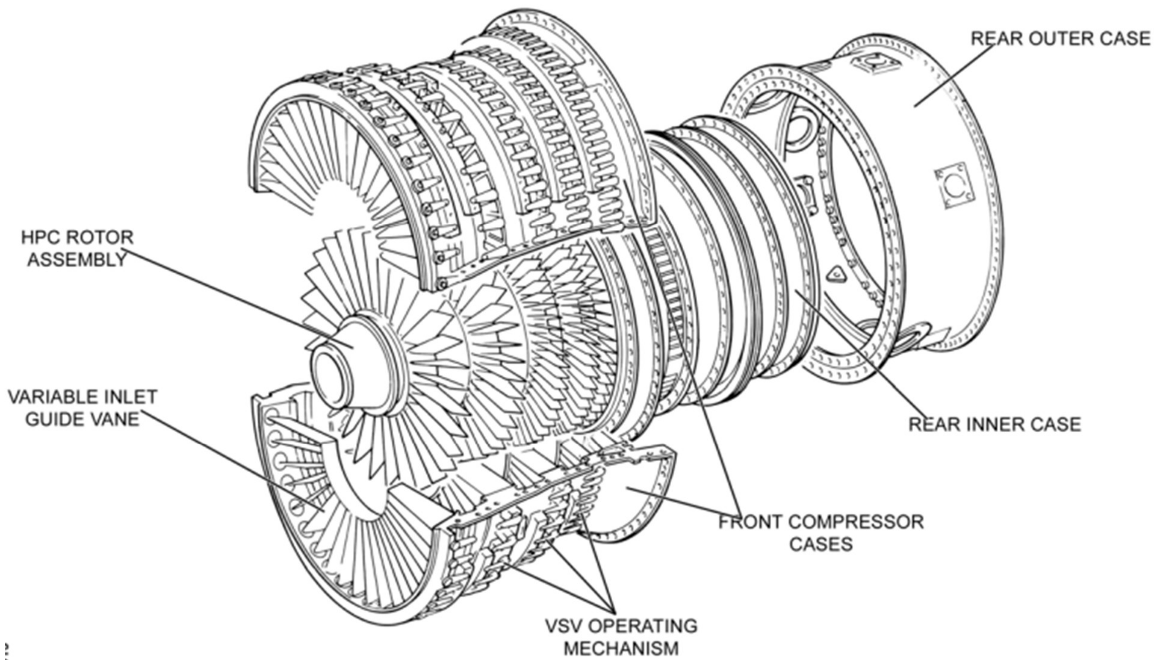

Figure 8: High Pressure Compressor (HPC) modules

The HP compressor assembly has a rotor assembly and stator case. The compressor stages are numbered from the front, with the first stage is stage being designated as stage 3 of the whole engines compressor system. Airflow through the compressor is controlled by variable inlet guide vanes (VIGV); variable stator vanes (VSV) and handling bleed valves.

The rotor assembly has five sub-assemblies

1. Stages 3 to 8 HP compressor disks
2. A vortex reducer ring.
3. Stages 9 to 12 HP compressor disks
4. The HP compressor shaft.
5. The HP compressor rotating air seal.

The five sub-assemblies are bolted together to make the rotor. The compressor blades in stages 3 to 5 are attached to the compressor disks in axial dovetail slots and secured by lock plates. The stages 6 to 12 compressor blades are installed in slots around the circumference of the disks through an axial loading slot. Lock blades, lock nuts and lock screws hold the blades in position.

The HP compressor stator case has two primary subassemblies, the HP compressor front and rear cases. Further, the HP compressor front case assembly has two split cases bolted together along the engine horizontal center line.

The front case assembly contains the VIGV's, the stages 3 to 5 VSV's and the stage 6 stator vanes. The front lower outer case provides a mounting for the VIGV and VSV actuator. The front case assembly is bolted to the intermediate case and to the rear outer case.

The HP compressor rear case assembly has five inner ring cases and an outer case. Flanges on the inner cases form annular manifolds, which provide stages 7 and 10 air offtakes.

The five inner cases are bolted together, with the front support cone bolted at the stage 7 case and the stage 11 case bolted to the rear outer case. The five inner cases contain the stages 7 to 11 fixed stator vanes. The rear outer case is bolted to the diffuser case and to the rear flange of the HP compressor front case. Access is provided in the compressor cases for borescope inspection of the compressor blades and stator

HP Compressor Drums - (Rotor)

The rotor assembly is in two-parts: The stage 3 to 8 drum The stage 9 to 12 drum and the two rotor drums are bolted together with a vortex reducer installed between the 8 and 9 stages. The vortex reducer straightens the stage 8 airflow, which passes to the center of the engine for internal cooling and sealing.

HP Compressor-Blades

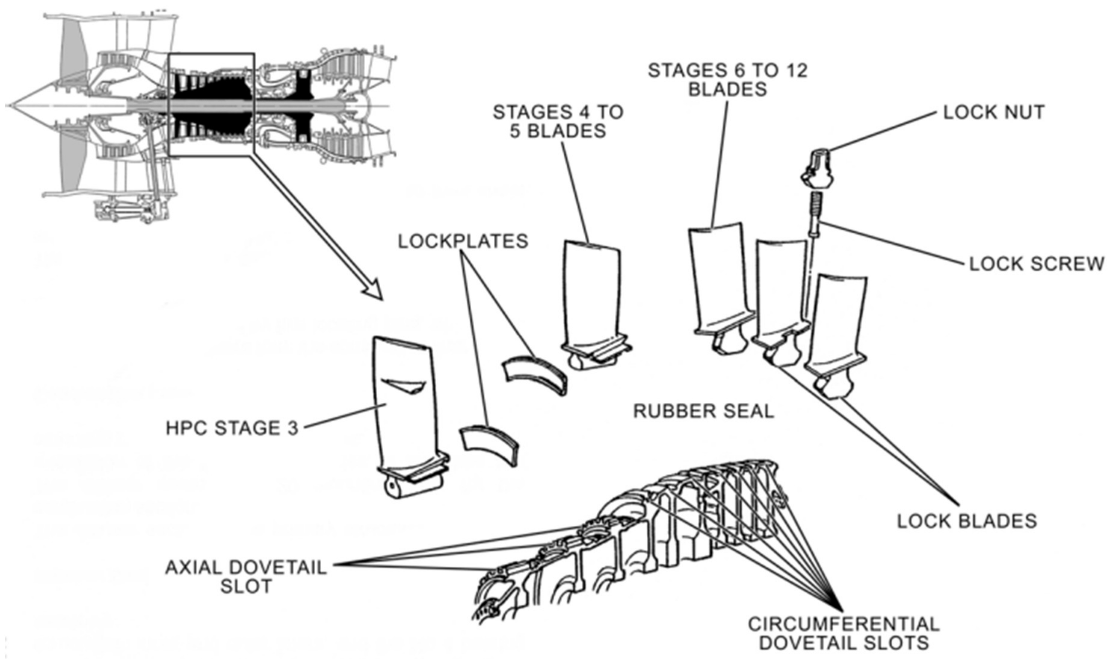

Figure 9: HPC Blades

The compressor blades in stages 3 to 5 are attached to the discs in axial dovetail slots and secured by lock plates. Rubber strips bonded to the underside of the platform seal gaps between the blades. The stages 6 to 12 are installed in a slot around the circumference of the discs. Each disc has one axial loading slot to enable the blades to be installed into the disc. Four lock blades are installed on each disc, two on each side of the loading slot, which are locked by lock nuts and jackscrews.

1.6.3.2.1 History of HPC 3rd Stage Blade fracture:

HPC 3rd Stage is the very first stage of HPC section. It contains total 31 rotor blades. The HPC 3rd stage blades are made up of titanium alloy Ti-6Al-4V. The part no. of HPC 3rd stage blades of the event engine is 6A8688.

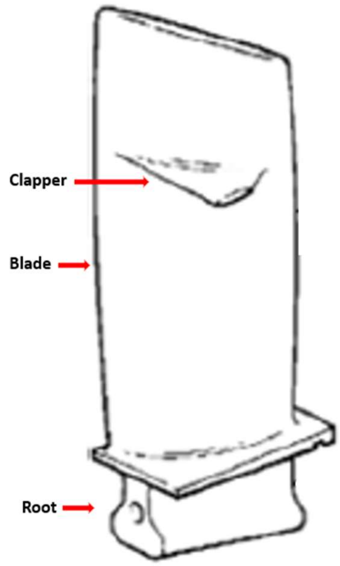

Figure 10: HPC 3rd Stage Blade

In 2005, clapper wear was identified as a major in-service issue affecting the HPC 3rd Stage Blade. This degradation led to rotor blade fractures. The fracture of the 3rd Stage HPC rotor blade ultimately resulted in engine failure. To address this issue OEM has issued a SB 72-0487. In addition to this OEM has also added inspections for clapper of the HPC 3rd stage blade after FOD or bird strike into its Aircraft Maintenance Manual (AMM Task 72-00-00-210-012).

In January 2005, Service Bulletin (SB) 72-0487 was released by the OEM. The relevant details of the Service Bulletin are given below:

a) **Service Bulletin number:**
SB V2500-ENG-72-0487.
b) **Reason/problem:**
Wear of the abutment faces of the HP Compressor Stage 3 Blade clappers may occur. In severe cases this can lead to premature fatigue deterioration of the blade. The problem has been attributed to a combination of high stresses and differential movements between adjacent clappers.
c) **Description:**
A revised HP Compressor Stage 3 Blade is introduced, similar to the existing item except for the following:
The clapper thickness has been increased at the intersection between the blade aerofoil and the clapper aerofoil.
The thickness of the clapper is increased by 0,50mm.
The length of the abutment face is increased to a minimum of 13,00mm.
The clapper radii have been reduced from 2,50mm to 1,00mm.

The incidence angle of the suction side clapper angle is reduced by 0.8 degrees relative to the engine axis and the pressure side angle is increased by 1.0 degrees.

d) Compliance:

Category Code 6

Accomplish when the sub-assembly (i.e., Modules, accessories, components, build groups) is disassembled sufficiently to afford access to the affected part and to all affected spare parts.

The event V2527-A5 engine (ESN V16666) embodied SB 72-0487 on production.

Later in year 2008, OEM had issued a new service Bulletin "**SB V2500-ENG-72-0561**" with heading as "***ENGINE - HIGH PRESSURE (HP) COMPRESSOR - V2500 SELECTONE PRODUCTION - HP COMPRESSOR UPGRADE***" for V2500 -A5 Series propulsion System. The background of this SB was "*The V2500 SelectOne is a committed programme to enhance the V2500 engine for improved time on wing, efficiency and durability. The package features an optimised aerodynamic and mechanical design of the HP compressor blades and vanes*".

The event engine (ESN V16666) was already complied with abovementioned SB 72-0561. Therefore, the part no. HPC 3rd stage blades of the event engine was 6A8688.

As per OEM's records, after release of SB 72-0487 in 2005, OEM has no records of HPC 3rd Stage blade fractures with SB 72-0487 incorporated, in which clapper wear/misalignment was identified as the root cause for engine failure prior to 2014. However, since 2014, there have been 57 High Pressure Compressor (HPC) 3rd-stage blade fracture events caused by High Cycle Fatigue (HCF) in V2500 engines that had already complied with both the Service Bulletin (SB) 72-0487 and SB 72-0561.

1.6.4 Engine Maintenance

1.6.4.1 Engine Installation/ Removal Details

Post incident, the maintenance records were scrutinized, and the installation/removal history of the involved engine is summarized in the table below:

Table 1: Engine Installation/ Removal History

Engine Model: V2527-A5
Engine Serial No: V16666

Operator/ Aircraft Reg.	Event	Date	Total Time	Total Cycles	Position	Model
IGO	New Engine Build	07-02-2013	00:00	0	-	V2527-A5
VT-IFM	Installed	04-03-2013	00:00	0	ENG01	V2527-A5
	Removed	19-08-2017	15913:00	10928		
IGO	Shop Visit	07-02-2018	15913:00	10928	N/A	V2527-A5
VT-IFM	Installed	14-02-2018	15913:00	10928	ENG01	V2527-A5
	Removed	20-10-2021	27030:48	16567		
VT-XXX	Installed	20-10-2021	27030:48	16567	ENG01	V2527-A5
	Removed	06-01-2022	27731:48	17031		
VT-XXX	Installed	06-01-2022	27731:48	17031	ENG02	V2527-A5
	Removed	28-03-2022	27736:47	17033		
M/S IndiGo / VT-IFM	Installed	28-03-2022	27736:47	17033	ENG02	V2527-A5
	Removed (Incident)	29-10-2022 (Post incident)	29603:43	18273		
	VT-XXX- Represents another aircraft's registration mark					
	IGO- Indigo and N/A- Not Applicable					

The V2527-A5 engine (serial no. V16666) installed at position # 1 on the A320 aircraft VT-IFM was removed/uninstalled on 19 August 2017 at 15913:00 hours (TSN) and 10928 cycles (Total) for shop visit. The reason for removal was "Combustor Distress beyond AMM Limits". Subsequently, the Engine V16666 was inducted in the engine Maintenance Repair Overhaul (MRO) shop on 17 October 2017 at 15913:00 hours (TSN) and 10928 (CSN). During the shop visit, several observations were made. The observations relevant to this investigation are presented below:

I. **Stage 3 Rotor Path (HPC Front Case Assembly)**

a) Significant in-service rotor path wear observed.
b) No indications of rotor path FOD / gouging damage observed.
c) Minor rotor path Top Coat (Abradable) degradation observed.

II. **VSV Stage 3**

a) Pad clearance measurements are within EM limits
b) Minor airfoil nicks/dents observed
c) No airfoil FOD observed
d) No vane leading edge erosion observed
e) No spindle wear observed

III. **Stage 3 Inner Seal Rings**

a) Minor seal ring path wear observed
b) All inner bushings present

IV. **Stage 3 Blades**

a) Minor airfoil nicks/dents observed
b) No airfoil FOD observed
c) Minor blade leading edge erosion observed
d) No blade tip curl observed
e) **Extensive clapper wear observed**

Figure 11: Extensive clapper wear

f) No blade tip rub observed
g) Installed blade set passed porcupine check for clapper wear
Actual Clearance: 0.308"
Engine Manual Limit: 0.140"
h) No significant blade root galling observed

V. **Stage 3 Locking Plates**

a) All locking plates present

During the shop visit, based on the engine incoming inspection findings, maintenance/rectification actions were performed.

In HPC 3rd Stage, all 31 blades were found to be beyond AMM limits. Hence, 21 blades were replaced with serviceable blade (New), whereas 10 blades were repaired in the shop. **But the OEM does not have much information about this.** The details of the work carried out on the HPC 3rd-stage blades are summarized in the table below.

Table 2: HPC 3rd Stage Blade Condition

PART OFF CONDITION								
ATA	**LID**	**PN**	**QPE**	**SV**	**IS**	**RS**	**REP**	**Defect**
72-41-15	724115-01-200	6A8688	31	0	21	0	10	See Disposition Table

PART ON CONDITION				
PN	**NEW**	**REP**	**SV**	**Information Only**
6A8688	21	10	0	V2500-ENG-72-0561

DISPOSTION TABLE				
Type	**PN**	**Qty**	**Defect Location**	**Defect Detail**
IS	6A8688	2	Root Bottom	Bent/Dented/Bowed
IS	6A8688	2	Slots/Windows/T/E	Bent/Dented/Bowed
IS	6A8688	15	Chord Width	Dimension Under Minimum
IS	6A8688	1	Flange	Dimension Under Minimum
IS	6A8688	1	Groove/Slot	Nick(s) Galled

On completion of maintenance task, V2527-A5 engine (ESN V16666) was tested and released to service with CA Form 1 dated, 07 February 2018. Post shop visit, V2527-A5 engine (ESN V16666) was initially installed on the aircraft VT-IFM on 14 February 2018, at 15913:00 Hours (TSN) & 10928 Cycles and was subsequently, removed on 20 October 2021 at 27030:48 Hours (TSN) & 16567 Cycles. Thereafter, M/s IndiGo had installed, utilized, and subsequently removed engine (ESN V16666) on two different aircraft, at different engine positions.

Later, the V2527-A5 engine (ESN V16666) was re- installed on the aircraft VT-IFM at 27736:47 Hours (TSN) & 17033 Cycles on 28 March 2022 at position no. 2. Post installation on the aircraft VT-IFM, the engine had accumulated 1866:56 hours and 1240 cycles till the incident flight. However, the V2527-A5 engine (ESN V16666) had accumulated 13690.43 hours, Time Since Last Shop Visit (TSLSV) and 7345 Cycle Since Last Shop Visit (CSLSV).

1.6.5. Post Incident Engine Inspection

On 28 October 2022, after incident based on the defect/snag entry made by the flight crew in the technical logbook, the involved V2527-A5 engine (ESN V16666) and aircraft's other components such wheels, brakes etc. were subjected to an in-situ inspection, to determine the serviceability of the event engine (V16666) and other aircraft's components based on the relevant AMM tasks.

During this inspection, all brakes were checked for overheating in accordance with the AMM Task 05-51-16-200-001-A. All Main landing Gear (MLG) tires were checked for flat spot and tire pressure were also measured. In accordance with AMM task 32-41-00-210-002A wheels were checked. Inspections outcome was satisfactory.

The event engine no. 2 (V16666) was also inspected by maintenance personnel. During the inspection the thrust reverser was found deployed, same was stowed in accordance with the AMM task 78-32-00-860-011. Further Inlet, exhaust and the Bleed Valves were examined. 7B handling Bleed valve and 2.5 Bleed valve exhaust were found damaged. Later Borescope Inspections (BSI) of LPC stages and HPC stages 3,6 & 7 and Combustion chamber were also carried out. BSI of engine no.2 revealed substantial damage in the HPC. Hence the event engine (ESN: V16666) was declared unserviceable. Later, the engine no. 2 was replaced with a Serviceable engine. The event V2527-A5 engine (ESN V16666) was removed from the aircraft VT-IFM on 29 October 2022, at 29603:43 hours (TSN) and 18273 cycles.

1.7 Meteorological Information

METAR recorded and issued by Indian Metrological Department situated at IGI Airport, Delhi (VIDP) for runway 28, between 1530 UTC and 1630 UTC on 28 Oct 2022 is given below:

Time (UTC)	1530	1600	1630
Wind (KT)	Calm	Calm	Calm
Visibility (M)	1500	1500	1500
Weather	FU	FU	FU
Clouds	NSC	NSC	NSC
Temp (℃)	24	24	24
Dew Point (℃)	17	17	17
QNH (hPa)	1014	1014	1014
Trend	NOSIG	NOSIG	NOSIG

1.8 Aids to Navigation

All navigational aids installed at IGI airport, Delhi and navigational equipment installed on the aircraft VT-IFM were serviceable. There were no navigational aids related issues or lapses relevant to this Serious Incident.

1.9 Communications

On 28 October 2022, while operating Flight no. 6E-2131, the aircraft VT-IFM was always in positive two-way communication with ATC Delhi. There were no communication related issues or lapses. While operating Flight no. 6E-2131, the aircraft was in contact with Delhi Ground on 121.9 MHz frequency till reaching the holding point. Subsequently, she switched over to tower/Approach Control on 118.1 MHz frequency. The transcript of relevant communication is placed below:

a) At 1553 UTC, the flight crew contacted Delhi Ground (on 121.9 MHz frequency) and requested for push back and engine start. The Ground controller acknowledged the request and informed the flight crew to expect 3-4 minutes delay.

b) At 1557 UTC, based on the flight crew's request, the Ground controller gave the push back and start up instructions *"IFLY TWO ONE THREE ONE FACING NORTH EAST ABEAM TWO ZERO THREE START UP APPROVED"*

c) At 1603 UTC, the flight crew requested Delhi Ground for taxi and, the Ground controller gave the initial taxi instructions as *"IFLY TWO ONE THREE ONE TAXI VIA NOVEMBER LINK THREE THREE KILO HOLD SHORT OF LINK THREE TWO"*.

d) At 1609 UTC, the Ground controller gave the subsequent taxi instructions *"IFLY TWO ONE THREE ONE CONTINUE TAXI VIA LINK 32 MIKE LINK THREE ZERO KILO JULIET SEVEN HOLDING POINT RUNWAY TWO EIGHT"*.

e) At 1614 UTC, upon reaching the holding point, the flight crew contacted Delhi Tower (on 118.1 MHz frequency). The Tower controller gave the lineup instruction as *"IFLY TWO ONE THREE ONE DELHI TOWER NAMASKAR LINE UP RUNWAY TWO EIGHT VIA JULIET SEVEN"*

f) At 1616 UTC, Tower controller gave the take -off clearance "*IFLY TWO ONE THREE ONE DELHI TOWER RUNWAY TWO EIGHT CLEARED FOR TAKE OFF WIND'S CALM"*

g) At 161716 UTC, other aircraft on the taxiway transmitted "*AIRCRAFT JUST TRYING TO TAKE OFF THERE SEEMS TO BE A FIRE COMING OUT FROM THE BACK PORTION OF THE AIRCRAFT CAN YOU GET IT CHECKED*" and informed Delhi tower regarding fire. The Tower Controller immediately transmitted "*IFLY TWO ONE THREE ONE DELHI TOWER CONFIRM MONITORED*" to enquire with the flight crew of the flight 6E-2131.

h) At 161753 UTC, the flight crew transmitted "*IFLY TWO ONE THREE ONE WE ARE STOPPING ENGINE FAIL STAND BY*" to inform ATC Tower about the rejected take-off and engine failure.

i) At 161857 UTC, ATC Tower transmitted "*FOLLOW ME THREE EXPEDITE REACHING HOLDING POINT RUNWAY TWO EIGHT ON WHISKEY"* to direct Follow Me towards runway 28 to provide assistance to the aircraft VT-IFM.

j) At 1621 UTC, in order to provide Follow Me assistance to the aircraft ATC Tower transmitted "*FOLLOW ME THREE DELHI TOWER AIRCRAFT CROSSING IMMEDIATE VACATION VIA RUNWAY PROVIDE THE GUIDANCE".*

k) At 1622 UTC, ATC Tower transmitted *"CFT SEVEN DELHI TOWER EXPEDITE REACHING HOLDING POINT NEAR WHISKEY"* to direct the CFT towards Runway 28 to provide assistance to the aircraft VT-IFM.

l) At 1623 UTC, ATC Tower transmitted "*FOLLOW ME THREE DELHI TOWER CONFIRM ANY FIRE IN ENGINE NUMBER TWO*" to confirm fire. Then the Follow Me Three responded "*SIR ONLY SMOKE OBSERVED"*

m) At 1624 UTC, the flight crew requested ATC tower "……. *SIR REQUEST IMMEDIATE VACATION AND CLOSEST BAY FOR US ".* Tower responded "ROGER *IFLY TWO ONE THREE ONE VACATE RUNWAY VIA KILO ONE.*

n) At 1626 UTC, the flight crew requested ATC Tower "*SIR WE WILL REQUEST IF THE FOLLOW ME WHICH IS NEXT TO US CAN ALSO CHECK IF THE TYRES ARE ALL RIGHT ON THE RIGHT SIDE IF THEYARE NOT DEFLATED*". ATC Tower asked Follow Me *"FOLLOW ME THREE CAN YOU CONFIRM THE SAME"*. However, Fire Tender reported *"FIRE TENDER CALLING SIR EVERYTHING APPEARS TO BE NORMAL SIR".*

o) Aircraft taxi on its own power (single engine) and parked at the assigned bay. At 1638 UTC, the Follow me reported to ATC Tower "*SIR AIRCRAFT FULLY PARKED ON STAND ONE SEVEN EIGHT".*

1.10 Aerodrome Information

1.10.1 General

Indira Gandhi International (IGI) Airport is operated by Delhi International Airport Limited (DIAL) and AAI maintains Communication, Navigation and Surveillance (CNS) & Air Traffic Management (ATM) services at the airport. The IATA location identifier Code is DEL and ICAO location identifier Code is VIDP.

Airport Co-ordinates: -

Latitude: 28°34'07" N

Longitude: 77°06'44" E.

Airport Elevation (AMSL): 237 m/777 ft

The detail of runway 10/28 is as below:

Runway	TORA(M)	TODA (M)	ASDA (M)	LDA (M)	WIDTH (M)	RESA (M)	Elevation
10	3813	3813	3813	3813	45	240 x150	721 feet
28	3813	3813	3813	3813	45	240 x150	778 feet

1.11 Flight Recorders

Immediately after this Serious Incident, both Solid State Cockpit Voice Recorder (SSCVR) and Solid-State Flight Data Recorder (SSFDR) were downloaded, and readout was carried out.

1.11.1 DFDR Recording

The downloaded DFDR data was analyzed and the relevant events recorded in the DFDR are as given below: -

a) At 160056 UTC, ENG1 ML-ON (Master Lever at ON position), ENG2 ML-off (Master Lever at off position), TLA1 (-2.81), TLA2 (-2.81), N11 & N12 at 3.4 and N21 & N22 at 5.6. Engine no.1 switched ON.

b) At 160218 UTC, ENG1 ML-ON, ENG2 ML-off, TLA1 at (-2.81), TLA2 at (-2.81) N11 started increasing from 3.4 to 4.5. N12 increases from 25 to 25.3, N12 at 3.4 and N22 at 5.6. This indicates number 01 engine's N1 started building up.

c) At 160506 UTC, ENG1 ML-ON, ENG2 ML-off, TLA1 at 5.63, TLA2 at (-2.81), N11 at 35.5, N21 at 72.1 and GSC at 4. This indicates commencement of taxi.

d) At 160849 UTC, ENG1 ML-ON, ENG2 ML-ON, TLA1 at (-2.81), TLA2 at (-2.81), N11 at 23.6, N12 at 3.4, N21 at 60.4 and N22 at 0 and GSC at 11. Engine no. 2 switched ON.

e) At 161651 UTC, True Heading 283, GSC at 4, TLA1 at 8.44, TLA2 at 8.44, N11 at 35.5, N12 at 40.4 N21 at 75, N22 at 75.1. This indicates commencement of take-off roll.

f) At 161704 UTC, True Heading 286, GSC at 46, TLA1 changed from 33.75 to 30.94, TLA2 changed from 33.75 to 30.94, N11 at 82.1, N12 decrease from 52.9 to 30.5, N21 changes from 89.6 to 89.4, N22 decreases from 89.1 to 78.9, FF1 decreases from 3431 to 3416 and FF2 decreases from3500 to 2440, EGT1 changes from 499 to 500, EGT2 changes from 511 to 515, EPR1 was at 1.3 & EPR _CMD_1 was at 1.281, EPR2 was at 0.99 & EPR _CMD_2 was at 1.281, **ENG2 N1 & N2 both vibration started increasing from 0 to 0.2**

g) At 161705 UTC, True Heading 288, GSC at 46, TLA1 changed from 30.94 to (-19.6), TLA2 changed from 30.94 to (-16.8), N11 at 78.8, N12 decrease from 30.5 to 21.4, N21 changes from 89.4 to 89.8, N22 decreases from 78.9 to 73.1, FF1 decreases from 3416 to 2613,

FF2 decreases from 2440 to 370, EGT1 at 500, EGT2 changes from 515 to 519. **ENG2 stall warning triggered.** EPR1 was at 1.24 & EPR _CMD_1 was at 1.281, EPR2 was at 0.99 & EPR _CMD_2 was at 1.281, **ENG2 N2 vibration further increased from 0.2 to 5.2 and kept on increasing, it reached up to 7.6 (at 161710 UTC).**

h) At 161708 UTC, True Heading was at 282, GSC at 43, TLA1 was at (-8.44), TLA2 was at (-8.44), N11 was at 63.9, N12 was at 11.8, N21 was at 81.5, N22 was at 61.6, FF1 was at 1633, **FF2 was decreased quickly to 254**, EGT1 at 503, EGT2 was at 531. EPR1 was at 1.03 & EPR _CMD_1 was at 1.281, EPR2 was at 0.99 & EPR _CMD_2 was at 1.281. ENG1 Oil Prs was at 222 and ENG2 Oil Prs at 126, Which decreased sharply to ‘0’ at 161811 UTC.

i) At 161708 UTC, ENG2 ML-off. Engine no. 2 was switched off.

The above-mentioned data are elaborated further with the help of two self- explanatory Graphs i.e., Graph 1 and Graph 2.

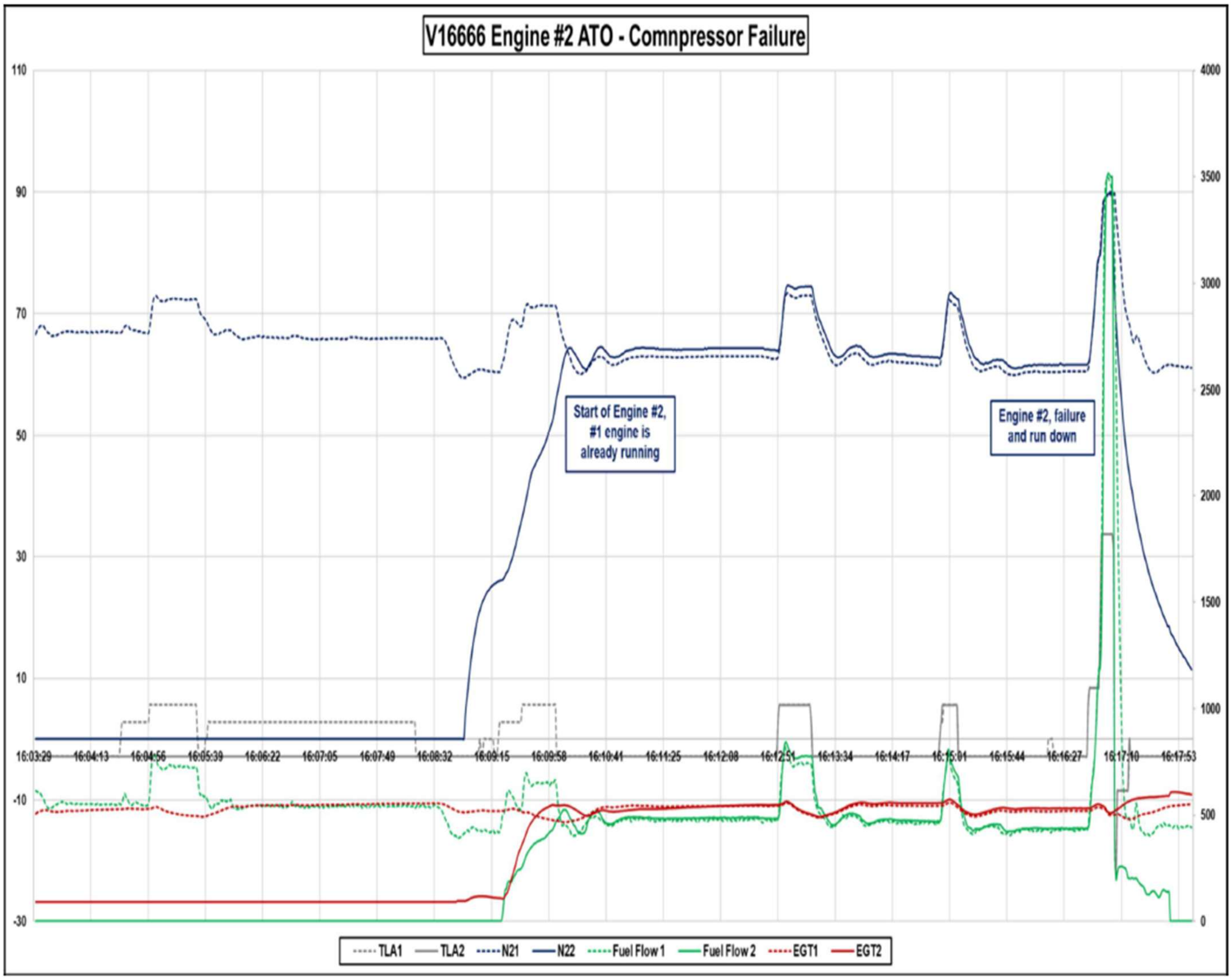

Figure 12: Graph 1

In Graph 1, the engine no. 2 starts up point is shown as thick gray lines. The High spool speed N22 of engine no. 2, shown as thick Navy-Blue line rises more than 60% before it got almost stabilized at around 65%. It also depicts the engine no. 2 failure point and run down.

In Graph 2, plot near the engine no. 2 failure event is enlarged to give more clarity. Few crucial engine no. 2 parameters were also added such as EPR shown as thick yellow line, EPR CMD shown as thick brown line. Enlarged plots gives more precision about the changes occurred in some significant engine parameters such as N22, Fuel, EPR and EPR CMD.

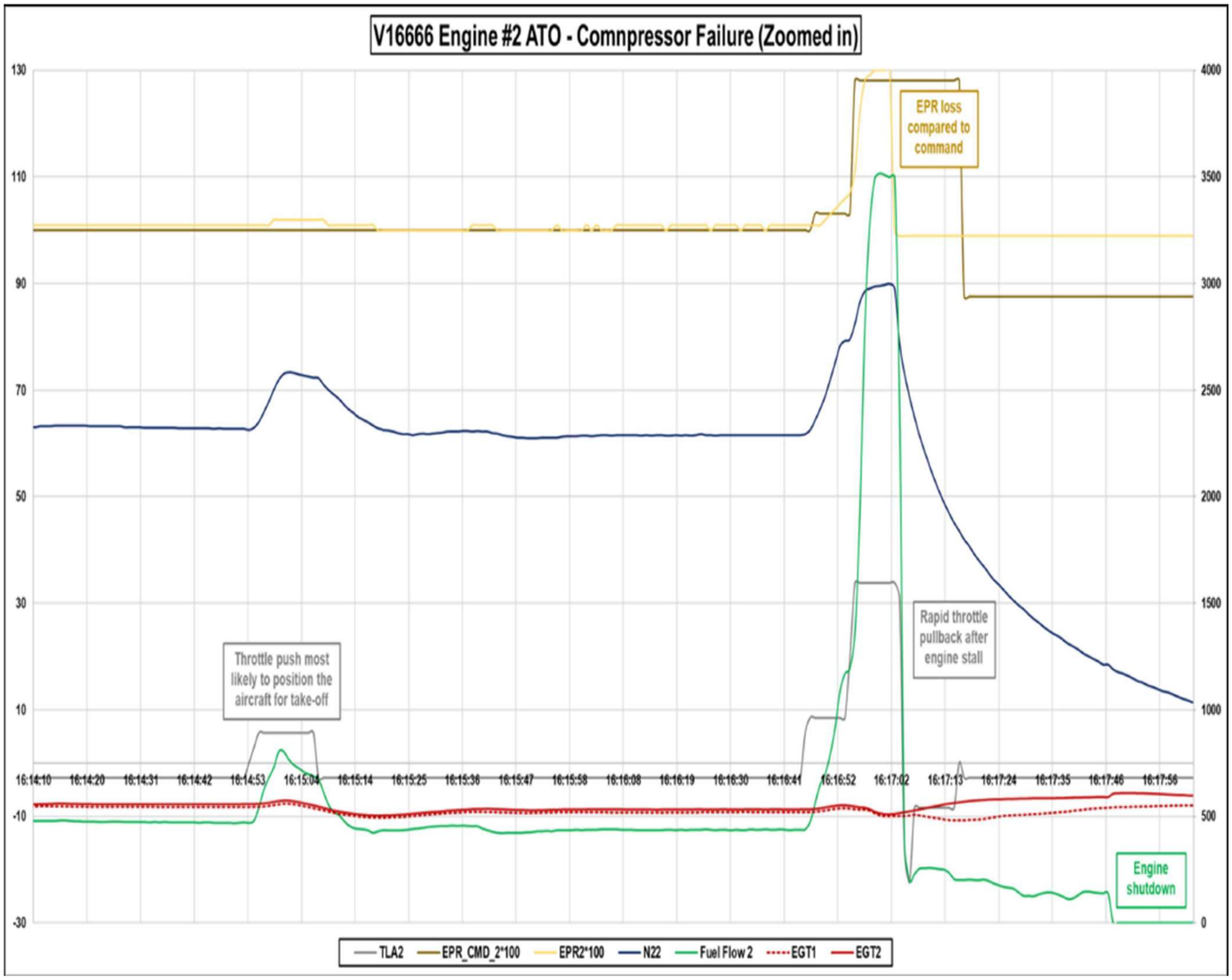

Figure 13: Graph 2

During the investigation DFDR data was shared with the OEM for comments. The OEM has provided a brief DFDR analysis (with above two graphs). As per OEM's DFDR analysis "***No Significant observations (engine parameters) were seen prior to the event***". It is also stated that *"**There are no engine parameters identified as precursors to the event**"*.

The analysis of DFDR also revealed that the throttles were pushed forward to initiate the take-off at 16:16:45 UTC. The engine no. 2 (V16666) event occurred at 16:17:03 UTC, The Flight crew immediately pulled back the throttles for rejecting the take-off at 16:17:05 UTC. During the event, loss of EPR against the CMD EPR noticed on the engine no. 02, followed by a sharp decrease in the Fuel Flow and N22. The loss of EPR against the CMD EPR, followed by decrease in Fuel Flow and N22 indicates engine no. 2 failure.

1.11.2 CVR Recording

The CVR readout was analyzed, some salient points are given below:

- The flight crew started engine no. 1, first.
- While taxiing, the flight crew started engine no. 2 approximately seven minutes after engine no. 1 was started.
- The flight crew had carried out the checklists, as when it was required such as pre-flight, taxi, line-up, take-off etc.
- The flight crew initiated the take-off, only after obtaining take-off clearance. A few seconds later a loud thud sound was heard by the flight crew.
- The Flight crew put master of engine no. 02 to off position.
- Both Flight crew the considered engine no. 02 as damaged engine and pressed the engine fire button and discharged the agent no.1 (engine fire extinguisher).
- The Flight crew followed the FCOM and performed the checklists.
- The Flight crew reviewed the prevailing emergency situation by enquiring another aircraft who saw the fire.
- The Flight crew also informed that assistance for runway vacation is required. However, evacuation might not be required.

1.12 Wreckage and Impact Information

Nil

1.13 Medical and Pathological Information

Both flight crew had undergone the preflight medical examination (Breath Analyzer Test) at Chennai, to ascertain the non-consumption of alcohol and other psychoactive substances before departure as per requirement of CAR Section 5, Series F, Part III. The test result was satisfactory.

1.14 Fire

There was no fire on the aircraft. However, due to engine no. 2 failure, for some time fire was observed coming out of the engine no. 2 exhaust area. As per another aircraft fire was observed coming out of the engine no. 2 exhaust area. In accordance with the applicable Flight Crew Operating Manual (FCOM) “Abnormal and Emergency procedures” flight crew handled the situation and on anticipating damage in the engine no.2 (ESN V16666), engine fire extinguisher was used. Relevant extract of FCOM is appended below:

A318/A319/A320/A321 FLIGHT CREW OPERATING MANUAL	PROCEDURES ABNORMAL AND EMERGENCY PROCEDURES ENG

ENG 1(2) FAIL (Cont'd)

Ident.: PRO-ABN-ENG-BJ-00017667.0003001 / 04 JUN 19

L2 An engine flame-out may be recognized by a rapid decrease in EGT, N2, FF, followed by decrease in N1 for CFM engines, or EPR for IAE engines.

The flight crew can suspect an engine damage if the flight crew observes two or more of the following symptoms:
- Rapid increase of EGT above the red line
- Important mismatch of the rotor speeds, or absence of rotation
- Significant increase of aircraft vibrations and/or buffeting
- Hydraulic system loss
- Repeated or uncontrollable engine stalls

L1 **LAND ASAP**

■ **Before takeoff or after landing:**

THR LEVER (AFFECTED ENGINE).. IDLE
ENG MASTER (AFFECTED ENGINE).. OFF

■ **IF DAMAGE:**

ENG FIRE P/B (AFFECTED ENGINE).. PUSH
AGENT 1.. DISCH

■ **IF NO DAMAGE:**

L2 For CFM engines, if conditions permit, do not restart the engine. A new engine start would erase FADEC troubleshooting data.

L1 ENG (AFFECTED) RELIGHT.. CONSIDER

L2 *If no damage, a new start sequence may be initiated.*

L12

ASSOCIATED PROCEDURES

ENG 1(2) SHUT DOWN

Apply the ENG SHUT DOWN procedure (Refer to PRO-ABN-ENG ENG 1(2) SHUT DOWN), if damage or if engine relight is unsuccessful.

L1 ■ **In flight:**

ENG MODE SEL.. IGN

L2 *Selection of continuous ignition confirms the immediate relight attempt made by the FADEC.*

L1 THR LEVER (AFFECTED ENGINE).. IDLE

Continued on the following page

Figure 14: Relevant extract of FCOM

1.15 Survival Aspects

The Serious Incident was survivable. Passengers were deboarded normally from the aircraft on the bay.

1.16 Tests and Research

1.16.1 Tear Down Inspection of the Engine

Post incident the damaged engine (ESN V16666) was removed from the aircraft and was sent to an OEM's approved engine Maintenance Repair and Overhaul (MRO) shop for defect investigation.

The event engine (ESN V16666) was inducted in the engine MRO shop for disassembly and detailed examination. During the engine examination the following relevant observations were made:

a) FEGV (Fan Exit Guide Vanes) two panels removed –no notable/visual damage observed.
b) **Bleed Valves**: All valves were found packed with heavy debris. 7B Bleed Valve was found burnt through silencer/diffuser.

Figure 15: Bleed Valve7B

c) **LPC:** Heavy damage was observed to 2.5 blades and 2.3 vanes from VIGVs. Large amount of metal debris was found in 2.5 bleed and in 2.5 bleed path.

Figure 16: Damages in LPC 2.5 Blade (LH) and in LPC 2.5 vanes (RH)

d) HPC: Substantial damage observed in the HPC

Figure 17: Damaged HPC all Stages

i. VIGV levers were found bent and several lever bushings were found broken and missing. VIGV many levers were found disengaged from the unison rings. Majority of the VIGV were found missing and debris in the 2.5 bleed and LPC.

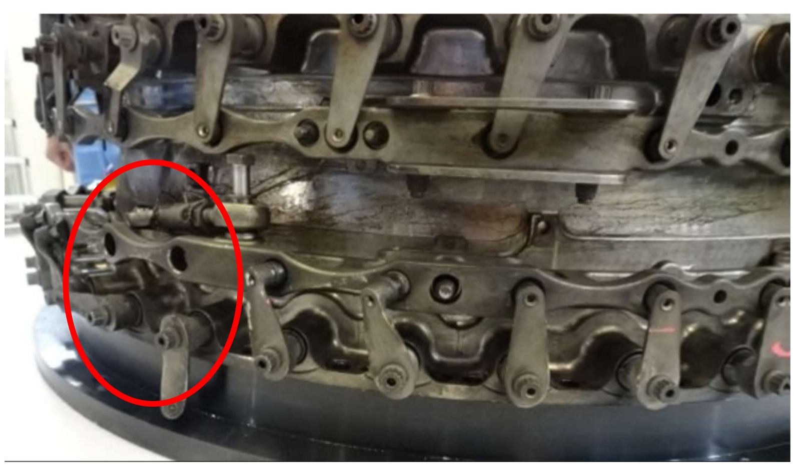

Figure 18: Deformed Lever arms of VIGV

ii. VSV HPC 3rd stage levers were found bent with many lever bushings broken and missing and disengaged from unison ring.

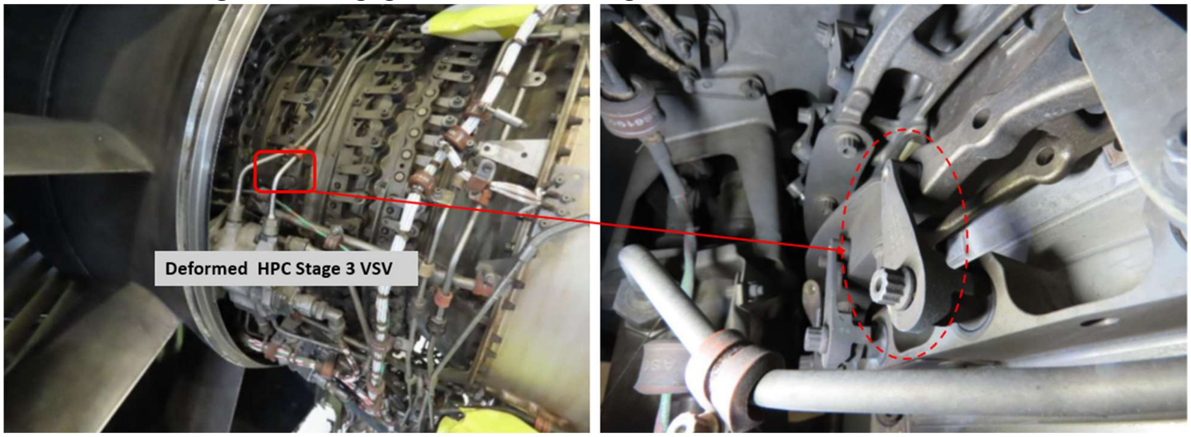

Figure 19: Damaged HPC 3rd Stage VSV

iii. One HPC 3rd stage blade was found with below platform fracture (#1). Both pieces recovered. Five HPC 3rd stage blade fracture above platform. Only 11 VIGV were found whereas, all others were missing. All HPC vanes were found damaged.
iv. Majority of the VIGV were missing and their debris was in the 2.5 bleed and LPC.
v. HPC rear case seems to be deformed.
vi. All blades' platforms of HPC 4-12 stage were found.
vii. Starting around HPC 5th stage thermal damage can be observed.
viii. In HPC 5-11 Stage, vanes were found with no airfoils remain.
ix. In HPC 3rd stage, 1 lock plate was found missing.
x. Possibly One retaining plate found in gas path.

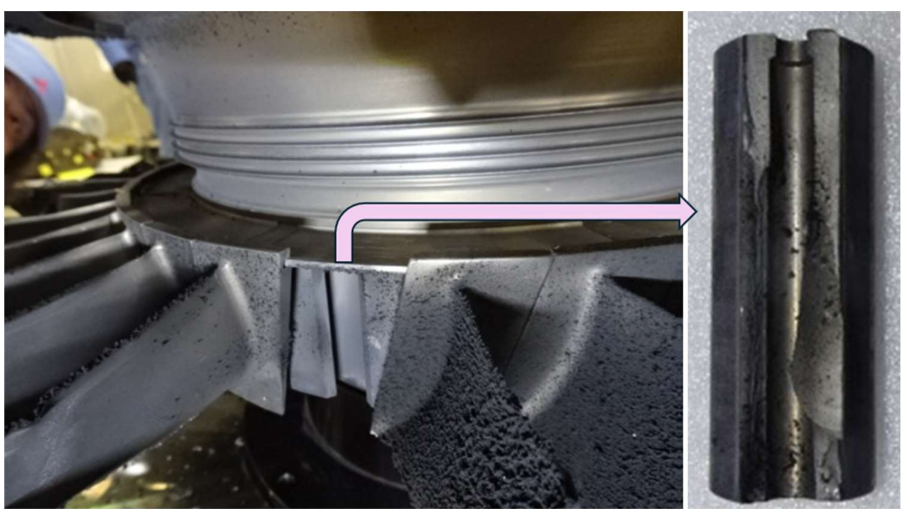

Figure 20: Damage HPC 3rd Stage

xi. In HPC 3rd stage, blade tips missing above platform damage nicks, dents, tears.
xii. In HPC 3rd stage, leading edge and trailing edge damaged (nicks, dent, tears)
xiii. In HPC 3rd stage, all clappers damaged. Clappers cracked, broken, missing material. Clapper contact wear.

xiv. No major damage is found at combustion Chamber and NGV Modules. Metal Debris-melted welds are adhering at some location of these Modules

xv. No major damage is found at HPT. Metal Debris-melted welds are adhering at some location of HPT

xvi. No major damage is found at LPT. Metal Debris-melted welds are adhering at some locations of LPT Stage 3.

1.16.1.1 Inference drawn of the engine examination:

a) N1 and N2 do not rotate freely. Blue light inspection revealed only small indications of animal remains on the concave side. It is highly unlikely that a bird was ingested to initiate this event.

b) Major damage of LPC Stage 2.5 Blades and Vanes are found. Many metal debris are found around LPC Stage 2.5. These debris are suspected as HPC VIGV. It seems that the VIGV surged at the HPC and flowed back to the LPC Stage 2.5

c) All Airfoil (Stage 3 to Stage12 of HPC) are majorly damaged and some airfoils are missing. Metal Debris-melted welds are adhering to most of all over the HPC Module area as checked visible area by borescope. Many debris are especially found at around area of HPC Stage 12. Fallen shroud is found at around HPC Stage 7 to 8.

d) Based on damage assessment of the event engine (ESN V16666) and previous history of HPC Stage 3 blade failure events, the following comments can be made:
   - Major damage in 2.5 are consistent with secondary damage as noted by HPC metal debris found in this area.
   - Damage on the HPC is consistent with a stage 3 blade fracture as the primary damage.
   - Damages on stages 4-12 are consistent with secondary damage. Compressor rapid oxidation, and blade decobbing stages 6-12 are known outcomes of HPC stage 3 blade fracture.

e) All other areas of the engine show hardware typical of service run.

1.16.2 Metallurgical testing of HPC 3rd stage associated hardware

During the engine examination at OEM's approved engine Maintenance Repair and Overhaul facility, certain engine parts of HPC of the V2527-A5 engine (ESN V16666) were identified and segregated for further laboratory testing. These includes the HPC Blades, Vanes, variable inlet guide vanes (VIGVs), HPC VIGV levers, and multiple bags containing various HPC blade and vane pieces. The purpose of this testing was to establish the cause of damage sustained by the High-pressure compressor (HPC) 3rd stage blades and vanes. The above-mentioned parts and debris were subsequently sent to the NTSB laboratory for metallurgical testing.

These parts were extensively examined using various methods and technologies such a scanning electron microscope (SEM), the Keyence VHX-7000 optical microscope etc. Some items were also sent to a research institute to determine the residual stresses. During the laboratory examination, the following observations were made:

1.16.2.1 HPC 3rd Stage Blade:

a) HPC 3rd stage blades had been labeled from 1 to 31 in a clockwise direction as viewed forward looking aft. Blade 1 shown in figure 21 was fractured in the blade root below the platform. The dovetail piece of the blade was recovered from its respective disk slot, and

Figure 21: Blade no. 1 showing the dovetail piece and mating piece with the platform and airfoil root (upper image) and the root end face of the dovetail (lower image).

a battered mating piece shown in below figure 21 was recovered during the engine teardown. The root end face markings for blade 1 are shown in the lower image in figure 21. The blade was marked with part number 6A8688 and manufacturer code D0272. The blade was also marked with repair codes VRS 6236 and VRS 6616, indicating the clapper coating was replaced and damaged or worn clapper abutment faces were repaired by welding, respectively. Triangle repair codes 1, 2, 4, and 6 indicate vibro polishing to restore the surface finish, glass/ceramic bead peening the airfoil to restore peened surface condition, restoration of dry film lubricant on the dovetail, and shot peening the root to restore fatigue strength, respectively. Additional alphanumeric markings included FNZK-26 and AJ.

b) The remaining blades labeled 2 through 31 as shown in figure 22 were damaged in the airfoil region above the platform. Blade 14 was fractured through the chord just above the platform, and blades 2, 5, 6, 15, and 26 were fractured near midspan.

Figure 22: *concave side (upper image) and convex side (lower image) of the HPC 3rd stage blades 2-31 positioned consecutively. LE- Leading edges and TE- trailing edges.*

c) The fracture surface for blade 1 had scattered black deposits on the surface in the as-received condition shown in figure 1. The deposits were cleaned. Views of the fracture surface on blade 1 after cleaning are shown in figure 23 (A1). The fracture intersected a cylindrical cavity extending longitudinally through the blade root. Portions of the fracture surface on each side of the cavity had relatively smooth features with curving crack arrest lines, **features consistent with fatigue**. The fatigue region on the concave side of the dovetail is shown in the middle image in figure 23 (A2), and the fatigue region on the convex side is shown in the lower image in figure 23 (A3). The fatigue region extended along approximately ¾ of the concave side and ¼ of the convex side to the respective boundaries indicated with dashed lines in figure 23 (A2&A3). On the concave side, the fatigue features emanated from a primary origin located at the convex side surface approximately 0.266 inch away from the leading edge. Multiple secondary origins were also observed along the surface at location indicated with unlabeled arrows in the lower image in figure 23 (A3). On the convex side, multiple origins were located at the interior cavity surface near the leading edge. The location of the origins and fractographic features on the convex side were consistent with secondary fatigue crack initiation following cracking on the concave side.

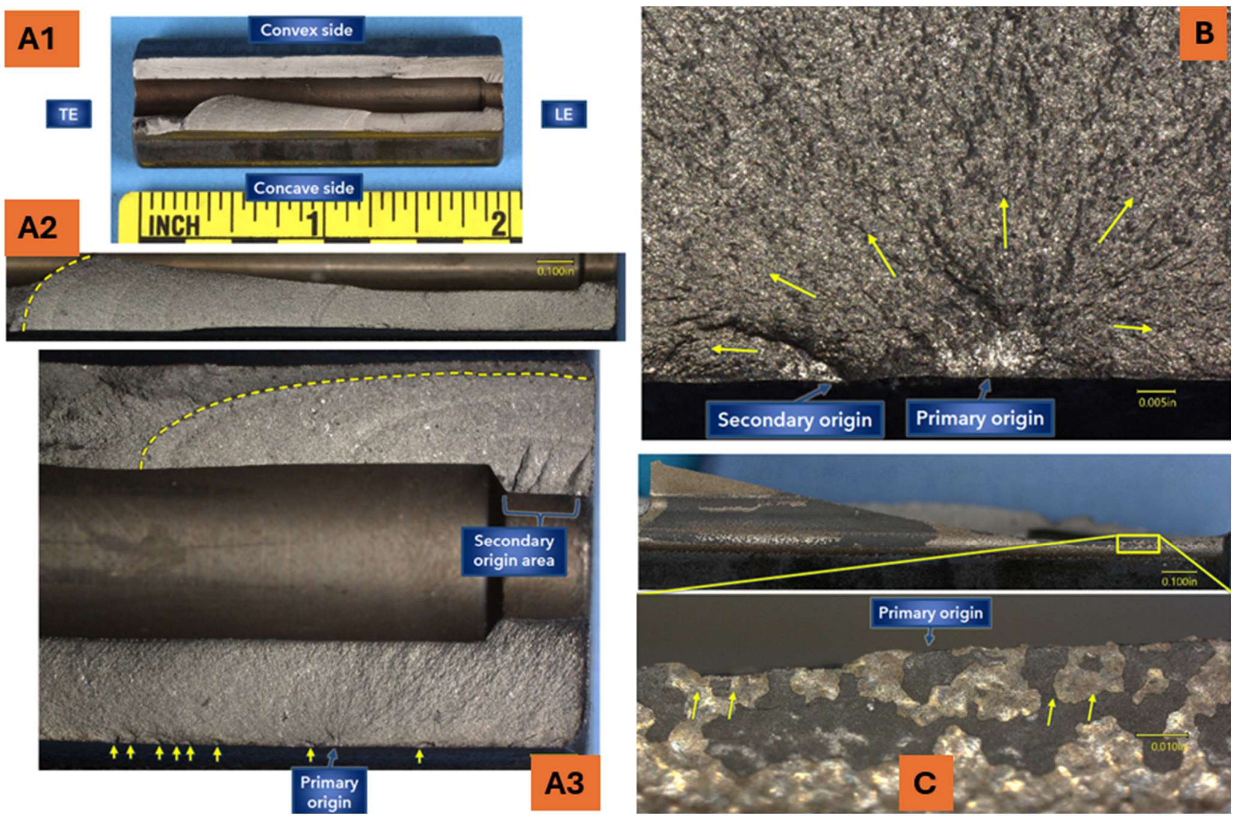

Figure 23: A1- Fracture surface of blade 1 (upper image, A2- closer views of the fatigue region on the concave side (middle image) and A3-origin areas at the leading end of the dovetail (lower image). B- the primary origin area on the blade 1 fracture surface. C- Surface adjacent to the primary origin area showing a peened surface finish

d) A closer view of the primary origin on the concave side of the fracture is shown in figure 23 (B). A secondary origin near the primary origin is also shown. Radial features oriented parallel to the crack growth direction were observed emanating from the primary origin area, and unlabeled arrows indicate the directions of local crack propagation based on these features. Near the origin areas, the fracture surface had a more reflective appearance in the optical imaging shown in figure 23 (B).

e) The concave-side surface of the dovetail adjacent to the fracture is shown in figure 23(C). The dovetail surface had a dimpled appearance consistent with a shot peened finish. The fatigue origin was located 0.350-inch outboard of the root end face in the dovetail radius, which is outboard of the disk slot face contact region of the dovetail. Secondary cracks were observed on the surface adjacent to the primary origin at locations indicated with unlabeled arrows in the lower image in figure 23(C). Additional secondary cracks were also observed adjacent to the fracture surface closer to the leading edge.

f) Next, the fracture surface was examined using a scanning electron microscope (SEM). A montage of images stitched together to present an overall view of the leading end of the fracture surface on the convex side of the dovetail is shown in the upper image in figure 24 A. Rectangular areas that appear darker in the montage represent areas where more detailed images of fracture features were obtained, such as those shown in the lower images in figure 24(B) and in figures 24 (D) and 25.

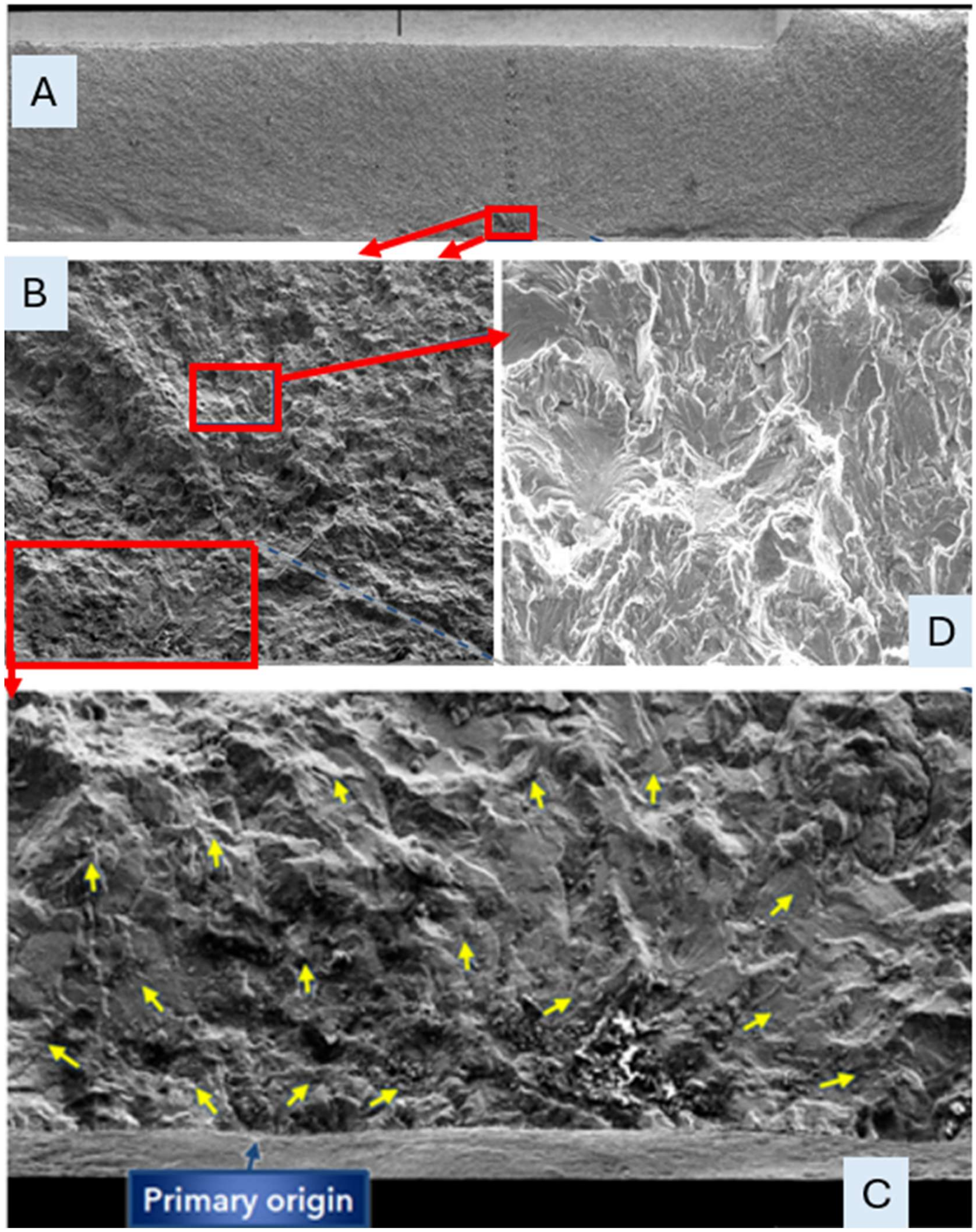

Figure 24: A & B -Montage SEM images of the fatigue region on the blade 1 concave-side fracture surface showing the leading end. C- closer views of the primary origin area. D- SEM image of fatigue fracture features.

g) Closer views of the primary origin area are shown in the middle and lower images in figure 24 (B&C). The origin area was partly obscured with nonconductive surface deposits that remained adherent on the surface after cleaning. However, most of the origin area was visible for examination. The origin area had feathery features consistent with fatigue propagation on varied planes and growth orientations consistent with crystallographic influence from individual grains. Unlabeled arrows in the lower image in figure 24 (c) show local directions of crack propagation emanating from the primary origin located at the blade surface as indicated.

h) Within approximately 0.013 inch of the origin, the fracture surface had a mostly faceted feathery appearance with limited areas showing striations. A view of typical fracture features in this area near the origin is shown in figure 24 (D). Further from the origin, fracture features transitioned to more areas showing striations, and mostly striations were observed at a distance of 0.018 inch. The fatigue striations were observed on varied planes and growth orientations consistent with crystallographic influence from individual grains, and figure 25(A) shows typical fatigue features observed in this region. At deeper crack depths, fine striations were observed between more prominent crack arrest lines such as the area near the fatigue boundary shown in figure 25(B).

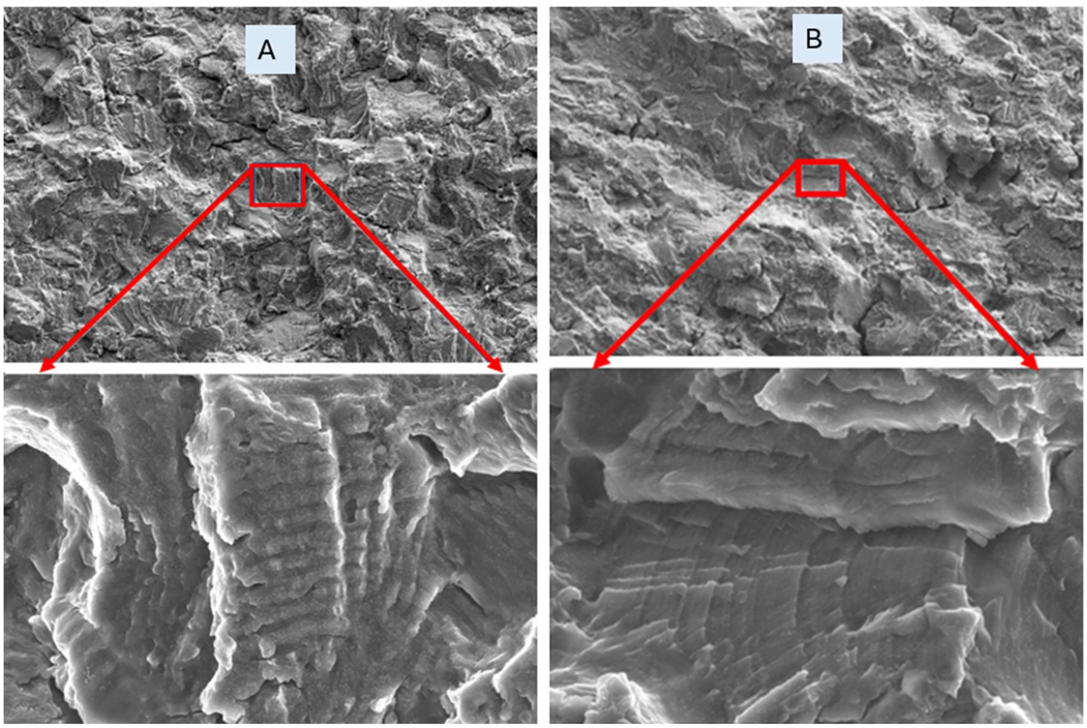

Figure 25: *A & B- SEM image of fatigue fracture features* approximately 0.0358 inch and 0.563 inches away from the primary origin respectively

i) The primary origin area was partly obscured by non-conductive deposits that remained on the surface after cleaning. However, several of the secondary origins were free of deposits. The origin areas showed feathery trans granular features emanating from the blade surface such as the image of a typical secondary origin shown in figure 26.

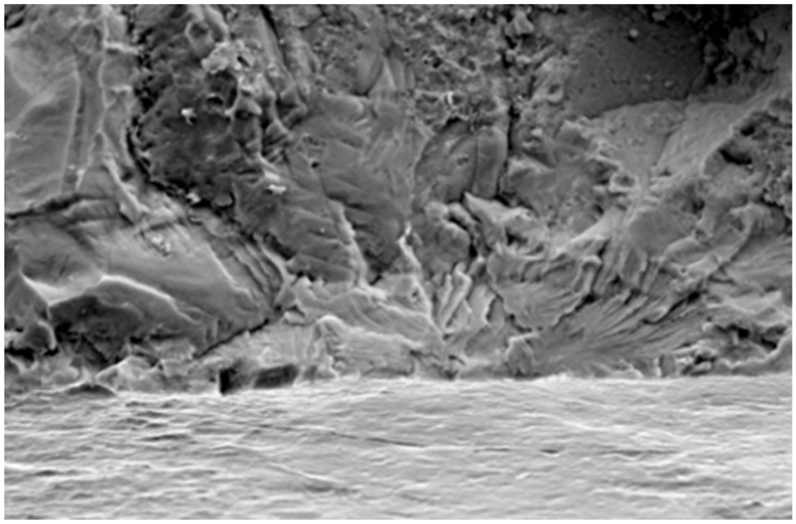

Figure 26: SEM image of a secondary origin area

j) Views of the disk slot contact faces for the blade 1 dovetail are shown in figure 27 (A&B). The contact face showed patches of areas with relatively reflective features with underlying darker areas associated with disk slot contact where the surface appeared smeared slightly in the radial/chordwise orientation. Gold-colored areas consistent with relatively undisturbed surfaces were present between the darker patches. The smearing and darker patches were more prominent on the convex side shown in the lower image in figure 27 (B).

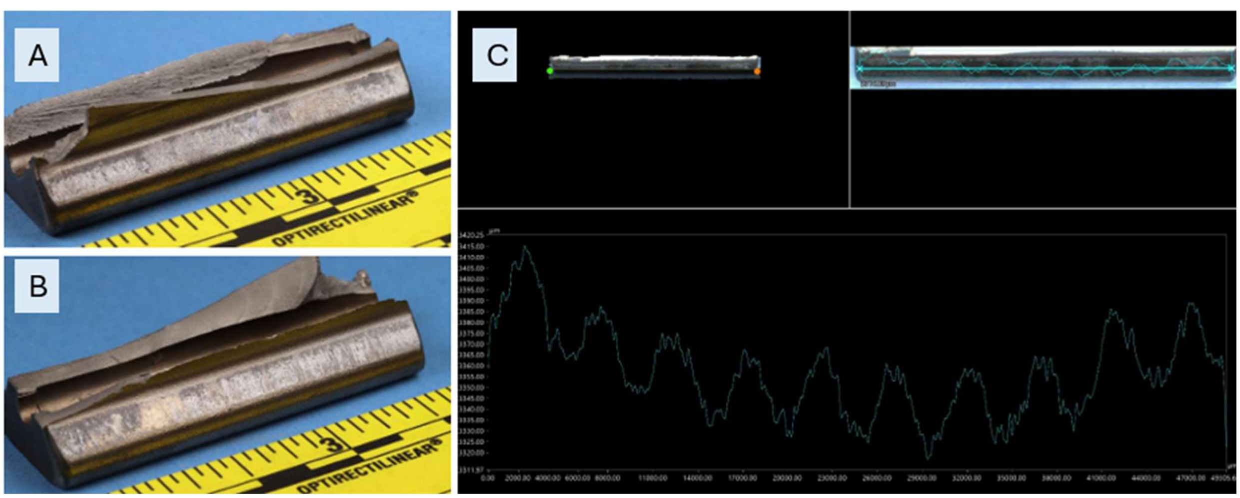

Figure 27: Oblique views of the blade 1 dovetail piece showing the concave-side (A-upper image) and convex-side (B-lower image) disk slot contact faces. C - Relative vertical height map along a longitudinal trace of the concave-side contact face on blade 1 acquired using a Keyence VHX-7000 optical microscope

k) Vertical height maps were obtained on the dovetail contact surfaces using an optical microscope set with a 40x objective lens. The relative height profile along a linear trace near the middle of the contact face was then obtained on each contact face. The resulting trace for the concave-side contact face is shown in figure 27(C). A relative height profile with similar features was obtained on the convex-side contact face. The height profiles for each flank of the dovetail showed 10 evenly-spaced relative peaks between the leading and trailing edges of the blade dovetail. The peaks generally corresponded to areas associated with the patches of radial/chordwise smeared surface features.

l) A transverse cut was made through the blade 1 dovetail at the location of a secondary origin on the fracture surface to prepare a metallographic cross-section. The secondary origin selected for the metallographic examination was located closer to the leading edge relative to the primary origin (arrow to the right of the primary origin as viewed in figure 23). The sectioned piece was then mounted in a metallographic mount, polished, and then etched using Kroll's reagent.

m) In figure 28, an overall view of the microstructure adjacent to the fracture surface at the concave side of the cross-section is shown in the upper image, and a closer view of typical microstructural features is shown in the lower image. The microstructure consisted of alpha grains (appearing white) intermixed with areas of alpha plus beta (appearing darker).

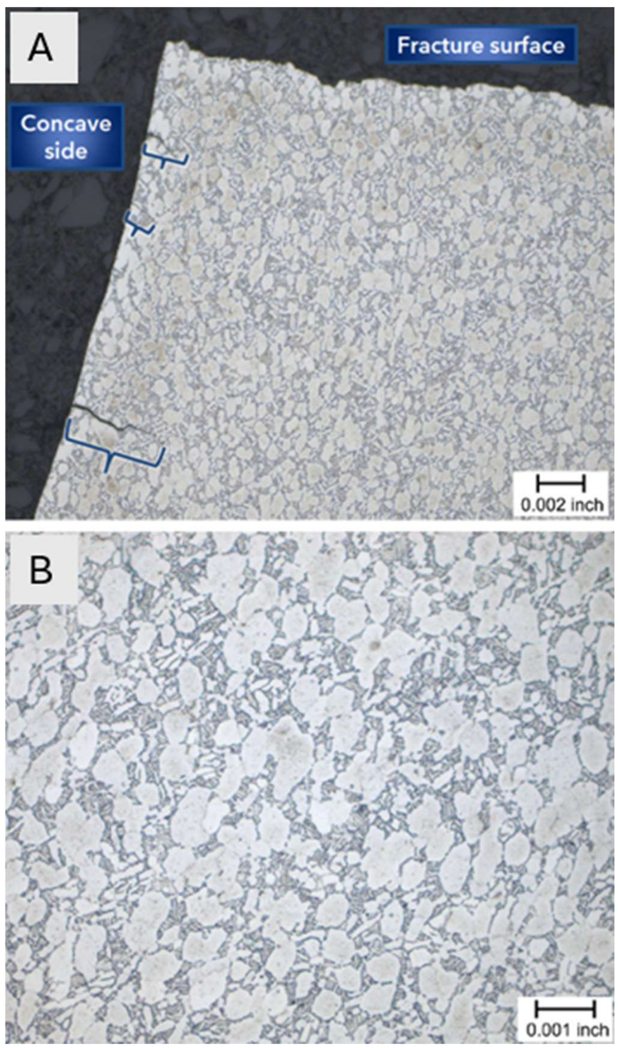

Figure 28: The fracture surface and adjacent surface in the dovetail radius (A) and the typical microstructure at higher magnification (B).

n) Another transverse cut was made through the dovetail piece of blade 1 near midspan, and the trailing piece was sent to one Research, institute for depth profile measurements of residual stress in the radial direction using x-ray diffraction. Measurements were made in the dovetail radius between the disk contact face and the fracture surface, and results are shown plotted in figure 29. Measurements showed compressive stresses at the surface and up to a depth of nearly 0.008 inch with a peak compressive stress of -448 MPa.

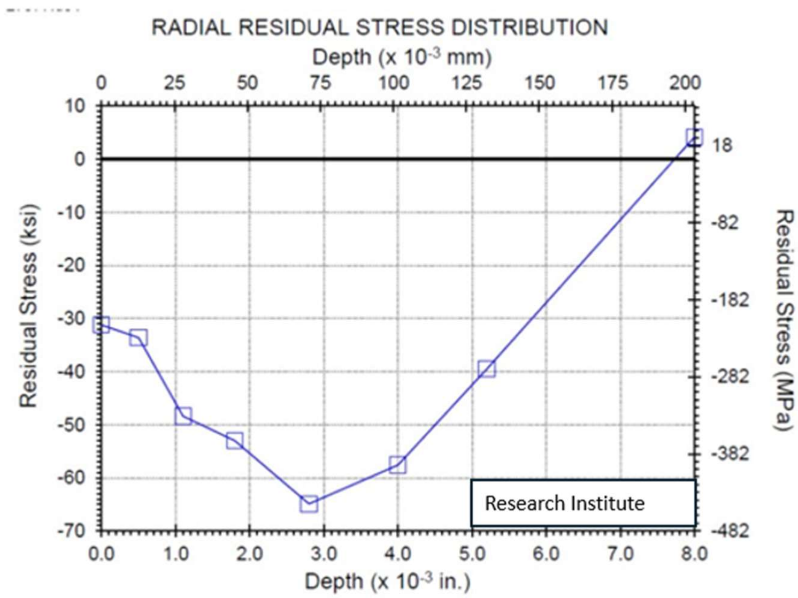

Figure 29: Chart of residual stress in the radial direction measured in the dovetail radius on the concave side of blade 1.

o) A representative sample of the remaining damaged HPC 3rd stage blades is shown in figure 30(A). Fractures in the remaining blades were all above the platform and showed no evidence of preexisting cracks or damage associated with the fractures. Many of the blades were cracked at the trailing edge just above the platform such as the crack in blade 5 shown in figure 30 (B). The area around the crack at the trailing edge showed heat tinting consistent with frictional heating. The trailing edge crack in blade 5 was opened slightly, and fracture features were visible as shown in the detail image in figure 30(B). Fracture features showed heat-tinted surfaces with prominent curving crack arrest marks consistent with progressive cracking. Ratchet marks were also observed consistent with multiple origins. Overall, the crack progression was **consistent with high-amplitude fatigue**. In blade 16 shown in figure 30(A), the trailing edge crack was gaped open and extended across most of the chord, and fracture features near the trailing edge **showed heavy contact damage from fracture surface recontact**. The fracture surface for blade 14 that fractured just above the platform was on slant angles and did not show evidence of a preexisting crack.

p) The dovetail radius region on each of HPC 3rd stage blades 2 through 31 was cleaned and expose the surfaces for examination using a stereo microscope at up to 80x magnification. No evidence of a crack was observed in any of the examined dovetail surfaces.

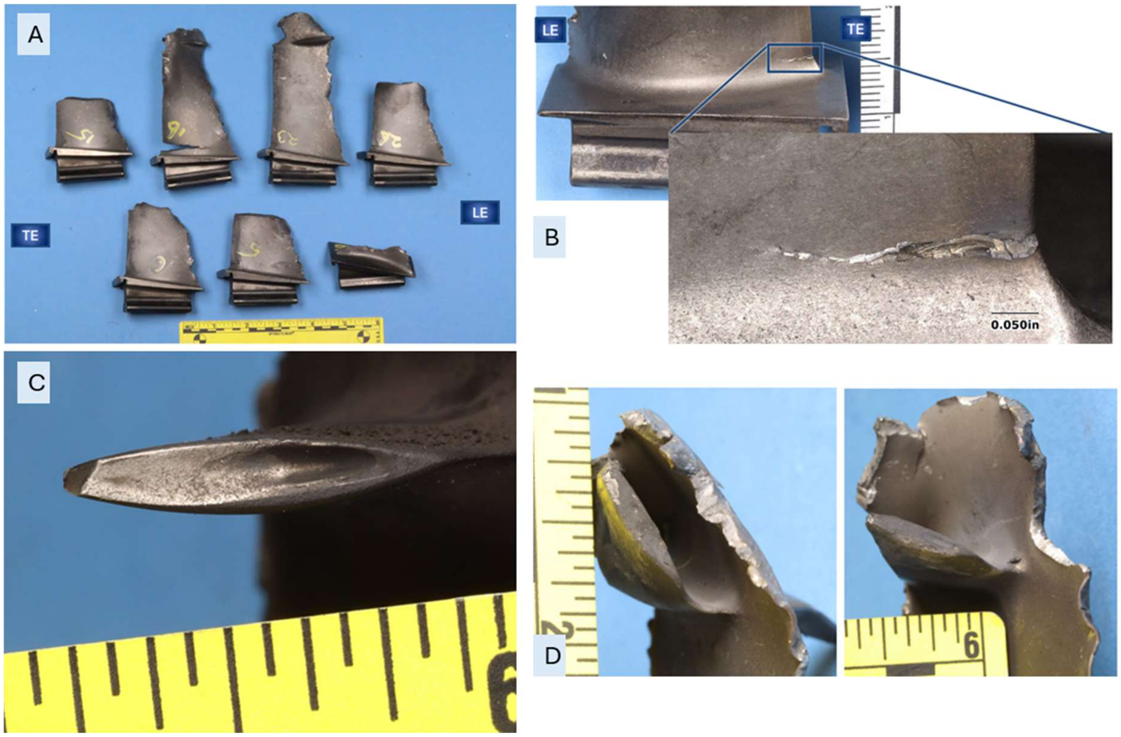

Figure 30: A- Closer view of 7 blades showing representative damage signatures. B- Trailing edge crack on blade 5. C - Fretting contact on the clapper end face on the convex side of 31st blade. D- End faces of clappers on the convex sides of 21st blades (left image) and 23 (right image) showing surfaces covered with black deposits.

q) Blade clappers, spacer arms that extend circumferentially outward near the blade tips, were bent and end faces were damaged on most of the HPC 3rd stage blades, but intact end faces for the clappers were present on blades 21, 23, and 31 as shown in figures 30(c) and 30 (D). The clapper end face on the convex side of blade 31 shown in figure 30(c) mated to the clapper for blade 1. The clapper was straight and intact, and the end face had a shiny rubbed appearance on the trailing two thirds of the clapper surface consistent with heavy and uneven wear. The clapper end faces on the convex sides of blades 21 and 23 shown in figure 30(D) were bent radially outward, and the end faces were covered with sooty black deposits.

1.16.2.2 HPC 3rd Stage Vanes:

a) Overall views of the HPC 3rd stage vanes are shown in figure 31 (A&B). Most of the vanes were partially or mostly covered with loosely-adherent sooty black deposits. The airfoils showed damage consistent with impacts at the leading and trailing edges. Closer views of several selected vanes with representative damage are shown in figure 31(C &D). The outer spindles showed limited deformation and contact marks corresponding to contact with the pitch control lever arms.

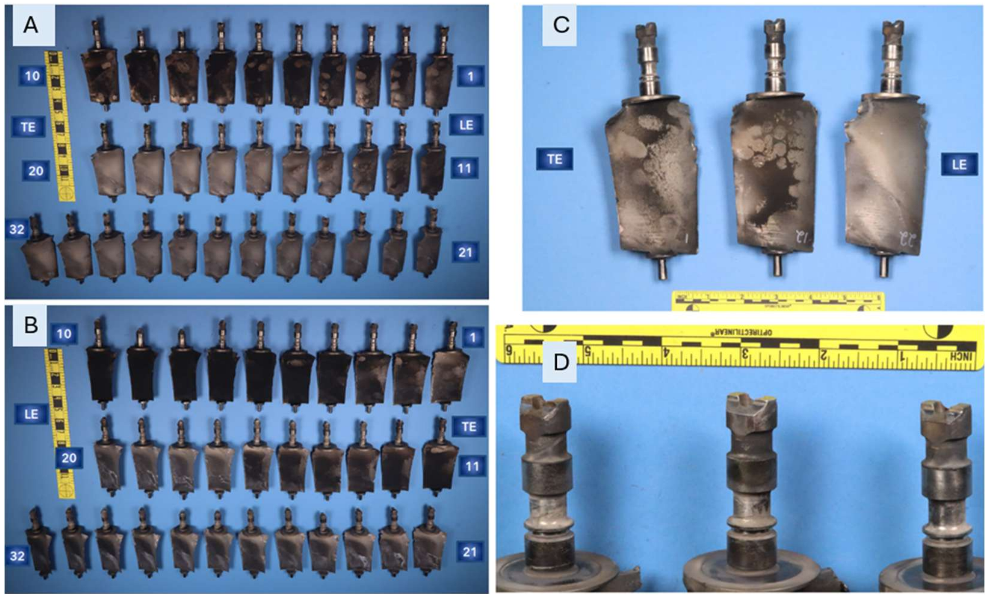

Figure 31: (A &B)- The HPC VIGV Vanes. (C&D)- The VIGV Vanes showing representative damage signatures.

1.16.2.3 HPC VIGV Levers:

a) Overall views of the HPC VIGV levers are shown in figure 32(A&B). Most of the lever arms were twisted to varying degrees between the control pin and the VIGV spindle attachment, except for VIGV levers 20 and 26. The bushing on the control pin was missing from many of the levers, and the bushing was fractured on several others. Closer views of several selected VIGV levers with representative damage are shown in figure 32 (C&D). Many of the levers showed fretting contact damage at the VIGV spindle contact areas as indicated with arrows in figure 32 (C&D). Similar fretting damage was also observed on the relatively undeformed VIGV levers 20 and 26. The fretting damage had a relatively shiny appearance consistent with relatively recent damage from high loads following the blade out event.

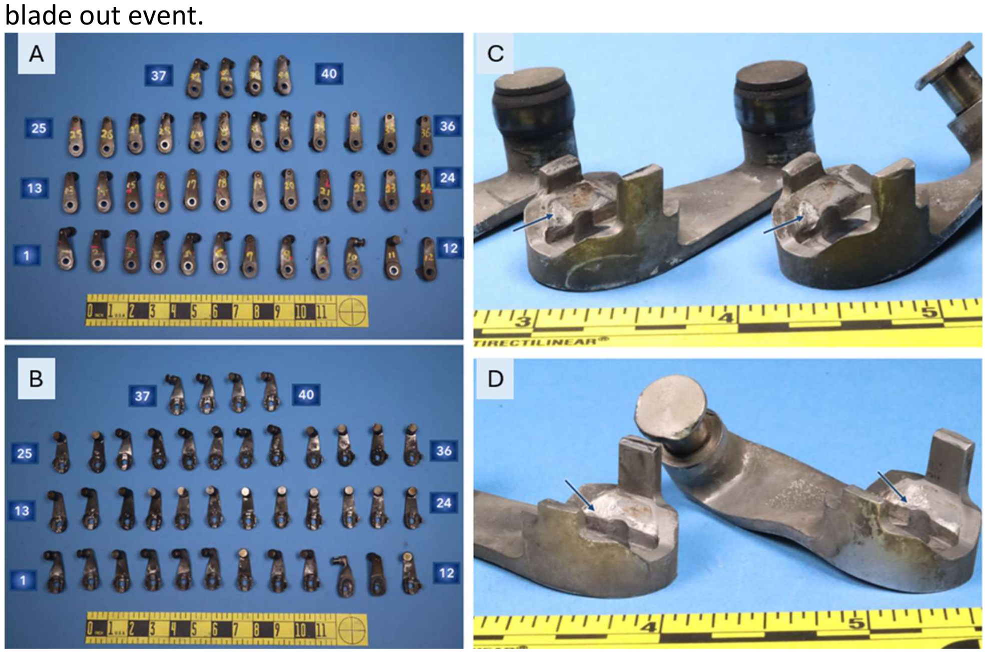

Figure 32 : (A&B)- (A &B)- The HPC VIGV levers. (C&D)- The VIGV levers showing representative damage signatures.

1.16.2.4 HPC VIGVs:

a) Overall views of the HPC VIGV pieces recovered from their installed positions are shown in figure 33. Most of the VIGVs were fractured adjacent to the platform associated with the outer spindle. The remaining intact VIGVs showed impact damage at the leading and trailing edges and substantial impacts on the convex side of the airfoil. Airfoils were bowed to varying extents across the span such that the convex side was deformed to a concave shape in the spanwise direction. The airfoil fracture surfaces adjacent to the outer platform for the fractured VIGVs were heavily damaged, but no evidence of a preexisting crack was observed on the fracture surfaces, including the fracture surfaces for VIGV numbers 20 and 26. The outer spindle surfaces that contacted the VIGV levers had fretting damage that corresponded to the fretting damage observed on the VIGV levers.

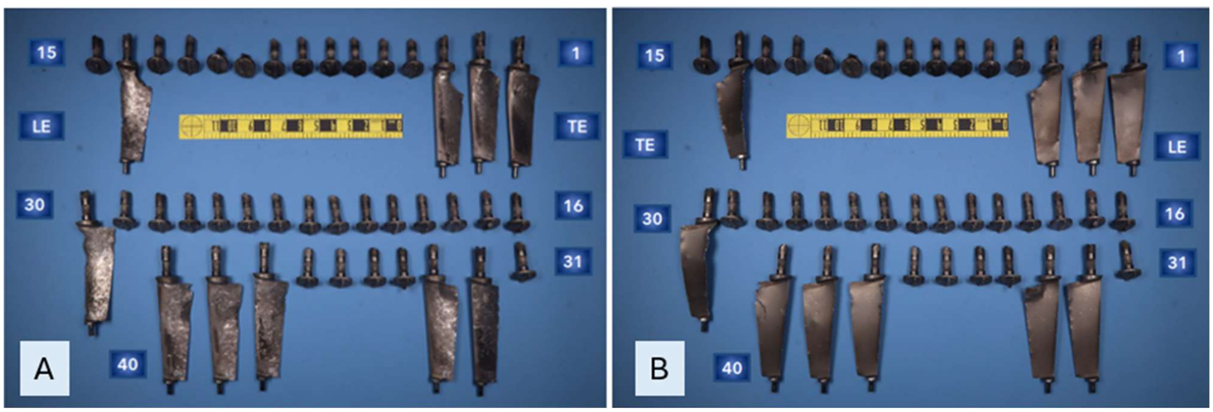

Figure 33: The HPC VIGVs (A- Convex side) & (B- concave side)

b) Additional pieces of HPC VIGVs and HPC 3rd stage blades were recovered from other parts of the engine including mostly from the fan case and fan bleed duct. **The fracture surfaces on the pieces were examined for progressive fracture features.**

c) The pieces recovered from the fan case included several VIGV airfoils. In two of the VIGV pieces recovered from the fan case, the airfoil remained attached to the inner platform with an intact inner spindle. In the remaining recovered VIGV pieces from the fan case, the VIGV was fractured through the airfoil adjacent to the inner platform or through the inner spindle adjacent to the inner platform. Among VIGV pieces recovered from the fan bleed duct, all were fractured through the airfoil adjacent to the inner platform, and all but one was also fractured through the inner spindle at the inner side of the platform.

d) **Evidence of progressive crack growth was observed on several of the HPC VIGV inner spindle fracture surfaces**. A spindle fracture with the largest progressive growth region is shown in figure 34. The fracture surfaces showed areas that were more reflective with curving crack arrest lines consistent with progressive fracture. The crack arrest lines emanated from origin areas on opposite sides of the spindle in line with the leading and trailing sides of the airfoil, consistent with progressive growth from reversed bending loads in line with the chordwise direction on the vane. The progressive regions for the spindle shown in figure 34 extended across approximately half the cross-section. Progressive growth regions observed in other spindles were substantially smaller covering about 10 percent or less of the fracture surface area, but origins were similarly located consistent with reversed bending parallel to the chordwise direction.

e) The HPC VIGV shown in figure 34 was sectioned chordwise near the inner platform to for an SEM examination of the spindle fracture surface. The origin area was relatively broad and had a relatively shallow smooth area near the surface that transitioned to rougher features with ductile tearing. **Overall, the fracture features were consistent with progressive fracture from cyclic overstress loading.**

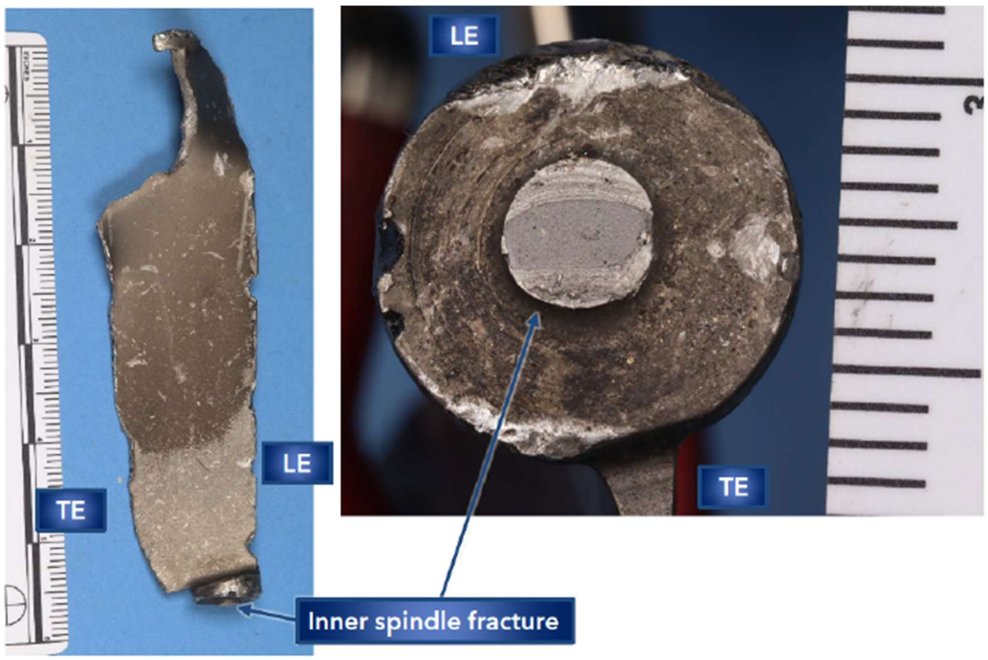

Figure 34: VIGV piece recovered from the fan case (left image). The inner spindle fracture surface (right image).

f) The HPC VIGV inner spindles were generally stained dark on surfaces corresponding to contact with the hat-shaped inner spindle bushings. Several of the intact spindles had dark stains or deposits that extended into the relief radius on the concave side of the vane

1.16.2.5 VIGV Inner Spindle Bushings:

a) The HPC VIGV inner spindle bushing pieces that were collected on disassembly of the HPC VIGV shroud, in that most of the pieces consisted of portions of the flange from the hat shaped bushings, and two included the barrel section in which the VIGV inner spindle would rotate.
b) The fracture surfaces generally showed irregular fracture features with matte gray feathery fractures with little to no deformation. Some areas had a more reflective appearance consistent with post-fracture rubbing damage.
c) Some of the pieces showed a loss of section on the inside diameter consistent with wear. The wear was located adjacent to the hat surface and had a profile that corresponded to the spindle shoulder adjacent to the relief radius. On pieces showing the wear pattern, the wear was located only on one side of the piece. On the inside face of the flange,

radial contact marks were observed consistent with contact with the split line between the forward and aft sides of the VIGV inner support.

1.17 Organizational and Management Information

1.17.1 InterGlobe Aviation Ltd. (Indigo)

The aircraft is operated by an Indian registered Scheduled airline, registered as M/s InterGlobe Aviation Ltd. (Indigo) and holding AOC No. S-19 in Passenger and Cargo Category, which is valid till 02.08.2027. M/s IndiGo was one of the launch customers for the Airbus A320 aircraft fitted with Neo engines.

It operates scheduled flights to both domestic and international sectors. It has got a fleet of 375 Airbus A320/A321 and 46 ATR-72 aircraft. As of 28 February 2026, M/s IndiGo has a total fleet of 26 (A320) CEO aircraft. The operator carries out its own maintenance as a CAR 145 approved organization.

1.17.2 International Aero Engines (IAE) AG

The Pratt & Whitney (P&W) is a USA based Original Equipment Manufacturer (OEM) for aero engine. Pratt & Whitney is a part of International Aero Engines (IAE) AG, a joint venture engine consortium for the V2500 engine. The V2527-A5 engine (serial number V16666) was manufactured by IAE in 2013.

As per OEM, the rate of in-flight shutdowns (IFSD) due to HPC 3rd stage blade fracture is tracked by the OEM and the Federal Aviation Administration (FAA). The present engine failure rate due to HPC 3rd stage blade fracture meets the FAA Continued Airworthiness threshold and is currently being managed internally by OEM's Safety Board for safe operation of the fleet.

Based on the events of HPC 3rd Stage blade failure due Clapper wear, the OEM has modified its existing Detonation Gun (D-gun) clapper coating technique with High Velocity Oxygen Fuel (HVOF). The HVOF process aims to improve the overall wear characteristics by reducing friction between the clapper hard-faces, thereby reducing the frequency of events.

Most of the reduction in friction and wear is from the change to HVOF process that affect the microstructure, in addition to the coating specification changes. This composition and coating improve the microstructure, therefore increasing durability of the clapper. Laboratory testing supports these improvements.

Therefore, the OEM has issued a Service Bulletin. Details of Service Bulletin is summarized below:

The relevant details of the service Bulletin are given below:

a) **Service Bulletin number:**
   SB V2500-ENG-72-0716.
b) **Reason/problem:**
   1. Condition: Wear on the 3rd stage HPC rotor blade clapper vertical face can lead to increased vibrational response of the blade, which may result in fracture above and below the platform. The fracture of the 3rd stage HPC rotor blade can result in engine damage.

2. Background: An investigation of the 3rd stage HPC rotor blade fracture identified clapper wear leading to High Cycle Fatigue (HCF) blade fracture. Clapper wear can lead to increased vibrational response and peak stress shift to the failure location, which can result in a facture above or below the platform.

3. Objective: Replace or modify the 3rd stage HPC rotor blade clapper coating with an improved coating process to increase durability.

4. Substantiation: In order to improve the wear characteristics of the clapper, a new hard coating application process will be used. A High Velocity Oxy-Fuel (HVOF) process will replace the current Detonation Gun (D-Gun) process, resulting in more durable coating as demonstrated by testing. The material coating is substantially the same with minor variations as required to suit the different application process. Final coating thickness with the new process will match the current process so final part dimensions will not be impacted.

c) Description:

Replace or modify the 3rd stage HPC rotor blade.

d) Compliance:

Category Code 6

Accomplish when the sub-assembly (i.e., Modules, accessories, components, build groups) is disassembled sufficiently to afford access to the affected part and to all affected spare parts.

1.18 Additional Information

Nil

1.19 Useful or Effective Investigation Techniques

Nil

2. ANALYSIS

2.1 Serviceability of the Aircraft

Based on the scrutiny of the aircraft maintenance records provided by the Organization, on the date of incident, the aircraft's Certificate of Registration, Certificate of Airworthiness, Airworthiness Review Certificate and weight schedule were valid as per the prevailing DGCA Civil Aviation requirements (CARs). All applicable scheduled inspections were carried out on the aircraft and engines in accordance with the applicable maintenance data. All applicable and mandatory Airworthiness Directives (AD) & Service Bulletins (SB) were complied with.

As per the aircraft records, prior to departure from Delhi Airport on 28 October 2022, no Minimum Equipment List (MEL) item related to engine no. 2 was open or pending on aircraft VT-IFM for rectification. Similarly, no deferred inspection or snag concerning engine no. 2 was pending for rectification on aircraft VT-IFM prior to departure from Delhi Airport. The Pre-Flight/Transit Inspection was carried out at Delhi airport and nil abnormalities were observed. **Till the date of incident, the engine hours and cycles accumulated on V2527-A5 engine (ESN V16666) was 29603:43 hours (TSN), 13690.43 hours (TSLSV), 18273 cycles (CSN) and 7345 (CSLSV).**

Based on the DFDR data analysis the OEM has confirmed that "**No Significant observations (engine parameters) were seen prior to the event**" and hence "There were no engine parameters identified as precursors to the event".

The analysis of DFDR also revealed that the throttles were pushed forward to initiate the take-off at 16:16:45 UTC. The V2527-A5 engine (ESN V16666) failed at 16:17:03 UTC, The Flight crew responded immediately and pulled back the throttles to reject the take-off at 16:17:05 UTC. During the event, on V2527-A5 engine (ESN V16666), loss of EPR against the CMD EPR noticed, followed by sharp decrease in the Fuel Flow and N22. The loss of EPR against the CMD EPR, followed by decrease in Fuel Flow and N22 is a clear indication of engine failure.

The V2527-A5 engine (ESN V16666) was removed from the aircraft VT-IFM on 19 August 2017, at 15913:00 hours (TSN) and 10928 cycles (Total) for the shop visit. The reason for removal was "Combustor Distress beyond AMM Limits". During the shop visit rest other modules were also subjected to inspection to check the condition or serviceability as per applicable AMM task. The HPC 3rd Stage was inspected. **During the inspection, the entire HPC 3rd Stage blades were found in unserviceable condition (Beyond AMM limits) i.e., none of the HPC 3rd stage blade pass the serviceable criteria**. **In addition, an extensive clapper wear was also observed on the HPC 3rd stage blades. Out of the 31 blades, 21 blades that could not be repaired were replaced with new serviceable blades, while the remaining 10 blades were repaired in the engine shop to make them serviceable in accordance with the AMM requirements.**

The HPC 3rd stage blade no. 1 (as marked during the engine disassembly at OEM engine facility) was one of the repaired blades installed during the last shop visit.

On completion of maintenance task as per work scope, the engine was assembled, and all necessary tests were carried out as per OEM's maintenance data. On successful completion of all checks, the V2527-A5 engine (ESN V16666) was finally released to service at 15913:00 hours (TSN) and 10928 cycles on CA Form 1, dated 07 February 2018 by the engine shop.

Post engine shop visit, V2527-A5 engine (ESN V16666) was initially installed on the aircraft VT-IFM at 15913:00 Hours (TSN) & 10928 Cycles on 14 February 2018 and removed at 27030:48 Hours (TSN) & 16567 Cycles on 20 October 2021. Thereafter, M/s IndiGo had installed, utilized, and subsequently removed the V2527-A5 engine (ESN V16666) on two different aircraft, at different engine positions.

Thereafter, the V2527-A5 engine (ESN V16666) was re- installed on the aircraft VT-IFM, at position 02, at 27736:47 hours (TSN) & 17033 Cycles on 28 March 2022. Post installation on the aircraft VT-IFM, the engine had accumulated 1866:56 hours and 1240 cycles till the incident flight.

Post incident, based on the inspections and assessments carried out by M/s Indigo's maintenance personnel, the V2527-A5 engine (V16666) was declared unserviceable and was removed from the aircraft VT-IFM. Subsequently, the event V2527-A5 engine (ESN V16666) was shipped to one of the OEM's approved Maintenance Repair and Overhaul (MRO) engine facility for engine defect investigation.

At the OEM's approved MRO, the event engine was thoroughly examined to understand the cause of event. During the engine examination the damage patterns and retrieval locations of the parts were documented and compared with the records of previous incidents, specifically focusing on similarities and differences in engine damage characteristics, failure progression, and component fragmentation.

Based on the above analysis of damage pattern observed on the event V2527-A5 engine (ESN V16666) and the OEM's previous knowledge of similar pattern of damage on other V2500 engines, the OEM has categorized **the damage in the HPC 3rd Stage as a primary damage and rest other damages as secondary damage. Damage patter and progression also confirms HPC 3rd stage VIGV Surge event.**

To confirm the engine examination outcome, the HPC 3rd stage parts and debris such as HPC Blades, Vanes etc. were sent to the NTSB laboratory for metallurgical testing. These parts were extensively examined using various methods and technologies. Later the collected data was analyzed by metallurgical experts and following conclusions have been drawn:

a) The were two types of fatigue crack origin region such primary origin and secondary origin. Multiple cracks initiated within the blade root. As the primary crack grew, it likely intersected with another crack plane, and continued to grow and eventually fracture.
b) The fracture of HPC 3rd stage blade No. 1 was the primary damage, while the remaining damages were secondary in nature.
c) Blade labelled as 1 was fractured in the blade root below the platform due to High Cycle fatigue. It was repaired during the shop visit in 2018. The primary reason for this High Cycle Fatigue fracture was heavy clapper wear.
d) The remaining blades labelled form 2 through 31 were damaged in the airfoil region i.e., above the platform, consistent with secondary damage.

2.1.1 HPC 3rd stage clapper (History)

In the HPC operation, the clapper (also called a mid-span shroud) is critical to the durability of the 3rd stage blade, in that it stiffens the blade during operation to ensure adequate vibratory margin. The Clapper wear/misalignment results in reduced blade damping which can then lead to blade fracture. In addition to wear, it was also known that Foreign Object Debris (FOD)/bird ingestion can also lead to clapper misalignment with resultant blade fracture.

Therefore, in 2005, clapper wear was identified as a major in-service issue affecting the HPC 3rd Stage Blade. This degradation led to rotor blade fractures occurring both above and below the platform. The fracture of the HPC 3rd Stage rotor blade ultimately resulted in engine failure.

In January 2005, Service Bulletin (SB) 72-0487 was released by the OEM to address the issue of clapper wear which can lead to High Pressure Compressor (HPC) 3rd stage blade fracture. The solution introduced by this Service Bulletin was a redesigned HPC 3rd stage blade with increased clapper thickness at the intersection between the airfoil and the clapper.

An inspection in the Aircraft Maintenance Manual (AMM) was also added to aid in identifying worn/misaligned clappers, when there was an indication of FOD/bird ingestion (AMM Task 72-00-00-210-012).

Although the HPC 3rd stage blade redesign introduced by SB V2500- ENG-72-0487 helped and reduce the rate of clapper wear/misalignment events. But the issue did not eliminate. **The event engine (ESN V16666) was production complied with SB 72-0487 and there was no report of bird/FOD ingestion for this engine (ESN V16666).**

As per OEM records, since 2014, there were 57 cases related to clapper wear that led to HPC 3rd stage blade fracture and subsequently resulted in engine failure/malfunction.

The technical analysis of clapper wear events, along with the investigation carried out on the engine (ESN V16666), revealed that clapper wear led to a High Cycle Fatigue (HCF) blade fracture, which subsequently resulted in engine failure.

Based on the engine occurrences, the existing clapper coating technique Detonation Gun (D-Gun) required to be replaced with a new method or material that would provide greater durability and better resistance to vibration. Following this, the OEM has changed its clapper coating technique to (High Velocity Oxy-Fuel (HVOF) process) and issued another Service Bulletin (SB) 72-0716 after conducting an extensive engineering analysis and Laboratory testing. The OEM expect that the new technique will provide more durability and better resistance to vibration and will achieve the desired result.

In Service Bulletin (SB) 72-0716, the OEM has made the Substantiation as *"In order to improve the wear characteristics of the clapper, a new hard coating application process will be used. A High Velocity Oxy-Fuel (HVOF) process will replace the current Detonation Gun (D-Gun) process, resulting in more durable coating as demonstrated by testing. The material coating is substantially the same with minor variations as required to suit the different application process. Final coating thickness with the new process will match the current process so final part dimensions will not be impacted".*

In view of the above discussions, it is concluded that the Clapper wear/misalignment has been identified as the primary root cause that led to HPC 3rd stage blade High Cycle Fatigue (HCF) fractures. Hence, the serviceability of the clapper was the main contributory factor to this serious incident.

2.2 Weather

As per METAR published by Indian Meteorological Department (IMD) office situated at Delhi Airport, the meteorological condition, while the Flight 6E-2131 take-off from Delhi airport was visibility was 1500 m with Calm wind. Hence, the weather was not a contributory factor to this Serious Incident.

2.3 Flight Crew Qualification and Aircraft Handling

Both flight crew were appropriately licensed, qualified, authorized and medically fit to operate the flight 6E-2131. The PIC of flight no. 6E- 2131 was an Airlines Transport Pilot License holder with more than 3052 hours of flying experience on A320 aircraft. The Co-pilot was also an Airlines Transport Pilot License holder with more than 2849 hours of flying experience on A320 aircraft. During the take-off roll the flight crew heard a loud bang accompanied with a right yaw movement at 16:17:03 UTC. The flight crew assessed the situation swiftly and immediately rejected the take-off with application brakes and the thrust reversals at 16:17:05 i.e., within 3 seconds of the event. The aircraft came to halt at 16:17:21 UTC. The flight crew handled the event of V2527-A5 engine (ESN V16666) failure in accordance with OEM's documented FCOM and emergency procedures. The flight crew carried out the ECAM action and followed the FCOM procedures. As per FCOM procedure crew used the engine fire extinguisher and shutdown the failed engine. The flight crew apprised Delhi ATC about the engine no. 02 failure, followed by the aircraft's rejected take-off on runway 28. The flight crew performed all necessary checklists. The flight crew kept the situation under control and did not get panic. Therefore, **it is concluded that the flight crew qualification and aircraft handling were not a contributory factor in this Serious Incident.**

2.5 Circumstances Leading to the Serious Incident

On 28 October 2022, when the flight crew of the aircraft VT-IFM, commenced the take-off by pushing the throttle forward, both the engine spooled up normally as per the given command. Engine no.1 kept working absolutely normal. Whereas inside the engine no. 02 (V2527-A5, ESN V16666), in its HPC 3rd Stage, Blade no. 1 (as labeled during the engine examination) fractured under High Cycle fatigue (Sequence of fatigue fracture: Heavy clapper wear of HPC 3rd Stage blades over a period of time resulted in improper alignment between blades and possible radial misalignment. These factors resulted in increased stresses at the blade root, eventually resulting in crack propagation and eventual fracture of Blade no. 1). Therefore, the primary source of damage to the subject engine was the release of the fractured blade no. 1 body, resulting in damage and secondary fractures to the rest of the HPC 3rd stage set as well as damage to the adjacent VIGVs and downstream hardware. This caused a probable VIGV surge at the HPC and flowed back to the LPC stage 2.5. This hardware damage causes a loss of HPC operability stability margin that ultimately leads to engine stall. This all happened within few seconds of commencement of take-off phase.

The flight crew followed the company's FCOM emergency handling procedure and shut down the affected engine. Later, after safety checks the aircraft taxi back and parked to a bay safely on its own single engine (i.e., engine no. 1) at Delhi Airport.

3. CONCLUSION

3.1 Findings

3.1.1 The aircraft had a valid Certificate of Airworthiness, Certificate of Registration and the Airworthiness Review Certificate before operating the incident flight.

3.1.2 The aircraft was maintained as per applicable maintenance data.

3.1.3 Nil snag or maintenance were due on engine no.2 prior to departure from Delhi Airport on 28 October 2022.

3.1.4 In last shop visit, In HPC 3rd Stage, out of 31 Blades, 21 blades were replaced with serviceable blade (New) whereas 10 blades were repaired in the shop. Extensive clapper wear was also noticed during the shop visit. The HPC 3rd stage blade no. 1 (as marked during the engine disassembly at OEM engine facility) was one of the repaired blades. But the OEM does not have much information about this.

3.1.5 Till the date of incident, the engine hours and cycles accumulated on V2527-A5 engine (ESN V16666) was 29603:43 hours (TSN), 13690.43 hours (TSLSV), 18273 cycles (CSN) and 7345 (CSLSV).

3.1.6 HPC 3rd stage blade no. 1 fractured due to cracks caused by High Cycle Fatigue (HCF), which developed as a result of clapper wear. The clapper wear led to a loss of damping, subsequently increasing vibratory stresses and ultimately resulting in HCF fracture.

3.1.7 Engine examination confirmed that the primary source of damage to the event engine (ESN V16666) was the release of the HPC 3rd Stage fractured blade no.1 body, resulting in damage and secondary fractures to the rest of the HPC 3rd stage set as well as damage to the adjacent VIGVs and downstream hardware.

3.1.8 No Significant observations (engine parameters) were seen prior to the event and There was no engine parameters identified as precursors to this event.

3.1.9 The weather was not a contributory factor to this Serious Incident.

3.1.10 The flight crew / pilots were appropriately licensed, qualified and medically fit to operate the flight 6E-2131 on 28 Oct 2022.

3.1.11 The Flight crew/pilots' actions post engine malfunction were in accordance with the Standard Operating Procedures and company's FCOM procedures.

3.1.12 The flight crew qualification and aircraft handling were not a contributory factor in this Serious Incident.

3.1.13 The rate of in-flight shutdowns (IFSD) due to HPC 3rd stage blade fracture is tracked by both P&W and the Federal Aviation Administration (FAA). The present HPC 3rd stage failure rate is well within the FAA Continued Airworthiness threshold.

3.2 Probable Cause of the Serious Incident

3.2.1 Probable Cause(s)

The probable cause of this serious incident is attributed to the HPC 3rd Stage heavy clapper wear that was found on the V2527-A5 engine (ESN V16666). The heavy clapper wear resulted in improper alignment between HPC 3rd stage blades and radial misalignment. Consequently, stresses increased at the root of HPC 3rd stage Blade no.1, eventually resulting in crack propagation and eventual HCF fracture of HPC 3rd stage Blade no.1.

The primary source of damage was the release of the fractured blade no.1 body, resulting in damage and secondary fractures to the rest of the HPC 3rd stage set as well as damage to the adjacent VIGVs and downstream hardware. This hardware damage causes a loss of HPC operability stability margin that ultimately leads to engine stall.

3.2.2 The contributory Factor(s)

The contributory factory to this Serious Incident was the design aspect related to the clapper coating of the HPC 3-stage blade i.e., the technique and type of material used for the clapper coating. The technique being utilized for clapper coating did not meet/withstand the durability results/expectation as desired while adopting that technique vide Service Bulletin SB 72-0487.

4. SAFETY RECOMMENDATIONS

It is recommended that

4.1 The OEM may establish a mechanism to capture and collect engine shop maintenance data, particularly where extensive maintenance work has been carried out on engine components/module, that have some history of failure or event. Similar to this case where during the shop visit in 2018, all HPC 3rd stage blades were found to be beyond the AMM limits and were subsequently replaced or repaired. However, the OEM has limited information, even though fractures in the HPC 3rd stage had been a known issue since 2005.

4.2 The FAA may establish a mechanism for sharing occurrence data on repetitive surging events, such as this case (i.e., HPC 3rd Stage blade fracture due to clapper wear resulting in engine failure), with the regulatory and investigative authorities of the state of operator. This would raise awareness and encourage all stakeholders to promptly share information on similar events with the OEM.

4.3 In 2018, during the MRO shop visit of engine ESN V16666, the entire set of HPC 3rd Stage blades was found to be in an unserviceable condition (beyond AMM limits). Consequently, 21 blades were replaced with new serviceable blades, while the remaining 10 blades were repaired in the MRO facility. Therefore, the OEM should take cognizance of this type of extensive maintenance situation and evaluate the feasibility of introducing special inspections (such as eddy current or ultrasound crack checks on the blade root after removal of the entire blade coating, once a blade is taken up for clapper repair).