FINAL REPORT

SERIOUS INCIDENT 2022/4594

State Commission on Aircraft Accidents Investigation (PKBWL)

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FINAL REPORT

Serious incident

OCCURRENCE NO – 2022/4594

AIRCRAFT – Boeing B-737/800-83N, SP-ENU

DATE AND PLACE OF OCCURRENCE – 15 August 2022, EPGD

The Report is a document presenting the position of the State Commission on Aircraft Accidents Investigation concerning circumstances of the air occurrence, its causes and safety recommendations. The Report was drawn up on the basis of information available on the date of its completion.

The investigation may be reopened if new information becomes available or new investigation techniques are applied, which may affect the wording related to the causes, circumstances and safety recommendations contained in the Report.

Investigation into air the occurrence was carried out in accordance with the applicable international, European Union and domestic legal provisions for prevention purposes only. The investigation was carried out without application of the legal evidential procedure, applicable for proceedings of other authorities required to take action in connection with an air occurrence.

The Commission does not apportion blame or liability.

In accordance with Article 5 paragraph 6 of the Regulation (EU) No 996/2010 of the European Parliament and of the Council on the investigation and prevention of accidents and incidents in civil aviation […] and Article 134 of the Act – Aviation Law, the wording used in this Report may not be considered as an indication of the guilty or responsible for the occurrence.

For the above reasons, any use of this Report for any purpose other than air accidents and incidents prevention can lead to wrong conclusions and interpretations.

This Report was drawn up in the Polish language. Other language versions may be drawn up for information purposes only.

WARSAW 2024

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Abbreviations

Abbreviation	Meaning
ACARS	Aircraft Communication Addressing and Reporting System
ACC	Area Control Centre
ALTN	Alternate airport
AMM	Aircraft Maintenance Manual
A/P	Autopilot
APP	Approach Control
APU	Auxiliary Power Unit
A/T	Auto-Throttle
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATOM	Actual Take-off Mass
ATS	Air Traffic Services
BITE	Built In Test Equipment
BSI	Aircraft Engine Borescope Inspection
CB	Cloud Cumulonimbus
CBZ/CRD	Central Reporting Database
CPT	Captain
CRM	Crew Resource Management
CSN	Cycles Since New (applies to engine components)
CVR	Cockpit Voice Recorder
EASA	European Union Aviation Safety Agency
EFS	Engine Fire Switch
EEC	Electro Engine Control
EGT	Exhaust Gas Temperature

EPGD	Gdansk, Lech Walesa Airport
EPPO	Poznan, Ławica Airport
EPWA	Warsaw, Chopin Airport
Eng.	Engine
ESN	Engine Serial Number
ETA	Estimated Time of Arrival
FADEC	Full Authority Digital Engine Control
FC	Flight Cycles
FDR	Flight Data Recorder
FL	Flight Level
FMV	Fuel Metering Valve
FO	First Officer
Ft	Foot (unit of length – 0.3048 m)
GCFV	Fuerteventura Airport
HMU	Hydromechanical Unit
hPa	Hectopascal (unit of atmospheric pressure.)
HPBT	High Pressure Turbine Blade
HPT	High Power Turbine
ICAO	International Civil Aviation Organization
IFSD	In-Flight Shut Down
IFR	Instrument Flight Rules
ILS	Instrument Landing System
kt	Knot (unit of speed–1.852 km/h)
LCF	Low Cycle Fatigue
LE	Leading Edge
LGSA	Chania Airport
LMT	Local Mean Time

LPT	Low Pressure Turbine
LVTO	Low Visibility Take-Off
LW	Landing Weight
MACTOW	Mean Aerodynamic Chord for Take Off Weight
MAYDAY	An emergency procedure word used internationally as a distress signal in voice-procedure radio communications.
MCD	Magnetic Chip Detector
MEL	Minimum Equipment List
MTOM	Maximum Take-Off Mass
NIL	None
N1	Low Pressure Rotor Rotational Speed
N2	High Pressure Rotor Rotational Speed
NITS	Nature, Intentions, Time available, Special Instructions
NNC	Non-Normal Check List
OAT	Outside Air Temperature
OFP	Operational Flight Plan
OPC	Operator Proficiency Check
ORO	Organization Requirements for Air Operations
PAN PAN	Radiotelephony urgency signal - Possible Assistance Needed
PANSA/PAŻP	Polish Air Navigation Services Agency
PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring
PN	Part Number
PPH	Pounds per hour
PS3	Compressor Discharge Static Air Pressure

PSI	Pounds per square inch
QNH	Altimeter sub-scale setting to obtain elevation when on the ground
RD	Repair Document
RMK	Remark
RRT	Recommended Removal Time
RVR	Runway Visual Range
RWY	Runway
SAV	Starter Air Valve
SB	Safety Bulletin
SCAAI/PKBWL	State Commission on Aircraft Accidents Investigation
SMS	Safety Management System
SID	Standard Instrument Departure
SOP	Standard Operating Procedures
STAR	Standard Instrument Arrival
STD	Standard Time of Departure
TBC	Thermal Barrier Coatings
TBV	The Transient Bleed Valve
TCU	Cloud Towering Cumulus
TDODAR	Time, Diagnose, Options, Decide, Act/Assign, Review
TRA	Throttle Resolver Angle
TWR	Aerodrome control tower
TSN	Time Since New
TSO	Time Since Overhauled
TWY	Taxiway
QAR	Quick Access Recorder
QEC	Quick Engine Change
ULC/CAA	Civil Aviation Authority (Poland)

UER	Unscheduled Engine Removal
UTC	Coordinated Universal Time
WPS	Words per second (recording rate)

General information

<table>
<tr><td>Occurrence reference number:</td><td colspan="4">2022/4594</td></tr>
<tr><td>Type of occurrence:</td><td colspan="4">SERIOUS INCIDENT</td></tr>
<tr><td>Date of occurrence:</td><td colspan="4">15 August 2022</td></tr>
<tr><td>Place of occurrence:</td><td colspan="4">EPGD, Poland</td></tr>
<tr><td>Type and model of aircraft:</td><td colspan="4">Boeing B-737/800-83N</td></tr>
<tr><td>Aircraft registration marks:</td><td colspan="4">SP-ENU</td></tr>
<tr><td>Aircraft user/operator:</td><td colspan="4">EnterAir</td></tr>
<tr><td>Aircraft Commander:</td><td colspan="4">ATPL(A)</td></tr>
<tr><td rowspan="2">Number of victims/injuries:</td><td>Fatal</td><td>Serious</td><td>Minor</td><td>None</td></tr>
<tr><td>-</td><td>-</td><td>-</td><td>177</td></tr>
<tr><td>Domestic and international authorities informed about the occurrence:</td><td colspan="4">ULC, EASA, ICAO, NTSB</td></tr>
<tr><td>Investigator-in-Charge:</td><td colspan="4">Jakub Cichocki</td></tr>
<tr><td>Investigating Authority:</td><td colspan="4">State Commission on Aircraft Accidents Investigation (PKBWL)</td></tr>
<tr><td>Accredited Representatives and their advisers:</td><td colspan="4">NTSB (USA), NSIA (Norway)</td></tr>
<tr><td>Document containing results:</td><td colspan="4">Final Report</td></tr>
<tr><td>Safety recommendations:</td><td colspan="4">NO</td></tr>
<tr><td>Addressees of the recommendations:</td><td colspan="4">-</td></tr>
<tr><td>Date of completion of the investigation:</td><td colspan="4">24 June 2024</td></tr>
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Synopsis

On 15th of August 2022, after take-off from EPGD airport during standard departure from RWY 11 at around FL110 the aircraft sustained failure of engine No. 2. The flight crew reported technical fault to ATC and began holding pattern but due to the weather conditions and thunderstorm clouds in the vicinity, the flight crew had to move to another navigation point with non-published holding pattern They declared PAN-PAN.

The crew decided to stay in holding pattern in the vicinity of EPGD to burn off fuel and land with the appropriate landing weight but after analysing the weather conditions at other airports and rapid deteriorating weather conditions at EPGD, and taking into account a suggestion from the operator Operations Department (OPS), the Captain decided to divert to EPWA. The flight crew declared MAYDAY. The flight to EPWA was uneventful and the flight crew performed a safe landing with the assistance of the airport emergency services. The passengers disembarked the aircraft following normal procedures using stairs.

The occurrence was investigated by PKBWL Investigation Team in the following composition:

Jakub Cichocki	Investigator-in-Charge
Paweł Jajkowski	Team Member

After the investigation PKBWL has determined the following causes of the serious incident and factors contributing to its occurrence:

1) The cause of the engine failure and related damage was a rupture of the main blade of the SNBWHN9B01.

Circumstances conducive to the occurrence:

1. Based on the analysis of the Borescope Test Report of June 13, 2022, which was the last BSI test of a high-pressure turbine (performed after 234 cycles) before the occurrence of IFSD, the most likely was that in the BSI test of main blade SNBWHN9B01 was used incorrect angle of view - which is recommended by the producer (justification described in the analysis).
2. Failure to comply with the SB 72-0886 security bulletin by the Operator with regard to the recommended shortened maintenance interval (assuming that the engine in question met the post-maintenance criteria for engines used in India).
3. No recommended RD 150-1551 study has been performed.
   Based on the repair records from Plant No. 23 in Singapore, it was concluded that RD 150-1551 was not tested. By State from the 2013 repair, the plant responsible for the major repair of the high-pressure turbine blades (Plant No. 23 in Singapore) has provided repair records for HPT 1957M10P01 blades installed in the 874306 engine (the engine that failed). According to the data contained, a complete set of 80 blades was repaired, of which 25 blades were repaired, including the main separated blade SN BWHN9B01. The remaining

55 blades were scrapped for various reasons. Among the reasons for scrapping the blades, the requirement to meet the conditions of the RD 150-1551 repair document was not given.

During the report preparation phase, the operator was briefed on the results of the investigation and potential recommendations. By the time the report was closed, the operator had confirmed the implementation of the recommendations and sent the relevant confirmation.

PKBWL has not formulated safety recommendations.

1. FACTUAL INFORMATION

1.1. History of the flight

On the 15th of AUG 2022, a crew was scheduled to operate the route: EPGD-GCFV, at STD 14:35 UTC[1]. The crew was planned to operate from EPGD, out of home base (EPPO). Crew rested in adequate hotel. Not reported any distraction in resting period. Crew reported in the airport: on-time. Having information that the plane would land with a minor delay from the previous sector, the pilots went to the aircraft as soon as possible. Previous crew have been met by operating pilots. No technical issues were reported. Pilots decided that FO will be PF on the sector EPGD-GCFV. Captain completed walk-around. Standard flight preparation has been completed.

Plane departed from EPGD at 14:59 UTC. Take-off run, lift-off and climb proceeded with no deviations. After departure from RWY 11, based on SID: DEXIR 2B, crew received clearance to climb to FL280. Plane departed southbound and during the climb pilots requested to deviate from standard routing to HDG 220º to avoid clouds. Further a right turn to HDG 230° for next 20NM was requested. At around FL110 the crew noticed abnormal noise coming from the engine No. 2 and its unstable parameters. The captain decided to take over PF role, therefore FO became PM.

The crew requested ATC to stop climbing and maintain FL120 in holding pattern. Crew reviewed situation and stated that plane is controllable. Therefore they shut down the engine No. 2 based on NNC. 8.2. Engine Fire or Engine Severe Damage or Separation and then they decided to restart failed engine. There were no indications of fire. Crew completed engine in-flight start, but the engine failed to restart. Due to cells of thunderstorm in the vicinity of the aerodrome the crew requested ATC to change position of holding and stated that due to technical problem they would like to come back to EPGD. But due to overweight, the pilots decided to burn fuel to reduce LW. Plane initially entered holding pattern over waypoint: GD704 and then due to thunderstorm changed holding position over waypoint GD531 which is located around 20 NM south of the EPGD. The crew had a problem to find clear airspace due to dynamic weather conditions changes. Finally they decided to fly to the N-E from the EPGD where area looked relatively clear. Flying in this area plane was around 10 NM from the Russian border which was reported to crew by ATC.

At that stage the crew declared PAN-PAN and completed TDODAR and NITS. The crew one more time reviewed indications of engine No. 2 and decided to restart engine in flight. Engine No.2 did not relight. WX at EPGD deteriorated and pilots requested current WX conditions from EPSC, EPSY, EPBY and EPMO. Additionally, ATC advised that EPBY TWR is out of service. Pilots requested WX conditions from EPPO. ATC reported CB clouds over EPSY airport and CAVOK conditions over EPPO. ATC informed the crew that their OPS Officer suggested diversion to EPWA. However, the crew replied that their primary plan was to land on EPGD, after burning some fuel to reduce LW.

[1] All times in the report are given in UTC. LMT= UTC + 2 h.

Fig. 1. General view of initial route of Flight ENT 427UM.
Source: https://www.radarbox.com/ [Access: 11.05.2023].

Alternatively, they were going to divert to EPPO. Pilots requested to forward this message to their OPS Officer. Then ATC informed the crew that their OPS requested them (in the event of diversion) to fly to EPWA. Pilots stated to ATC that after initial fuel burn, they are going to land in EPGD. If WX conditions will not permit – on request of EnterAir OPS Officer – pilots were going to divert to EPWA. Crew copied the latest WX report from the EPWA which showed CAVOK[2] conditions. Additionally, the crew asked about current conditions on the way from EPGD to EPWA. ATC advised no CBs between EPGD and EPWA airports. In the meantime, ATC informed pilots that Wizzair A-320 crew who were commenced approach in to EPGD for RWY 29 reported tailwind at 3000 ft up to 28 kt. Wind was slowing down to 8-10 kt at 1000 ft, shifting its direction to the right crosswind. However, the pilots of ENT472UM decided to divert to EPWA and consequently, at 17:48 UTC informed ATC accordingly, that due to landing performance on one operating engine and Flaps 15, EPWA is their final option to land.
Pilots decided to continue flight to EPWA at FL120. Initially maintaining HDG 160º the crew decided to change their status and declared MAYDAY. ATC requested them to switch transponder squawk to 7700. When passing EPGD southbound the crew received clearance to fly directly to waypoint GOSIT which is 9.8 NM final of RWY 11 in EPWA. The flight to EPWA was uneventful. Upon check-in to APP EPWA, the crew received clearance to initially descend to FL100 and further descend according to standard profile. The captain advised cabin crew to complete full emergency landing briefing to passengers. The crew calculated landing performance for Flaps 15 and one-engine operative for RWY11. At 18:34 crew received clearance for the approach. After

[2] **CAVOK** – The Visibility, Cloud, and Weather groups are replaced by the term CAVOK (cloud and visibility OK) when the following conditions exist simultaneously: Visibility is 10km or more. No CB or TCU and no cloud below 5000 feet or Minimum Sector Altitude (MSA) (whichever is the greater). No significant weather at or in the vicinity of the aerodrome.

execution of ILS-Y approach for RWY11 the plane landed safely at 18:37 and taxied to stand 25R.

1.2. Injuries to persons

Injuries	Crew	Passengers	Others	Total
Fatal	**-**	**-**	**-**	
Serious	**-**	**-**	**-**	
Minor	**-**	**-**	**-**	
None	**6**	**171**	**0**	**177**

1.3. Damage to aircraft

1. Engine #2 HPT Blade #80 fractured at ~15% of its span, while multiple HPT blades and downstream hardware were damaged due to impact from the liberated debris.

Fig. 2. HPT BSI results. Engine #2, HPT Blade #80 fracture at ~15% span, while multiple HPT blades and downstream hardware damaged due to impact from the liberated debris.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P. 4.

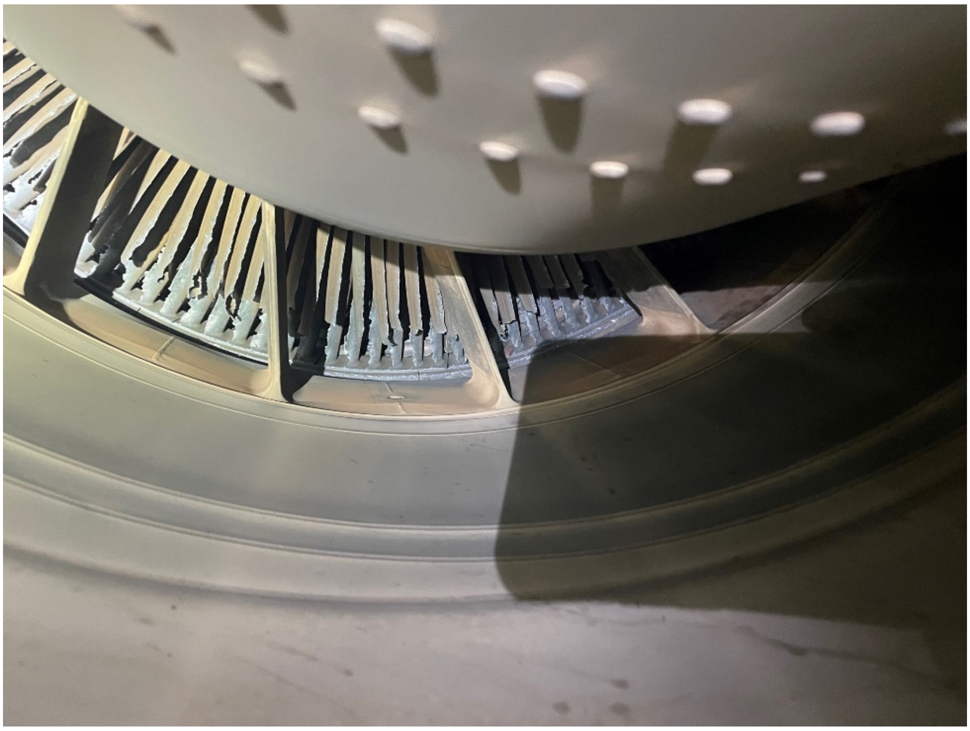

Fig. 3. Two pictures of stage 4 LPT blades of Engine #2 and downstream hardware damaged due to impact from the liberated debris.

Source: Provided by operator.

2. Dents on the right side of horizontal stabilizer.

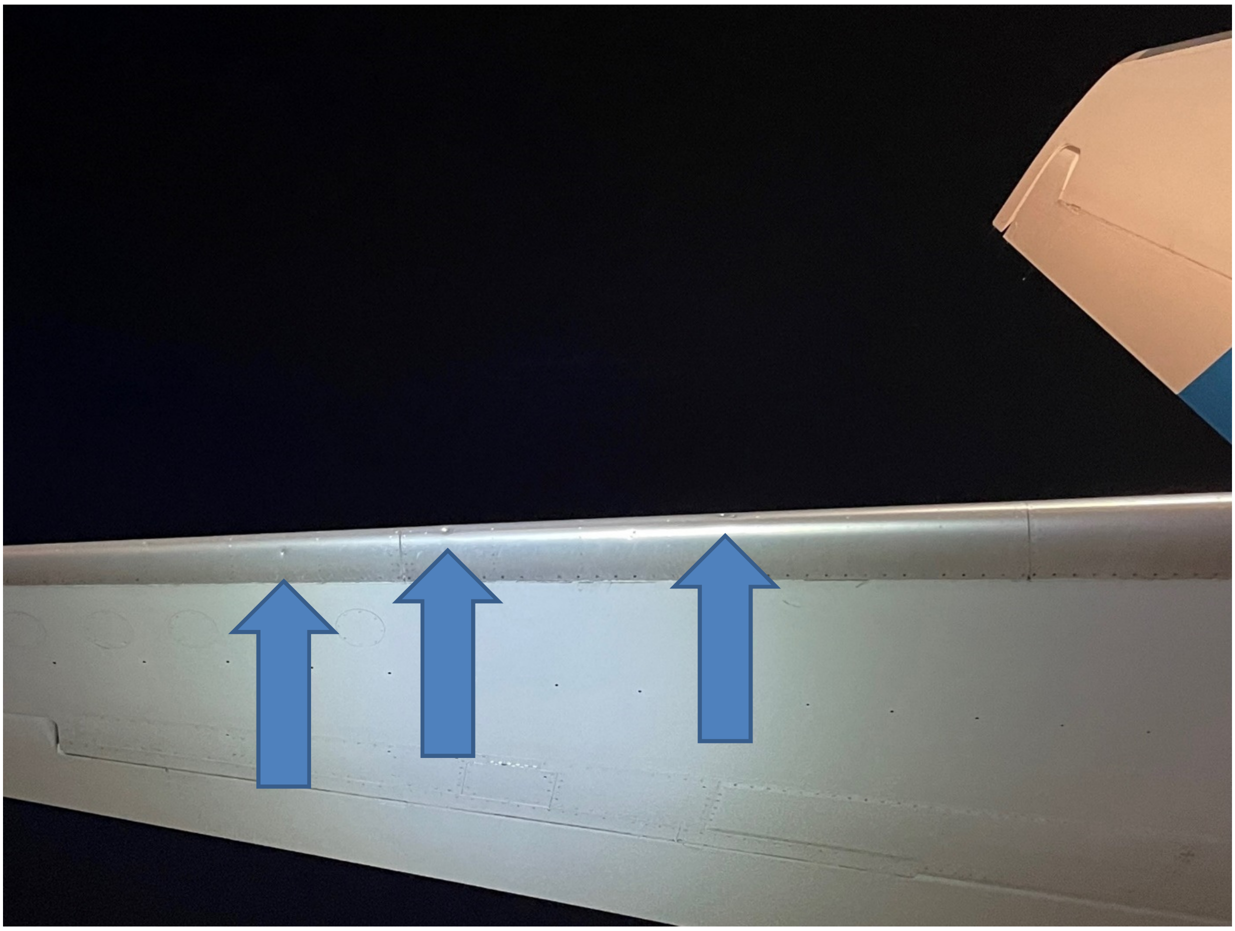

Fig. 4. Multiple dents on the right side of horizontal stabilizer.

Source: Provided by operator.

3. Scratches and dents on lower side of flap support fairing on right wing.

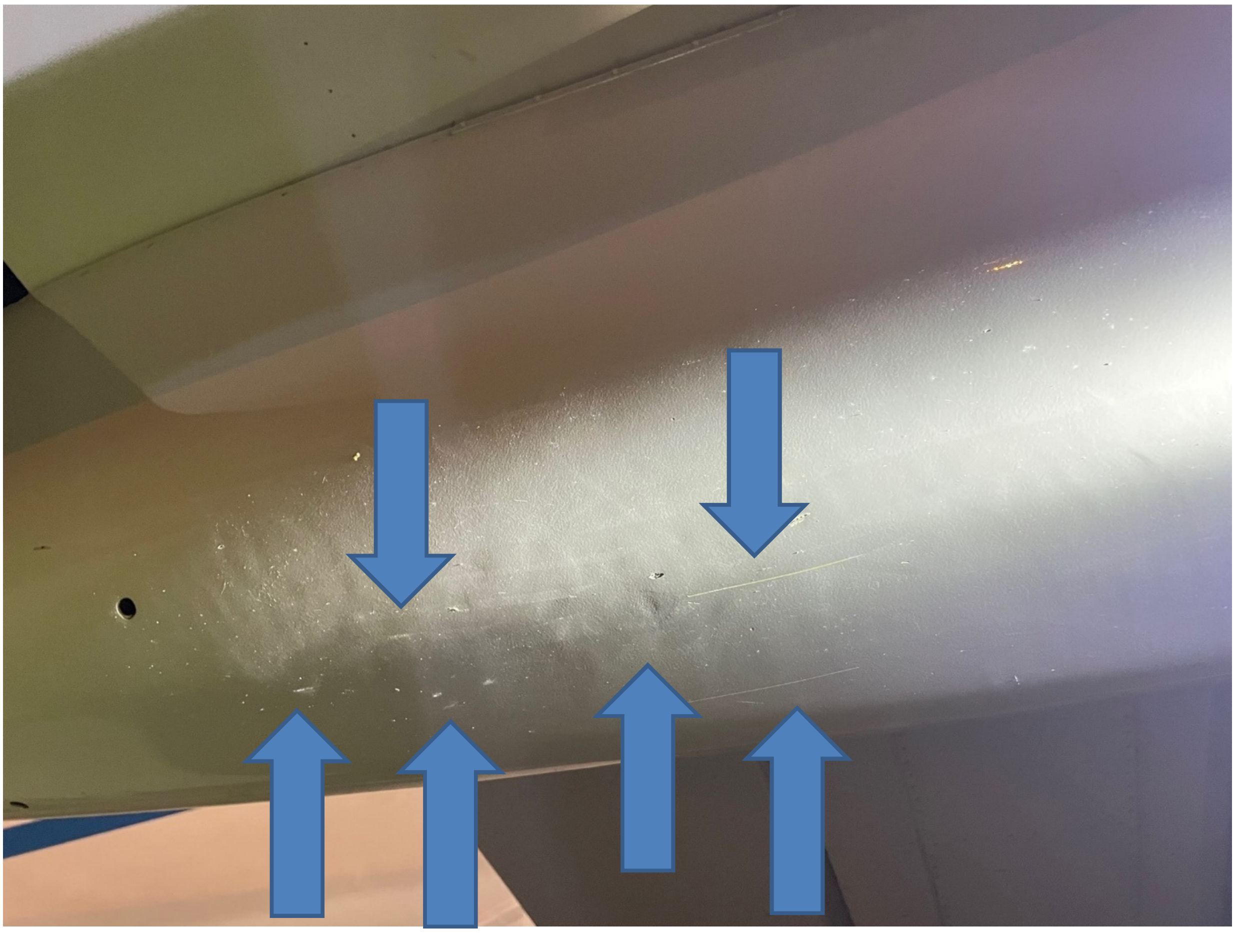

Fig. 5. Multiply scratches and dents on lower side of flap support fairing on right wing.

Source: Provided by operator.

4. Dent and crack on of leading edge of the right side of horizontal stabilizer.

Fig. 6. Dent and crack on of leading edge on leading edge of the right side horizontal stabilizer.

Source: Provided by operator.

1.4. Other damage

Nil.

1.5. Personnel information (crew data)

1.5.1. Captain (CPT)

Male, aged 47, holder of:

- ATPL(A) with a valid rating for Boeing B737 300-900;
- Aero-medical assessment: Class 1, valid – VDL limitations (correction for defective distant vision)[3];
- Role during the flight: Initially Pilot Monitoring, later after eng. no. 2 fail: Pilot Flying.

1.5.2. First Officer (FO)

Male, aged 28, holder of:

- ATPL(A) with a valid rating for B737 300-900;
- Aero-medical assessment: Class 1, valid – VDL limitations (correction for defective distant vision);
- Role during the flight: Initially Pilot Flying, later after eng. no. 2 fail: Pilot Monitoring.

1.6. Aircraft information

1.6.1. General information.

The B738 is a member of the B737 family of aircraft. The 737-800 is a stretched version of the 737-700 and replaces the 737-400.

Technical Data:

Wingspan (metric)	34.32 m
Length (metric)	39.50 m
Height (metric)	12.60 m

[3] **VDL** Wear corrective lenses and carry a spare set of spectacles. Correction for defective distant vision: whilst exercising the privileges of the licence, the pilot should wear spectacles or contact lenses that correct for defective distant vision as examined and approved by the AME. Contact lenses may not be worn until cleared to do so by the AME. If contact lenses are worn, a spare set of spectacles, approved by the AME, should be carried.

Fig. 7. Boeing 737-800 of EnterAir, SP-ENU.

Source : https://www.jetphotos.com/photo/8630848

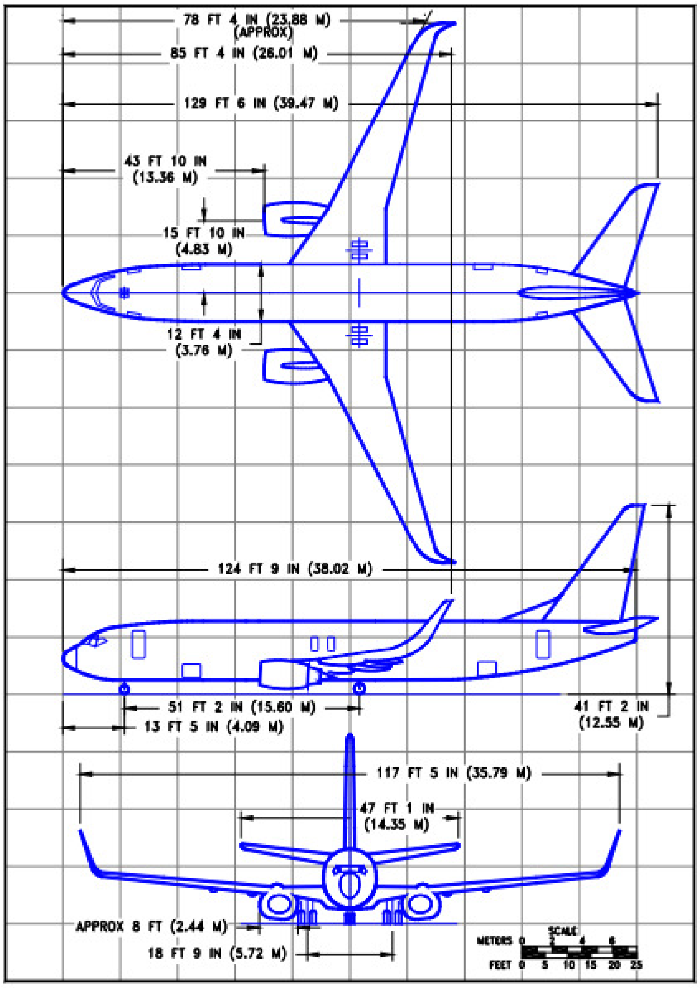

Fig. 8. General dimensions. Model Boeing 737-800 with winglets.

Source: 737 Airplane Characteristics for Airport Planning. Boeing commercial airplanes. Page 39.

Aircraft:

Year of construction	Aircraft manufacturer	Serial number	Registration	Number of registration	Date of registration in Poland
2001	Boeing Company	30 675	SP-ENU	4767	21 JAN 2019

Technical Certificate valid until: **15 MAY 2023.**

Airframe flight from the beginning of operation: **51 318.7 hours.**

Number of flights since new: **19 506 flights.**

Airframe flight since the last repair or inspection: **C-check 1081 hours.**

Service life remained until the next repair or inspection: **4919 hours/or 3626 Flight Cycles[4] or 20 months.**

Date of last periodic checks: **A-check 08 AUG 2022.**

- after total flight time: **51 231.2 hours.**

Check completed by: **KTW Maintenance base.**

Next periodic check:

- 48 hours: **left 32 hours.**
- Weekly: **left 2 days.**

Engines:

Engine No. 1.

Year of manufacture	Engine manufacturer	Serial number
1998	CFM	874539

Date of installation of engine **No. 1** on the airframe: **09 JUL 2020.**

Max. take-off power: **117kN.**

Engine operating time from the beginning of operation: **69 557.5 hours.**

Time since the last major repair: **13 816.6 hours.**

Service life remained until the next repair or inspection: **6500 hours**.

Date of last periodic weekly check: **09 AUG 2022.**

after working hours: **69 484.7 hours.**

- **Next periodic weekly check: left 2 days.**

[4] Flight Cycle: for aircraft, F/C is defined as a completed take-off and landing sequence. Touch-and-Go landings are counted as flight cycles.

Engine No.2.

Year of manufacture	Engine manufacturer	Serial number
1998	CFM	874306

Date of installation of engine **No. 2** on the airframe: **09 OCT 2019.**

Max. take-off power: **117kN.**

Engine operating time from the beginning of operation: **59 223.6 hours.**

Time since the last major repair: **4793 hours.**

Service life remained until the next repair or inspection: **13 500 hours.**

Date of last periodic weekly check: **09 AUG 2022.**

after working hours: **59 150.8 hours.**

- **Next periodic weekly check: left 2 days.**

1.7. Meteorological information

On 15th of August 2022 Poland was under influence of stormy weather. At 13:26 UTC for Warsaw Flight Information Region (FIR) MET Office issued SIGMET[5] 1:

EPWW SIGMET 1 VALID 151330/151730 EPWA - EPWW WARSAW FIR FRQ TS OBS WI N5420 E01855 - N5235 E01905 - N5210 E01645 - N5405 E01455 - N5450 E01820 - N5420 E01855 TOP FL390 MOV NW SLW NC=

The SIGMET meant that in Warsaw FIR there were observed frequent thunderstorms on line with coordinates: N5420 E01855 - N5235 E01905 - N5210 E01645 - N5405 E01455 - N5450 E01820 - N5420 E01855, reaching top of the clouds up to FL390 moving slowly to North-West. Described coordinates of storm line cover data included in WAFC Signficant Weather (SIGWX)[6] Map valid 12UTC the 15th of AUG 2022 (see blue arrow on map below).

[5] **SIGMET** information is information issued by a meteorological watch office concerning the occurrence or expected occurrence of specified en-route weather phenomena which may affect the safety of aircraft operations. (ICAO Annex 3: Meteorology). A SIGMET gives a concise description of the phenomena in abbreviated plain language. The following are examples of weather phenomena that may be described in a SIGMET: Thunderstorms, Cyclones (Tropical Revolving Storms), Severe turbulence, Severe icing, Severe Mountain Waves, Dust or Sandstorms, Volcanic Ash.
Source: https://www.skybrary.aero/articles/sigmet, [access: 01.06.2023].

[6] WAFC SIGWX - The World Area Forecast Centres Significant Weather forecasts are provided for 'fixed validity times'. This is as specified in ICAO Annex 3 – Meteorological Service for International Air Navigation and ICAO Doc 8896 – Manual of Aeronautical Meteorological Practice. However, ICAO have noted, in ICAO Doc 8896, that the WAFC SIGWX forecasts are 'usable' for a period of time extending from 3 hours before to 3 hours after the stated 'fixed' validity time.
Source: Guidelines for interpreting World Area Forecast Centre Significant Weather forecasts: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/services/transport/aviation/ga/sigwx-interpretation-guide.pdf, [access: 02.06.2023].

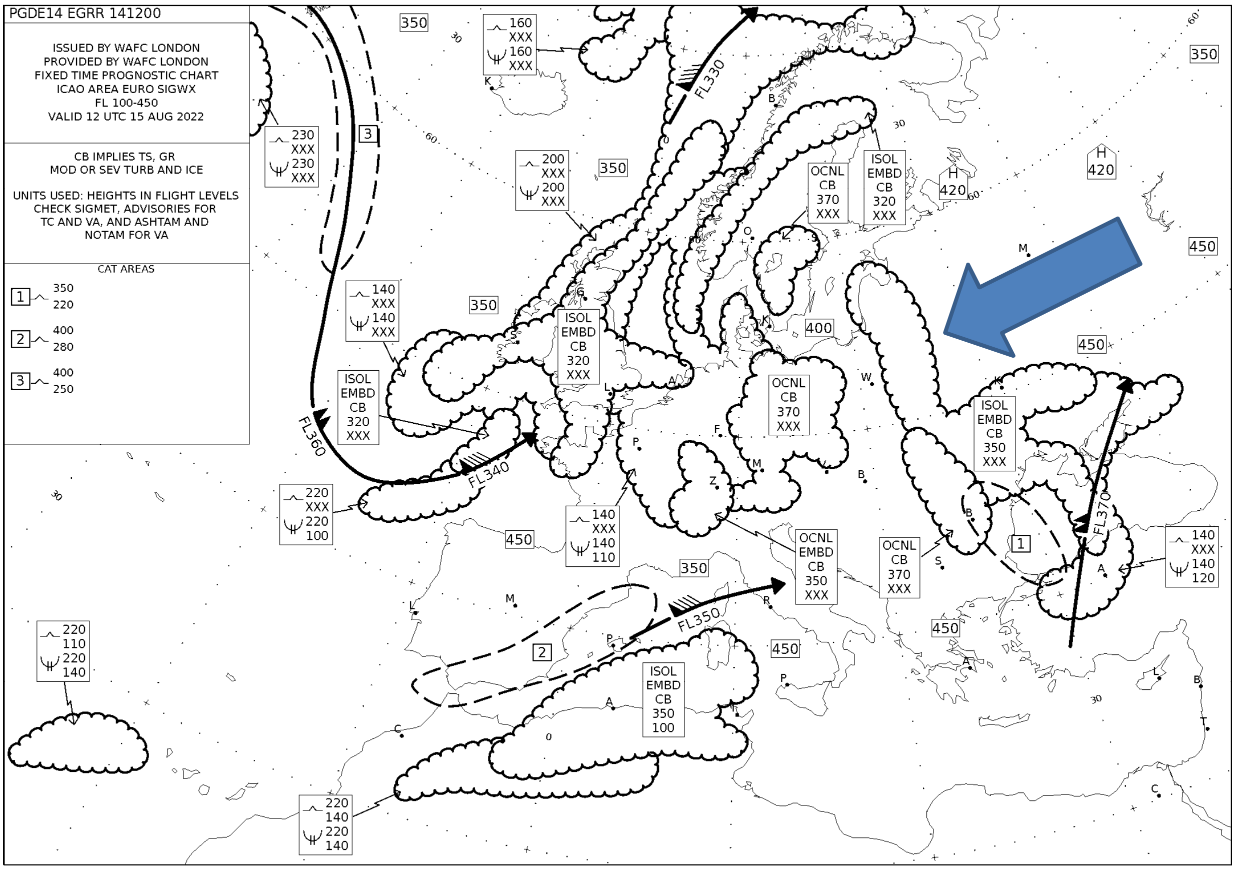

Fig. 9. WAFC SIGWX valid 12 UTC the 15th of August 2022.
source: https://awiacja.imgw.pl/sigmet/

Current METAR[7] which was implemented at 14:30 shows the following data:

2022/08/15 14:30 EPGD 151430Z 03011KT 360V060 9999 -SHRA VCTS SCT048CB 23/20 Q1008 RETSRA.

Wind from direction 030°, 11 kt, variable from 360° to 060° Visibility more than 10 km. Observed light shower rain. Thunderstorm noted in the vicinity of the aerodrome noted thunderstorm. Clouds 6-7/8 Cumulonimbus, cloud base 4800 ft. Ambient temperature +23°C, dewpoint +20°C, QNH 1008 hPa. Recently noted Thunderstorm with associated rain.

Implemented by IMGW (Polski Instytut Meteorologii i Gospodarki Wodnej – Polish Institute of Meteorology and Water Management) local SIGWX valid at 18:00 UTC the 15th of August 2022 shows frequent Cumulonimbus over North-West and West side of Poland and isolated Cumulonimbus over North-East side of Poland with unknown top of clouds and cloud base 3000-5000 ft. Central part of Polandwith 6-8/8 of Cumulus with

[7] Meteorological Aerodrome Report (**METAR**), also known as Meteorological Terminal Aviation Routine Weather Report, Meteorological Terminal Air Report or Meteorological Airfield Report is a format for reporting weather information. The World Meteorological Organisation (WMO) describes METAR as the aerodrome routine meteorological report.

cloud ceiling of 3000-5000 ft. Blue arrow shows location of EPGD airport. Green arrow shows location of EPWA airport.

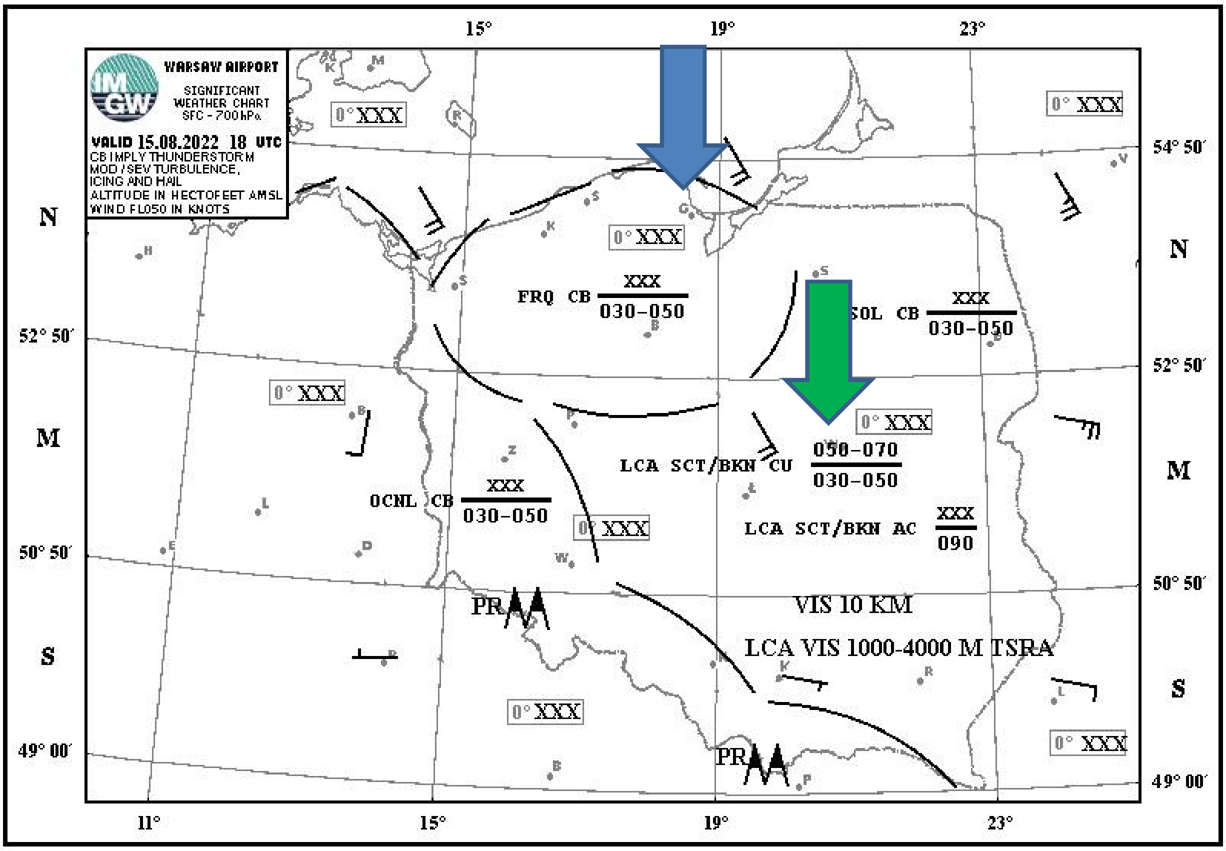

Fig. 10. Local SIGWX valid 18 UTC the 15th of August 2022.
source: https://awiacja.imgw.pl/sigmet/

1.8. Aids to navigation

The flight crew completed a standard instrument departure from **EPGD** airport based on RNAV1 capability.

The flight crew completed a standard ILS approach to RWY 11 of **EPWA**.

Aid type, cat. ILS/MLS (declination for VOR/ILS/MLS)	ID	Frequency	Working hours	Transmitting antenna position coordinates (WGS-84)/	DME ELEV	Notes
DME	WA	CH40X	H24	52°09'24.4'' N 020°58'22.7'' E	120 m AMSL	Designated operational coverage: 25 NM (up to FL100)
DME	WAS	CH36X	H24	52°10'16.2'' N 020°57'05.9'' E	120 m AMSL	Designated operational coverage: 25 NM (up to FL100)
DVOR/DME (6°E/Nov 20)	OKC	113.450 MHz CH81Y	H24	52°10'11.1'' N 020°57'36.2'' E	120 m AMSL	Designated operational coverage: 80 NM (up to FL250)
DVOR/DME (5°E/Oct 05)	WAR	114.900 MHz CH96X	H24	52°15'33.3'' N 020°39'25.8'' E	90 m AMSL	Designated operational coverage: 150 NM (000°-090°), 80 NM (090°- 000°) - up to FL500
ILS GP	-	333,800 MHz	H24	52°10'16.2'' N 020°57'05.9'' E	…	Coverage acc. to Annex 10 ICAO volume I. RDH: 53 ft. GP 3.0°

ILS GP	-	335.000 MHz	H24	52°09'24.4'' N 020°58'22.7'' E	…	Coverage acc. to Annex 10 ICAO volume I. RDH: 54 ft. GP 3.0°
ILS LOC (6°E/Nov 20)	WAS		H24	52°09'38.2'' N 020°59'07.5'' E	…	Coverage acc. to Annex 10 ICAO volume I. CAT. II
ILS LOC (6°E/Nov 20)	WA	110.300 MHz	H24	52°10'50.0'' N 020°57'15.0'' E	…	Coverage acc. to Annex 10 ICAO volume I. CAT. III A

Fig. 11. EPWA aids to navigation aids.
source: https://www.ais.pansa.pl/aip/pliki/EP_AD_2_EPWA_en.pdf AIP Poland.

Rodzaj pomocy, kat. ILS/MLS deklinacja dla VOR/ILS/MLS Type of aid, CAT of ILS/MLS (for VOR/ILS/ MLS give VAR)	**Znak rozpoznawczy ID**	**Częstotliwość Frequency**	**Godziny pracy Hours of operation**	**Współrzędne posadowienia anteny nadawczej (WGS-84) Site of transmitting antenna coordinates (WGS-84)**	**Uwagi Remarks**
NDB	GDA	322 kHz	H24	54°20'42.57"N 018°35'45.87"E	109°, 7.38 km FM THR 29
DME	IGDA	-	H24	54°22'18.22"N 018°29'06.44"E	DME IGDA CH40X ELEV 150 m AMSL
L	S	383 kHz	H24	54°22'03.90"N 018°30'21.22"E	109°, 1.00 km FM THR 29
ILS LLZ	IGDA	110.300 MHz	H24	54°22'57.08"N 018°26'46.16"E	CAT I RWY 29 289°, 0.42 km FM THR 11
ILS GP	-	335.000 MHz	H24	54°22'18.22"N 018°29'06.44"E	GP 2.9°, 0.12 km S FM RCL 0.42 km FM THR 29 along RWY RCL, RDH = 17.8 m

Fig. 12. EPGD aids to navigation aids.
Source: https://www.airport.gdansk.pl/UserFiles/file/EP_AD_2_EPGD_en.pdf .

1.9. Communications

Radio communication was carried out with standard means of communication of the aircraft was equipped. All recordings of communication between the flight crew and ATC in the Polish airspace were available for the Investigation Team. Communication in both directions was clear and readable.

1.10. Aerodrome information

Departure aerodrome:

Gdansk Lech Walesa Airport (EPGD) is certified and prepared to accept all aircrafts up to the reference code letter 4D, not greater than MD11. VFR and IFR operations are permitted according to ILS categories I, II and III and LVTO at RVR not less than 125 m. Apron management service is provided by the airport operator. Rescue and firefighting services – category 7.

1.	**ARP - współrzędne WGS-84 i lokalizacja** **ARP - WGS-84 coordinates and site at AD**	54°22'39.25"N 018°27'58.40"E Centralna linia RWY, 1800 m od THR 29./RWY centre line, 1800 m from THR 29.
2.	**Odległość, kierunek od miasta** **Direction and distance from city**	12 km (6.5 NM), BRG 285° GEO.
3.	**Wzniesienie lotniska/Temperatura odniesienia** **Elevation/Reference temperature**	149 m. 21.5°C (JUL).
4.	**Undulacja geoidy w miejscu pomiaru wzniesienia lotniska/Geoid undulation at AD ELEV PSN**	29 m.
5.	**Deklinacja magnetyczna i jej roczna poprawka** **MAG VAR/Annual change**	4°E (2007) +7'E
6.	**Zarządzający lotniskiem, adres, telefon, faks, teleks, AFS** **AD Administration, address, telephone, telefax, telex, AFS**	**Zarządzający lotniskiem/Aerodrome operator:** Port Lotniczy GDAŃSK Sp. z o.o. **Adres pocztowy/Postal address:** Port Lotniczy GDAŃSK Sp. z o.o. ul. J. Słowackiego 200 80-298 Gdańsk 43 **Adres telegraficzny/Telegraphic address:** AFS - EPGDYDYX **Telefony/Telephone numbers:** Sekretariat/Office - +48-58-348-1154 +48-58-345-2283 faks/fax Dyżurny Portu/Aerodrome Duty officer - +48-58-348-1159 +48-606-268-370 kom./mobile +48-58-348-1459 faks/fax www: http://www.airport.gdansk.pl E-mail: airport@airport.gdansk.pl
7.	**Dozwolony ruch lotniczy (IFR/VFR)** **Types of traffic permitted (IFR/VFR)**	IFR/VFR
8.	**Uwagi/Remarks**	**Telefony:/Phones:** TWR - +48-58-348-1152 +48-58-340-7469 faks/fax APP - +48-58-348-1109 +48-58-340-7479 faks/fax ARO - +48-58-348-1156 +48-58-340-7489 faks/fax FIS +48-58-340-7485 +48-58-340-7486 faks/fax Służba Ochrony Lotniska/Airport Security Services - +48-58-348-1132 +48-58-348-1267 faks/fax Catering - +48-58-348-1341 Biuro TAF/TAF Office - +48-58-628-8151

Fig. 13. EPGD Aerodrome data.
Source: https://www.airport.gdansk.pl/UserFiles/file/EP_AD_2_EPGD_en.pdf

Arrival aerodrome:

Warsaw Chopin Airport (EPWA) is certified and prepared to accept all aircrafts up to the reference code letter 4E. The airport operator allows the operation of aircraft with a higher reference code letter (B-748, A-380, C-5B Galaxy, An-124) in accordance with the procedure described in the Airport Operational Manual (INOP). VFR and IFR operations are permitted according to ILS categories I, II and III and LVTO at RVR not less than 125 m. It is allowed to perform take-offs from intermediate distances, in accordance with the published declared distances in AIP Poland and INOP. Apron management service is provided by the airport operator. Rescue and firefighting services – category 9.

1.	**ARP - WGS-84 coordinates and aerodrome location** 52°09'57''N 020°58'02''E - Runway intersection.
2.	**Distance, direction from city** 10 km (5.4 NM) BRG 205° GEO
3.	**Aerodrome elevation/Reference temperature** 362 ft./27.8°C
4.	**Geoid undulation at the aerodrome elevation measurement point** 103 ft.
5.	**Magnetic declination and its annual correction** 6°E (2020)/ 9'E
6.	**Aerodrome administrator, address, telephone, fax, telex, AFS** Przedsiębiorstwo Państwowe "Porty Lotnicze" ul. Żwirki i Wigury 1 00-906 Warsaw +48-22-650-1555 (tel.) AFS: EPWAYDYX www.lotnisko-chopina.pl
7.	**Permitted air traffic (IFR/VFR)** IFR/VFR
8.	**Notes** Duty Officers Shift Manager: +48-22-650-1555 +48-22-846-1100 +48-22-650-1343 +48-22-650-1428 Customs Department: +48-22-650-3403 +48-22-650-2873 ATM Shift Manager: +48-22-574-5542, +48-81-452-5542 +48-22-574-5543, +48-81-452-5543 +48-22-574-7000, +48-81-452-7000 ACC: +48-22-574-7029, +48-81-452-7029 +48-22-574-5539, +48-81-452-5539 (fax) FMP: +48-22-574-5532, +48-81-452-5532 +48-22-574-7051, +48-81-452-7051 +48-22574-5539, +48-81-452-5539 (fax) APP: +48-22-574-5552, +48-81-452-5552 TWR Shift Manager: +48-22-574-5562, +48-81-452-5562 TWR: +48-22-574-5563, +48-81-452-5563 ARO: +48-22-574-7173, +48-81-452-7173 +48-22-574-7188, +48-81-452-7188 (fax) Brigade General Walerian Czuma Border Guard Outpost at Warsaw-Okęcie: +48-22- 650-2244 Aerodrome and Handling Fee Collection Booth: +48-22-650-3878 Medical Unit: +48-22-650-2444

Fig. 14. EPWA Aerodrome data.
Source: https://www.ais.pansa.pl/aip/pliki/EP_AD_2_EPWA_en.pdf, AIP Poland.

1.11. Flight recorders

In accordance with the regulations, the aircraft was equipped with two types of recorders:

- Flight Data Recorder (FDR).
- Cockpit Voice Recorder (CVR).

And additional on Quick Access Recorder (QAR).

FDR – Honeywell solid state memory recorder, model SSFDR, P/N: 980-4700-042, S/N: 09283, recording rate 256 WPS. Read-out data from this recorder made by the aircraft operator and made available to the PKBWL investigation team on August 25, 2022. The read-out data covered the period of the last 25 flight hours. There were 386 parameters stored in the recorder memory (142 discrete and 244 analog). The acquired data was used to analyze the operation of the aircraft's power units and to reconstruct the sequence of events during the take-off and flight along the EPGD-EPWA route. Insight Analysis 4.9 and FDS 9 software were used to analyze.

CVR – Honeywell solid-state recorder, model SSCVR, P/N: 980-6022-001, S/N: CVR120-04013. The data from the recorder was not used for the investigation because about 4 hours elapsed from the engine failure to aircraft landing in EPWA., therefore the information interesting to the Investigation Team was overwritten.

QAR - Collins Aerospace solid state memory recorder, model ADM Lite Kit, P/N: 08716-0251-0015 S/N: 3-65728. Because the QAR records the same data as the FDR, the QAR recording was used by the PKBWL Investigation Team for its analysis.

1.12. Wreckage and impact information

Not applicable.

1.13. Medical and pathological information

Not applicable.

1.14. Fire

Fire did not occur.

1.15. Survival aspects

Not applicable.

1.16. Tests and research

One of the investigation methods was an analysis of the recorded data by the flight data monitoring system (FDMS). Investigation team compiled data from the FDMS with transcription of radio communication and mapped course of action of flight crew in terms of plane position.

Initial method related to examination of specific components in failed engine were disassembly and inspection. In advanced process of investigation experts used Special Investigation Work scope HPTB airfoil separation + LPT damages + debris in aft sump MCD (Magnetic chip detector). Method of investigation as per below:

- Take pictures of engine.
- Perform the accessories inventory.
- Perform the QEC inventory.
- Perform the Missing parts inventory.
- Check and inspect the filters, chip detectors and scavenge screens.
- Perform a Full Borescope inspection on the engine.
- Take e-pictures of all significant findings. If debris is collected, use suitable bags/ containers and tag.
- bags/ containers with appropriate information (ex: part name, location).
- Check N1 and N2 free rotation.
- Work on a step-by-step basis.

1.17. Organizational and management information

Not investigated.

1.18. Additional information

None.

1.19. Useful or effective investigation techniques

Standard investigation techniques were applied.

2. ANALYSIS

2.1 General

The Report was developed based on analysis of the collected materials and the statements of the flight crew members.

2.2 Flight operations

<u>Analysis of Flight Crew performance:</u>

On the date of incident both pilots had valid licenses with valid B-737/300-900 rating confirmed by standard endorsement and signature of TRE with number of examiner`s certificate. Medical check class I confirmed. Capt. and FO`s Limitations: VDL correction for defective distant vision.

Both pilots have been planned for their duties according to Flight Time Limitations. All details related to 90, 30 and last 7 days of operations have been checked. According to delivered roster, both pilots have been planned to operate together the 14th of AUG 2022 on route: EPPO-LGSA-EPGD, departure time 00:57. Crew landed in EPGD at 07:52.

The 15th of AUG 2022, crew was scheduled to operate route: EPGD-GCFV, STD 14:35. Crew was planned to operate from EPGD, out of home base (EPPO). Crew rested in adequate hotel. Not reported any distraction in resting period. Crew reported for their duty rested and ready to work. Reported in the airport on-time. Having information that plane will land with minor delay from the previous sector, pilots decided to go to the aircraft as soon as possible. Previous crew have been met by operating pilots. No technical issues have been reported. Pilots decided that FO will be PF on the sector EPGD-GCFV. Captain completed walkaround. Standard flight preparation has been completed.

Planned ramp fuel for departure: 17 736 kg. Crew decided to depart with 18 500 kg. Pre-flight security check has been completed. Loading of the aircraft, based on Load sheet which shows all parameters within the limit. Noted underload: 4394 kg, MACTOW: 19.7.

Crew completed Performance Calculations for departure from RWY11. Based on weather: wind 040/20 kt, QNH 1008h hPa, OAT +24C and wet RWY conditions crew decided to use taxiway HOTEL intersection figures. Based on above crew used assumed temperature of +33°C where in result obtained N1 98.17%. Flaps 5 wet speeds: V1- 141kt, VR – 149, V2 – 155 kt.

Plane moved from the stand with 10 min. delay at 14:45. Plane departed from EPGD airport at 14:59 (RWY11, SID: DEXIR 2H). Take-off roll, lift-off and climb with no deviations. After departure crew received clearance to climb to FL280. Plane departed southbound and during the climb pilots requested to deviate from standard routing to heading 220° to avoid clouds. Further right turn to heading 230° for next 20 NM was requested. At around FL110 crew noted abnormal noise coming from the engine number 2 and unstable engine parameters. Plane slightly banked to the right. Commander decided to take control and became role of PF. FO took the role of PM. Captain disconnected A/P and A/T. Gently reduced thrust of Eng. No. 2 to idle. Crew called to ATC with request to stop to climb and maintain FL120 in holding pattern. Crew reviewed situation and stated that plane is controllable and failed engine can be re-started in the air. Based on crew`s statement N1 and N2 indications (Flight Data Monitoring analysis is included in this section) have been observed, however due to unusual sound crew decided to complete check-list: *NNC. 8.2. Engine Fire or Engine Severe Damage or Separation*. No fire was detected. Completing mentioned check-list, Engine Fire Switch was not pulled up. Below extract from Boeing QRH with related memory items when completing Engine Severe Damage or Separation check-list. Point 4 shows that Engine Fire Switch must be pulled. Which crew did not complete.

8.2 BOEING
737 Flight Crew Operations Manual

ENGINE FIRE ( )
or
Engine Severe Damage
or Separation ( )

Condition: One or more of these occur:
- Engine fire warning
- Airframe vibrations with abnormal engine indications
- Engine separation.

1 Autothrottle (if engaged) . . . . .Disengage

2 Thrust lever
(affected engine) . . . . . . Confirm . . . . Close

3 Engine start lever
(affected engine) . . . . . . Confirm . . . . . CUTOFF

4 Engine fire switch
(affected engine) . . . . . . Confirm . . . . Pull

To manually unlock the engine fire switch, press the override and pull.

5 **If** the engine fire switch or ENG OVERHEAT light is illuminated

Engine fire switch
(affected engine) . . . . Rotate to the stop and hold for 1 second

Fig. 15. Extract from Boeing QRH. Part of the check-list: Engine Fire or Engine Severe Damage or Separation.

Source: Quick Reference Handbook, 737 Flight Crew Operations Manual.

Due to cells of thunderstorm in the vicinity of the airfield crew requested to change position of holding and stated to ATC that due to technical problem they would like to come back to EPGD airport. Being too heavy for landing pilots decided to burn fuel to reduce LW. Pilots decided to reduce weight for landing although Boeing allows an overweight landing. Below extract from 737 FCTM.

Overweight Landing

Overweight landings may be safely accomplished by using normal landing procedures and techniques. There are no adverse handling characteristics associated with overweight landings. Landing distance is normally less than takeoff distance for flaps 30 or 40 landings at all gross weights. However, wet or slippery runway field length requirements should be verified from the landing distance charts in the PI chapter of the QRH. Brake energy limits will not be exceeded for flaps 30 or 40 normal landings at all gross weights.

Note: Use of flaps 30 rather than flaps 40 is recommended to provide increased margin to flap placard speed.

Pilots entered holding pattern over the waypoint GD704 and then due to influence of thunderstorm changed holding over the waypoint GD531 which is located around 20 NM south of the airfield. Crew had a problem to find clear airspace due to dynamic weather conditions. Finally decided to fly to the North-East from the EPGD where area looks relatively clear. Flying in this area plane was around 10 NM from the Russian border (FIR Kaliningrad), which was reported to crew by ATC.

Crew declared PAN-PAN and completed TDODAR and NITS briefing for the cabin crew. Crew constantly was asking ATC for the latest MET report over EPGD airport. After completion TDODAR and NITS crew one more time reviewed indications of engine No. 2 and decided to restart engine in flight. Pilots commenced to complete check-list *QRH NNC. 7.24 Engine In-Flight Start*. Engine No. 2 did not relight. Pilots completed again *QRH NNC 8.2 Engine Fire or Engine Severe Damage or Separation*. Again did not complete point 4 from NNC. 8.2. In the meantime, pilots reviewed weather condition. Weather around EPGD airport deteriorated and pilots requested from ATC current weather conditions from EPSC, EPSY, EPBY, EPMO Airports. Additionally, ATC advised that EPBY TWR is out of service. So, pilots requested weather conditions from EPPO.

ATC reported CB clouds over EPSY airport and CAVOK conditions over EPPO. ATC stated to crew that they have got online EnterAir Operational Officer and he is suggesting diversion to EPWA. Burning fuel and reducing LW crew informed ATC that their primary plan is to land in to EPGD. Alternatively, they are going to divert to EPPO. Pilots requested to forward this message to their Operational Officer. ATC called again pilots and stated that EnterAir Operational Officer requested crew (in the event of diversion) to fly to EPWA, not to EPPO due to better maintenance support. Pilots stated to ATC that after initial fuel burn, they are going to land in EPGD. If WX conditions will not permit – on request of EnterAir OPS Officer - pilots are going to divert to EPWA.

Crew copied the latest WX report from the EPWA which shows CAVOK conditions. Additionally, crew asked about current conditions on the way from EPGD to EPWA. ATC advised no CBs between EPGD and EPWA. In the meantime, ATC informed pilots that Wizzair Airbus A-320 crew who was commencing approach in to EPGD for RWY29 reported tailwind at 3000ft tailwind 28kt. Wind is dropping down to 8-10kt at 1000ft shifting to the right crosswind. Two A-320 landed on the RWY29. After received such an information pilots of ENT72UM decided to divert to EPWA. At 17:48 pilots explained ATC that due to landing performance on one inoperative engine and Flaps 15, EPWA is their final option to land.

Pilots decided to operate to EPWA at FL120. Initially maintaining HDG 160° crew decided to change their status and declared MAY DAY. ATC requested to change squawk on 7700. Passing EPGD airport southbound crew received clearance to fly direct to navigation point GOSIT which is located on 9.8 NM final of RWY 11 in EPWA. Plane operates towards to EPWA uneventfully. Checking-in to APP EPWA, crew received clearance to initially descend to FL100. Further descend according to standard profile. Commander advised to cabin crew to complete full emergency landing briefing to passengers. Crew calculated landing performance for Flaps 15 and one-engine inoperative for RWY 11. At 18:34 UTC crew received clearance for the approach. After execution of ILS-Y for RWY 11 plane landed safely at 18:37. Plane taxied to stand 25R.

Prior to the flight the pilots were rested according to Flight Time Limitations (FTL) Scheme and related regulations. Both have been fit to fly and did not report any issues. Flight preparation was performed under some pressure due to late arrival of the aircraft from previous flight but that fact had no influence on crew`s performance (according to their statement). Operation out of base and preparation for the flight outside of standard briefing room environmental is a normal procedure for EnterAir crews.

Taking off with a plane close to MTOW in turbulent and stormy conditions can be a stressing factor for the crew. Bearing in mind that they were expecting to spend in the air 5h and 25min. and were prepared for a long trip and it is obvious that engine failure at early stage of a climb, created startle effect. Stormy weather was an additional hazard, which was identified by crew. It complicated crew performance and resulted in an extra tasks where crew was forced to find clear airspace to deal with engine failure. Proximity of Russian airspace was another threat and limiting factor.

Having noticed an unusual noise, vibrations and unstable engine No. 2 parameters, the crew classified the occurrence as Engine Fire or Engine Severe Damage or Separation (fig. 15.) and consequently referred to the *QRH NNC 8.2 Engine Fire or Engine Severe Damage or Separation,* which among others, lists the condition: *Airframe vibrations with abnormal engine indications*. Therefore, the crew executed the appropriate check list, but omitted its item No. 4 from the check list, which requires the crew to pull out Engine Fire Switch (EFS). Pulling out EFS has the following effects:

- arms one squib on each engine fire extinguisher,
- **closes fuel,** hydraulic shutoff and engine bleed air valves,
- disables reverser,
- trips generator,
- deactivates engine driven hydraulic pump.

Pulling EFSW is irreversible.

At the end of the check list (point 17 – see fig.16) it is clearly stated that landing should be completed at a nearest suitable airport, and the check list directs the crew to the *QRH NNC 7.32 One Engine Inoperative Landing* () check list.

BOEING 8.5

737 Flight Crew Operations Manual

▼ENGINE FIRE or Engine Severe Damage or Separation continued▼

12 Choose one:

◆APU is **available** for start:

APU . . . . START

When APU is running:

APU GEN switch
(affected side) . . . . .ON

►►**Go to step 13**

◆APU is **not** available:

►►**Go to step 13**

13 Balance fuel as needed.

YC476 - YC489, YD304 - YJ480, YJ931, YK139

14 Transponder mode selector . . . . TA

This prevents climb commands which can exceed single engine performance capability.

YC056 - YC207, YC731, YJ910, YK101 - YK104

15 Transponder mode selector . . . . TA ONLY

This prevents climb commands which can exceed single engine performance capability.

16 ISOLATION VALVE switch
(after the fire has been extinguished). . . . . AUTO

This step ensures bleed air is available to both wings if wing anti-ice is needed.

17 Plan to land at the nearest suitable airport.

Note: Do not use FMC performance predictions.

▼ Continued on next page ▼

Fig. 16. Extract from Boeing QRH. Part of the check-list: Engine Fire or Engine Severe Damage or Separation.

Source: Quick Reference Handbook, 737 Flight Crew Operations Manual.

The attempt to restart of engine No. 2 in flight by crew shows a kind of discrepancy and lack of full execution previous check list[8]. After identification that engine No. 2 showed signs justifying execution of *QRH NNC 8.2 Engine Fire or Engine Severe Damage or Separation* the crew decided to complete restart the engine in flight. Very dynamic

[8] Pulling out EFS closes fuel. This action is irreversible.

weather conditions and influence of EnterAir OPS Officer, who suggested diversion to EPWA distracted the crew from decision making process and decision execution.

The pilots worked in a stressful situation where they had to secure failed engine and deal with burning fuel to reduce LW (which was their decision), which increased task saturation, but was handled by the crew in a professional manner. Wide spectrum of requested weather conditions in the airports in the northern side of Poland – which was requested by operating crew, shows very good situation awareness and good planning process. Shortly after engine failure, the captain, as a more experienced, took control and became a role of PF, which was accepted by the FO.

Both pilots cooperated based on trained CRM model and both were involved in decision making process with good communication skills towards to ATC and cabin crew. Long operation on one engine, heavy plane in the vicinity of thunderstorm was handled by the crew accordingly. Therefore good airmanship skills were demonstrated.

Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary.

Event Summary, ESN 874306

Event Date: 15 Aug 2022

Event Details: SP-ENU, ENG No. 2 ESN 874306 experienced commanded IFSD, resulting in an Annex 13 investigation opened.

Post event BSI showed a single HPT blade with a liberated airfoil. HPT blade set was returned to General Electric engineering center for lab evaluation. The HPT blade set was a combination of PN 1957M10P01, P03, and P04. (5) blades PN 1957M10P01, including the separated blade, were repaired in the 2013 timeframe. HPT blade 1957M10P01, TSN/CSN: 46428 hours/ 19411 cycles.

Findings:

- HPT blade number 80 (PN 1957M10P01, SN BWHN9B01) exhibits airfoil separation at ~15% radial span.
- Metallurgical evaluation shows the prime blade-initiated cracks in the airfoil leading edge cavity at the internal crossover rib hole. Cracks propagated in LCF forward and aft on the convex and concave airfoil surfaces to airfoil separation. Finding is consistent with previous CFM56 field experience for this HPT blade configuration.

Aircraft Engine Borescope Inspection findings:

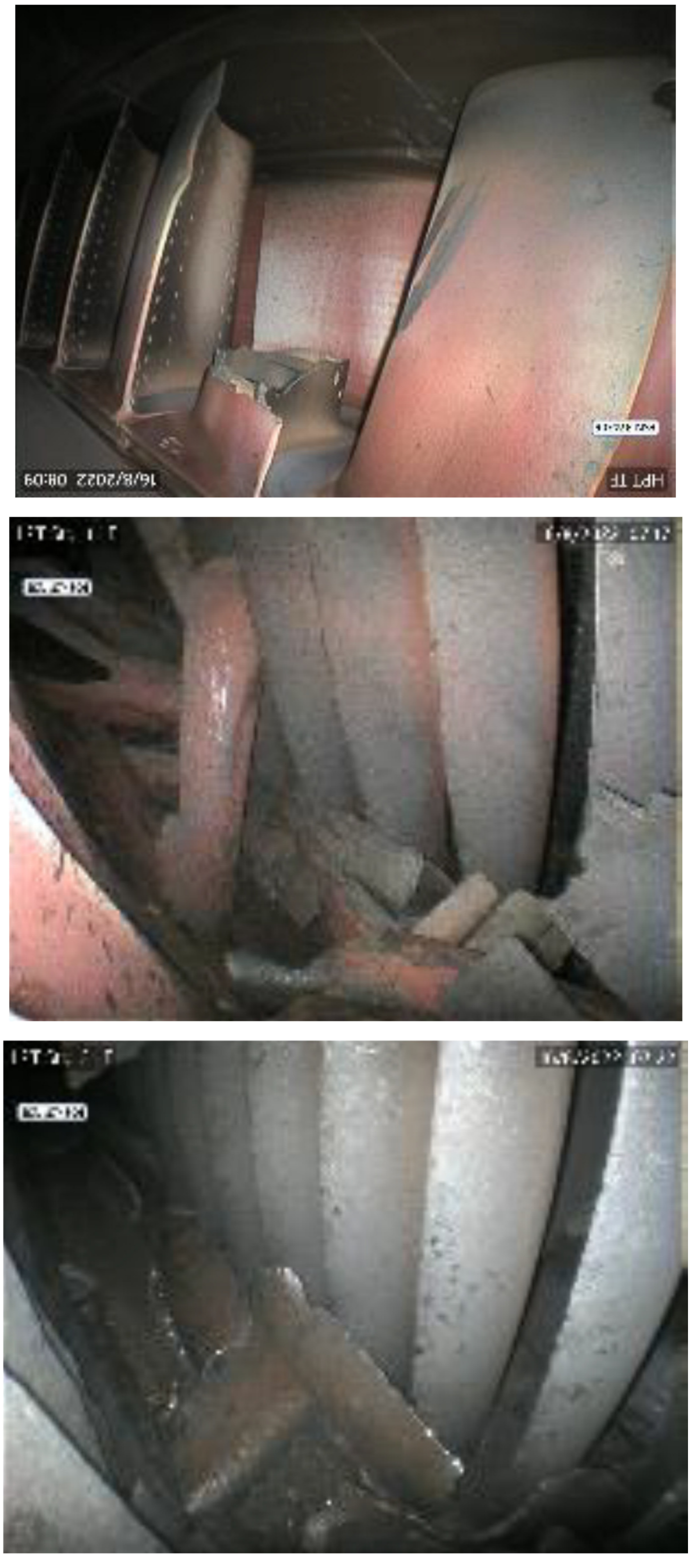

Fig. 17. Three pictures: HPT BSI results. Blade #80 fractured at ~15% span, while multiple LPT blades and downstream hardware were damaged due to impact from the liberated debris.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P. 4.

Engine teardown:

Fig. 18. Three pictures. Overview photos at HPT exposure. Blade #80. Multiple blades were damaged due to impact from the liberated airfoil debris.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P. 5.

Blade set overview:

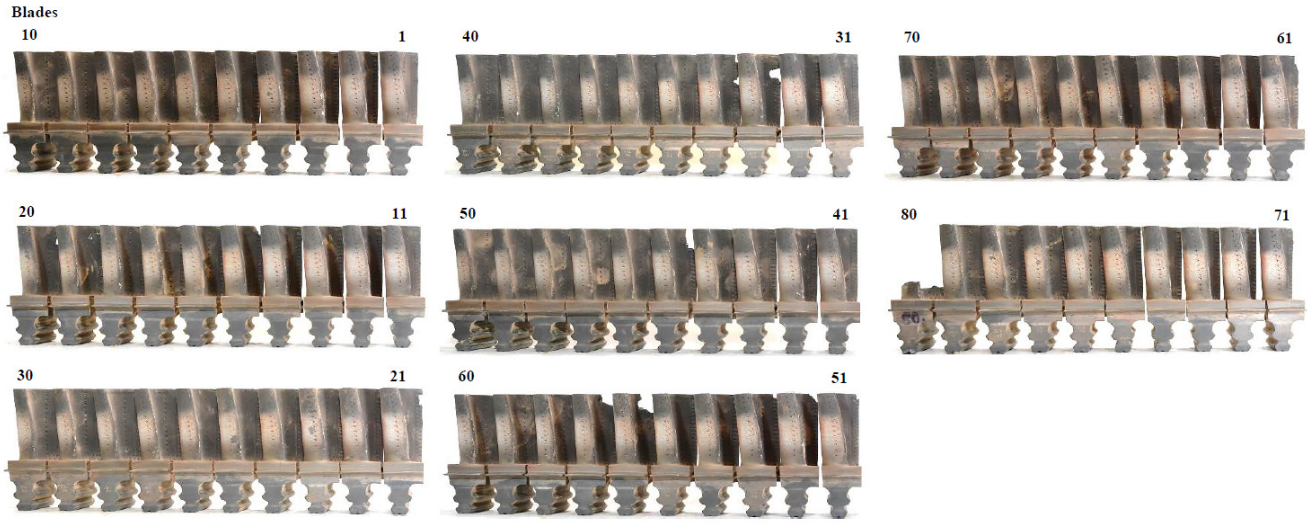

Fig. 19. Lead edge photos of complete blade set returned for evaluation in the as received condition. Blade #80 (SN BWHN9B01) shows airfoil liberation while the remaining blades show varying levels of trail edge damage.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P. 6.

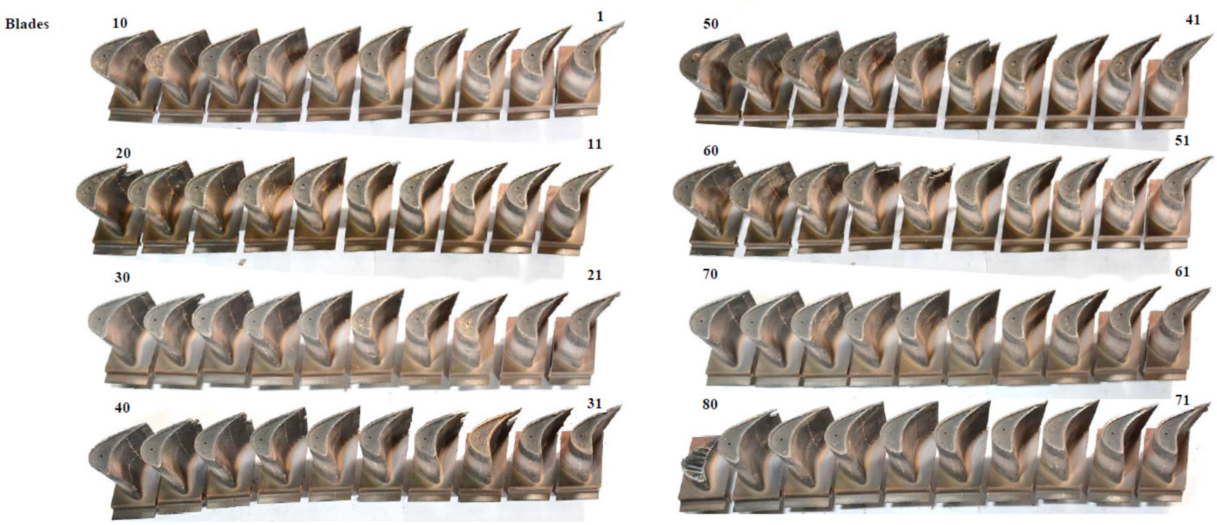

Fig. 20. Top-down photos of complete blade set returned for evaluation in the as received condition.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.7.

Prime Blade #80 airfoil liberation:

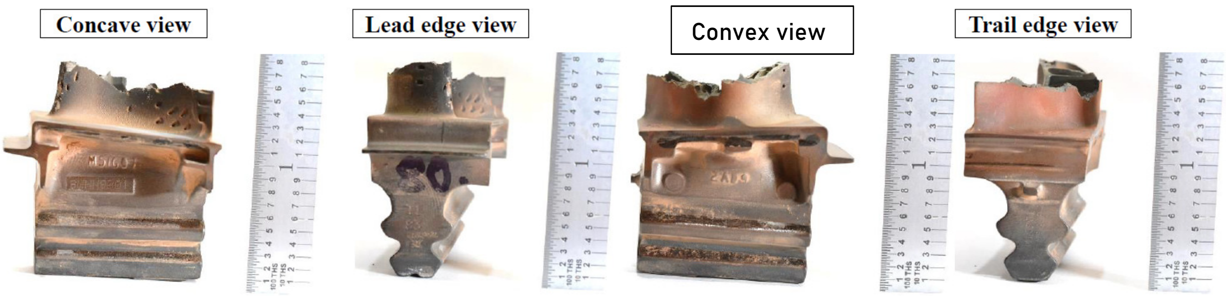

Fig. 21. Overview photos of the as-received blade #80 (S/N BWHN9B01) showing airfoil liberation.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.8.

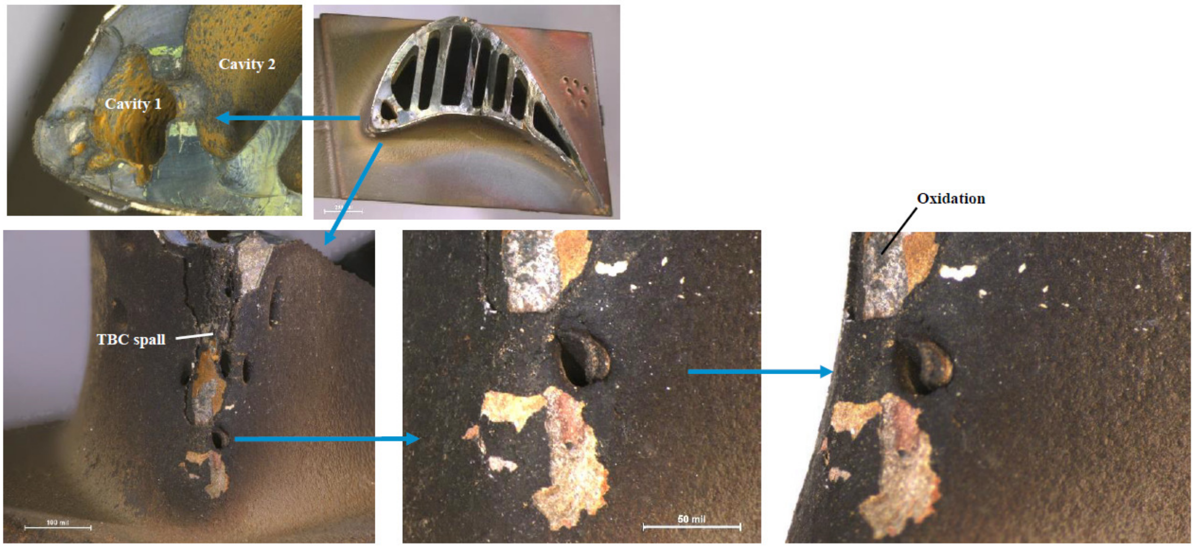

Fig. 22. Top-down & external surface photos of the as-received blade #80 (S/N BWHN9B01) liberation surface. TBC loss was identified along the lead edge below the fracture surface. The cavity 1 internal wall also showed significant dust-buildup, consistent with previous observations of HPT blades operated in a severe environment.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.9.

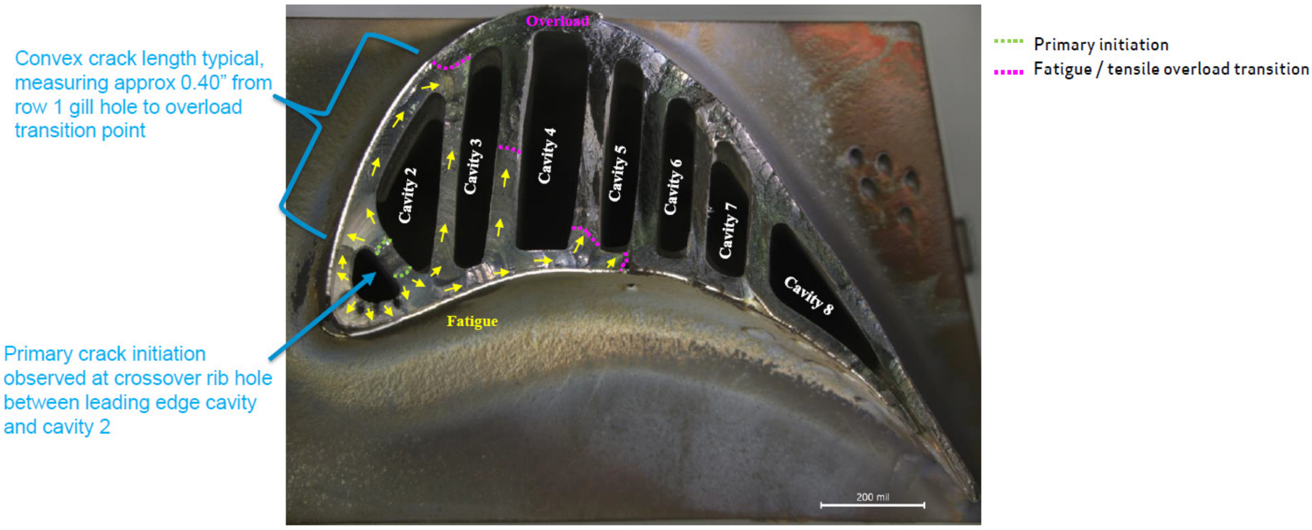

Fig. 23. Top-down photo of the cleaned blade #80 (S/N BWHN9B01) liberation surface. Primary initiation occurred at the cavity 1-2 rib cross-over hole moving toward the lead edge and aft through cavity 2-3 rib on the convex side and cavity 5 on the concave side. Progression lines and oxidation were observed all along the fracture surface consistent with low cycle fatigue.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.10.

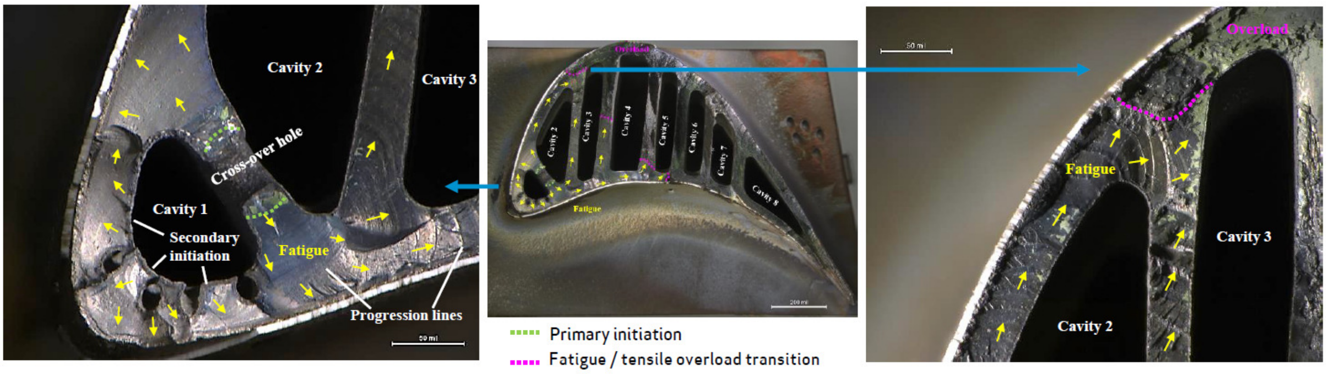

Fig. 24. Fracture surface photos of the cleaned blade #80 (S/N BWHN9B01) liberation surface showing primary initiation from the crossover hole. Progression lines and oxidation were observed along the entire crack propagation consistent with low cycle fatigue. The convex wall transition to overload is observed near cavity 3.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.11.

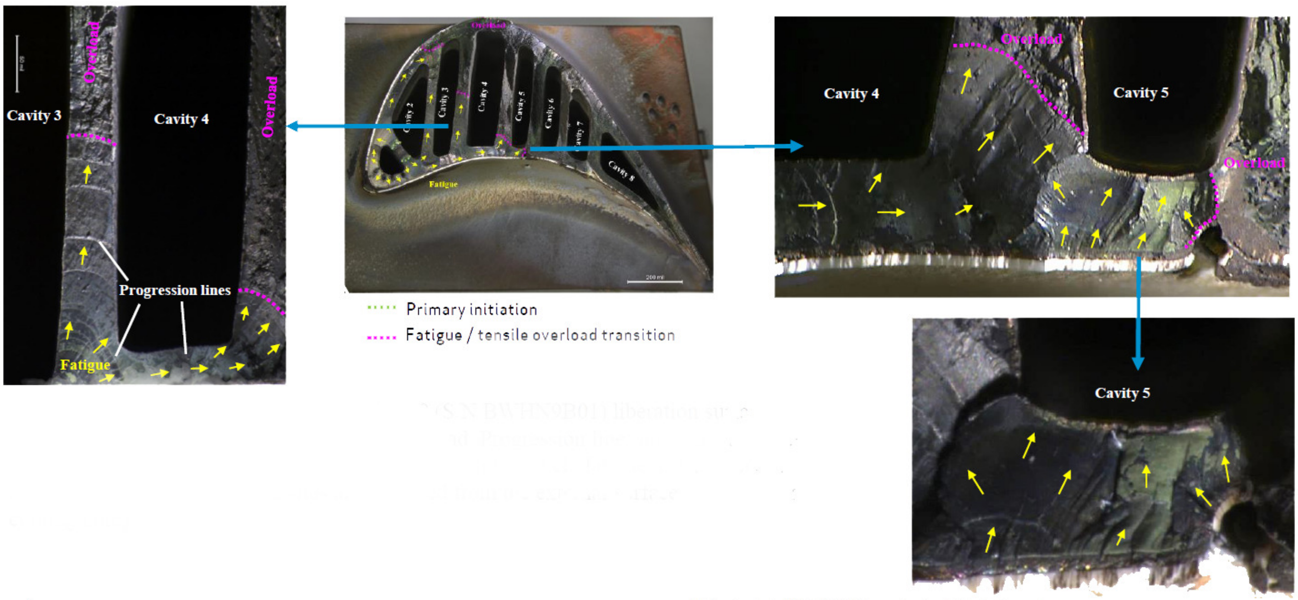

Fig. 25. Fracture surface photos of blade #80 (S/N BWHN9B01) liberation surface showing concave wall & rib transitions to overload. Progression lines and oxidation were observed along the crack propagation consistent with low cycle fatigue. Near cavity 5, additional secondary initiation sites are observed from the external surface and adjacent cooling hole.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.12.

1957M10P01 blade observations:

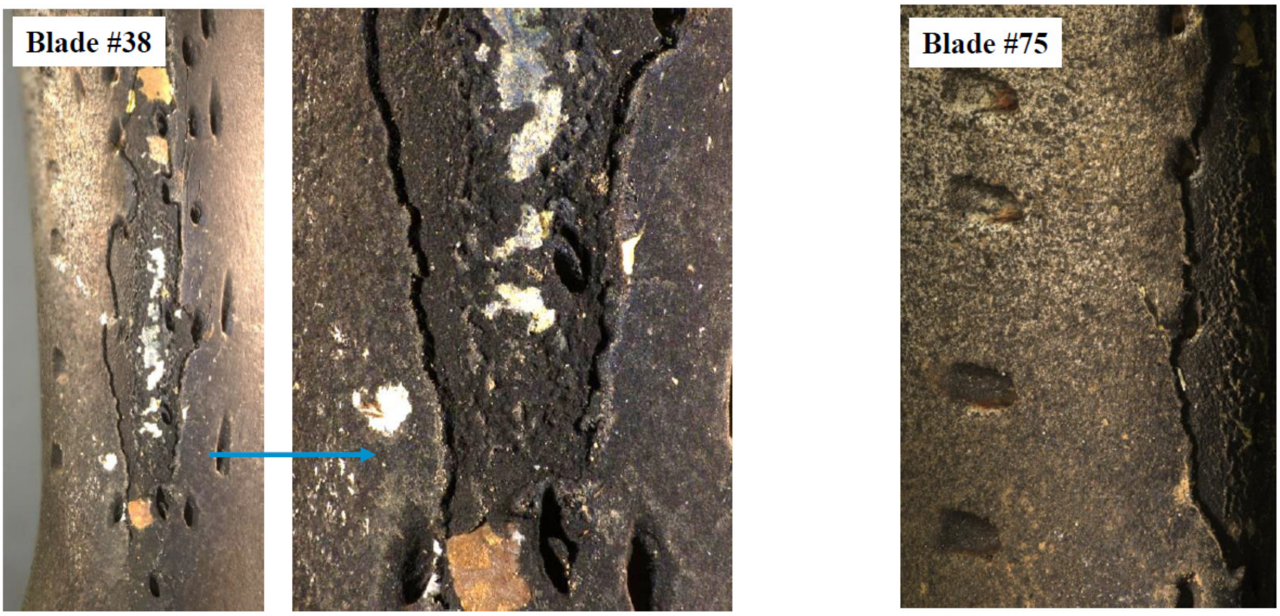

Fig. 26. Distress is also observed on other 1957M10P01 blades. Blade #75 (S/N BWHN6B89, P01) and blade #38 (S/N BWHN7C53, P01) show worst-case lead edge oxidation, which is subject to AMM limits for reduced BSI intervals.

Source: Report: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.13.

Investigation Findings:

History of the 5 blades PN 1957M10P01

- 2004: installed on engine HPTB CSN = 0 FC.
- 2008: engine SV and HPTB overhaul HPTB CSN = 8,151 FC.
- Early 2013: engine exited Jet Airways fleet HPTB CSN ~ 9,600 FC.
- May 2013: engine SV at Turkish Engine Center (TEC) HPTB CSN = 13,504 FC.

~9,600 FC operation in India

• HPT blades sent from Turkish Engine Center to the Singapore Plant 23 for inspection and repair.

• Safety Bulletin (SB) 72-0886, Repair Document (RD) 150-1551 HPT blade internal rib evaluation was a required inspection based on the operational history of this engine which met the "operational departures within India" SB criteria (HPTB > 5,000 CSN & 2,5 k departure from India).

• Singapore Plant 23 does not have records stating RD 150-1551 was requested by the customer during the 2013 engine overhaul:

- Aug 2022: IFSD HPTB CSN = 19,411 FC.

• RRT is 25,000 FC, per SB 72 0821.

• Last HPTB BSI c/o 234 cycles before event, all within Aircraft Maintenance Manual (AMM) limits with no re-inspection requirement.

Engine SN 874306 history:

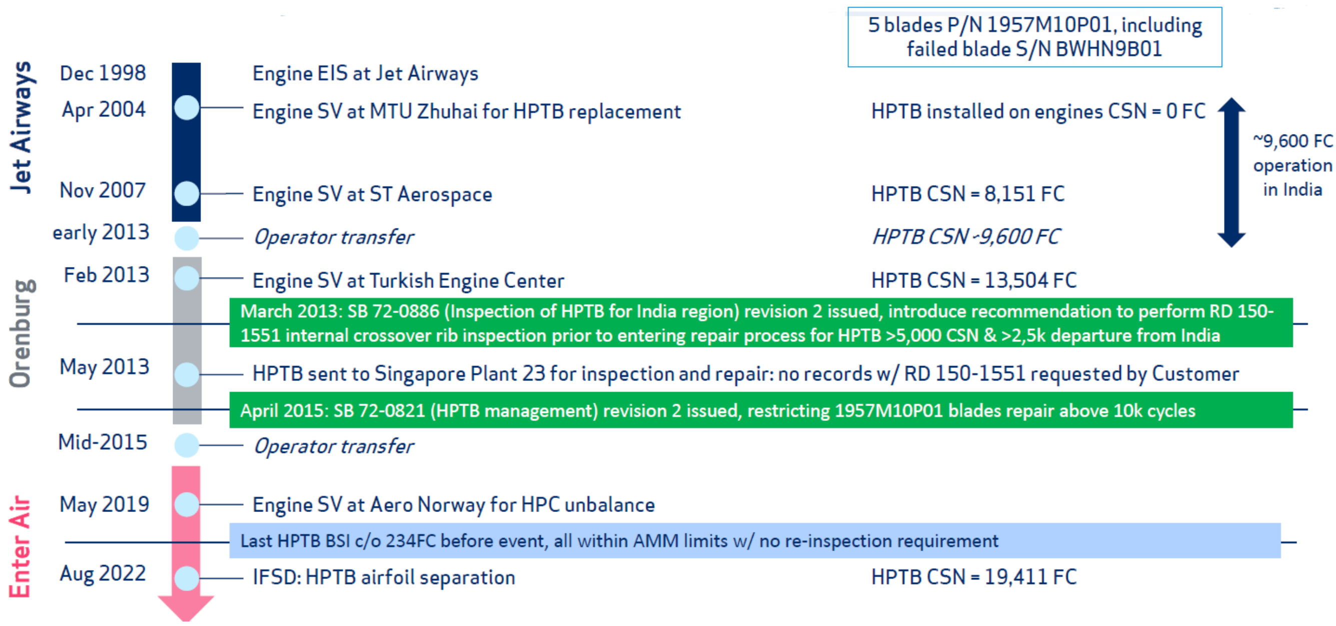

Fig. 27. History of engine SN 874306.

Source: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.15.

BSI prior to event:

EnterAir provided BSI report from 13 Jun 2022, which was the last HPT BSI at 234 cycles prior to the IFSD event

• All findings reported within AMM limits.

Field experience supports extended periods of operation for leading edge (LE) cracks to initiate and propagate to failure, consistent with AMM limits and SB inspection plan.

• PSE does not expect convex cracks to initiate and propagate to failure within 234 cycles from last BSI to event.

<u>As a part of post event analysis, the most-likely scenario is that cracks potentially were visible on prime blade SN BWHN9B01 at this BSI but were not detected.</u>
However, operator stated that: “crack was not detected”.
As an explanation of presented conclusion, below on the left demonstrated completed BSI on Engine 874306 and on the right-side correct angle of view during BSI. However, based on Operator`s statement: “the inspection was completed and blades have been checked from several sides and also with the straight and angular lenses, which have been in the equipment of EnterAir for 4 years”. Operator stated that photo included in figure 26 “is only an illustrative (…) to indicate that given engine sector was checked or to illustrate any damage found”.

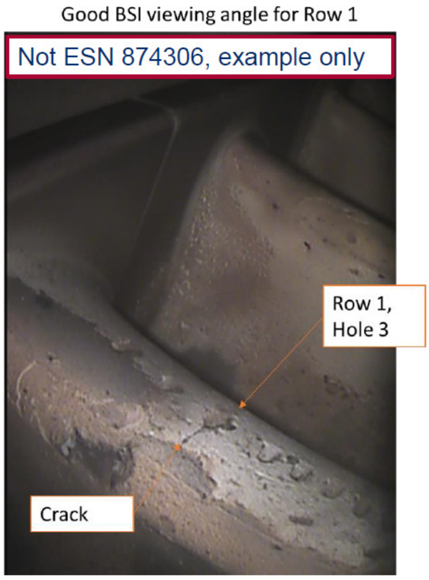

Fig. 28. BSI technique.

Source: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.17.

LE cracking field experience:
Airfoil separation due to LE cracking is a known failure mode for the 1957M10 configuration HPT blade. CFM history shows multiple prior occurrences, from both neutral region and severe environment operation.
• ~35% of occurrences resulted in significant events like IFSD.
• ~65% of occurrences resulted in a vibratory signature detected and subsequent Unscheduled Engine Removal (UER).
Previous metlab evaluation is consistent with findings on Engine SN 874306.
• Cracks initiate in the LE cavity at a cooling hole or at a crossover rib hole.
• Cracks then propagate in LCF to the 3rd or 4th internal rib, prior to airfoil separation due to tensile overload.
AMM and SB inspection criteria have proven successful to manage the LE cracking failure mode.

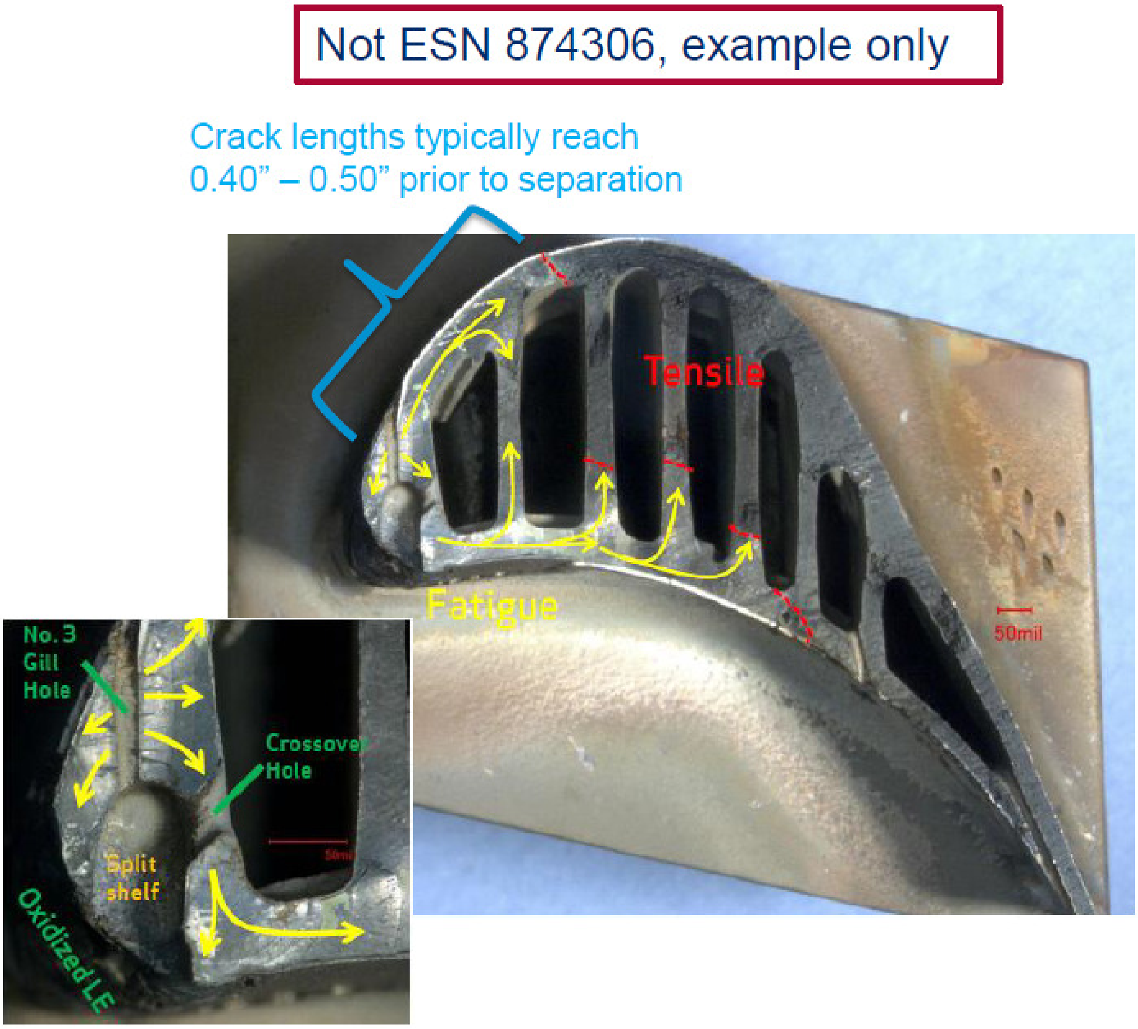

Fig. 29. LE cracking field experience - example.

Source: CFM56-7B Engine Serial Number: 874306 HPT blade airfoil separation event Metlab evaluation summary. P.18.

Summary of analysis:
HPT blade #80 (SN BWHN9B01) exhibits airfoil separation at ~15% radial span. Metallurgical evaluation shows the prime blade initiated cracks in the airfoil leading edge cavity at the internal crossover rib hole. Cracks propagated in LCF forward and aft on the convex and concave airfoil surfaces to airfoil separation.
Blade operational history shows opportunities were missed to detect LE cracking:
• M10P01 blades were operated in India environment ~9600 FC → SB 72 0886 recommends 800 cycle repeat BSI intervals after component repair. Inspection plan not followed.
• BSI views provided by customer are not optimal to detect LE cracking at the convex gill row 1 location.
• SB 72 0886 recommends internal crossover rib inspection per RD 150 1551 prior to 2013 repair. Inspection not performed as per below:

(2) For CFM56-7B engines that operated within India and are routed for shop visit, do as follows:

(a) If the HPT blades have accumulated more than 5,000 cycles since new (CSN) of operation and 2,500 or more of the total flight departures were from within India, when routed for repair, request inspection of the leading edge internal rib for evaluation of crack initiation and repair acceptability as specified in RD 150-1551. To make sure that the repair facility knows that the inspection is necessary, request inspection in RD 150-1551 be done on your repair request documentation. The HPT blades that pass CFM56-7B ESM serviceability inspections and the inspections as specified in RD 150-1551 will be identified by an X marked after the cycle count identification. For these HPT blades, when returned to operation, use the on-wing borescope inspection interval as specified in paragraphs 3.A.(1)(a)3 and 3.A.(1)(a)4.

3 For HPT blades that meet the India operation cyclic criteria specified above and removed and repaired during engine shop visit, then subsequently returned to operation in India, continue with the reduced borescope inspection interval applicable before the engine shop visit.

4 For HPT blades that meet the India operation cyclic criteria specified above and removed and repaired during engine shop visit, then subsequently returned to operation outside of India, continue with a reduced borescope inspection interval of 800 cycles.

Fig. 30. Repair Document (RD) 150-1551 (S1 or higher), High Pressure Turbine Rotor Assembly - High Pressure Turbine Rotor Blades - Alteration - Evaluation for Repairability of Blades Operated in Sandy/Dusty Environments
Source: Extract from Safety Bulletin 72 0886: ENGINE - HPT Blades (72-52-01) - Inspection of HPT Blades - India Region.

Proposed root cause is due to HPT blade leading edge cracking, consistent with previous CFM56 field experience for this HPT blade configuration.

Analysis of Flight Data Monitoring.

Short brief:
On 15 August 2022 SP-ENU ENG #2 ESN 874306 experienced commanded IFSD. 737-800 SP-ENU took off at 14:59 from EPGD to land in GCFV. After taking off from EPGD, the aircraft crew reported the engine damage and made a decision to return to EPGD, in line with the procedures. However, the landing in the EPGD could not take place immediately (based on crew`s decision) due to full fuel tanks and excessive MLW. In order to burn fuel and reduce the weight of the aircraft stayed in holding pattern. Before enough fuel could be burned, the weather conditions over the EPGD had deteriorated significantly. A landing in EPGD turned out to be unsafe, so the plane with 171 passengers on board headed towards the EPWA. Plane safely landed at the Warsaw airport at 18:37.

On the graphs below will be displayed specific data of engine parameters with related agenda.

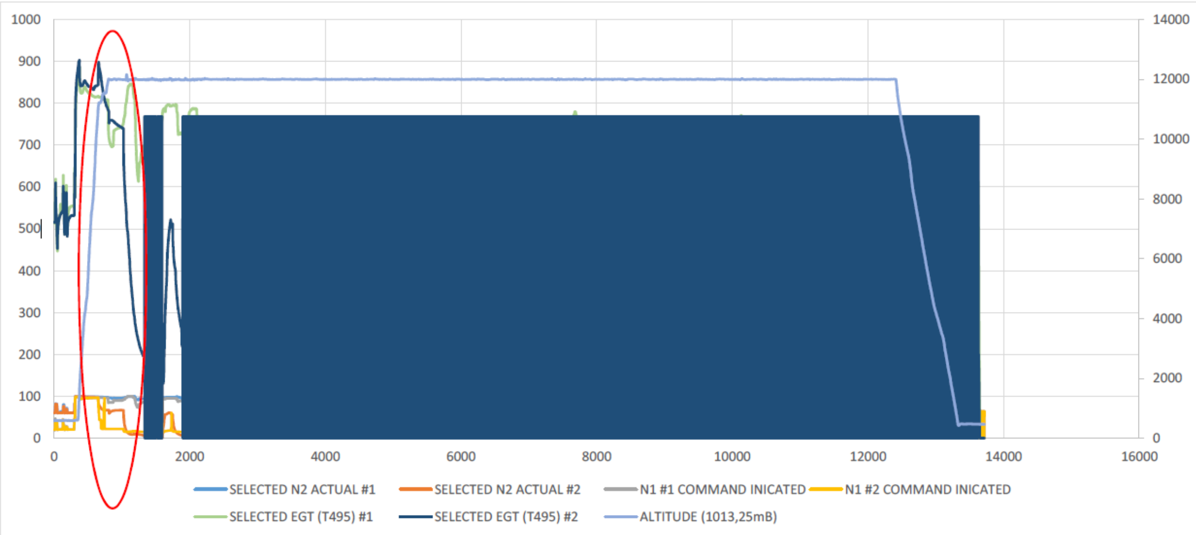

Fig. 31. Both engines graph. Highlighted initial part of the flight with detailed indications of selected parameters described in the agenda of the graph.
N1 – Low Pressure Rotor Rotational Speed,
N2 – High Pressure Rotor Rotational Speed,
EGT - Exhaust Gas Temperature.
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

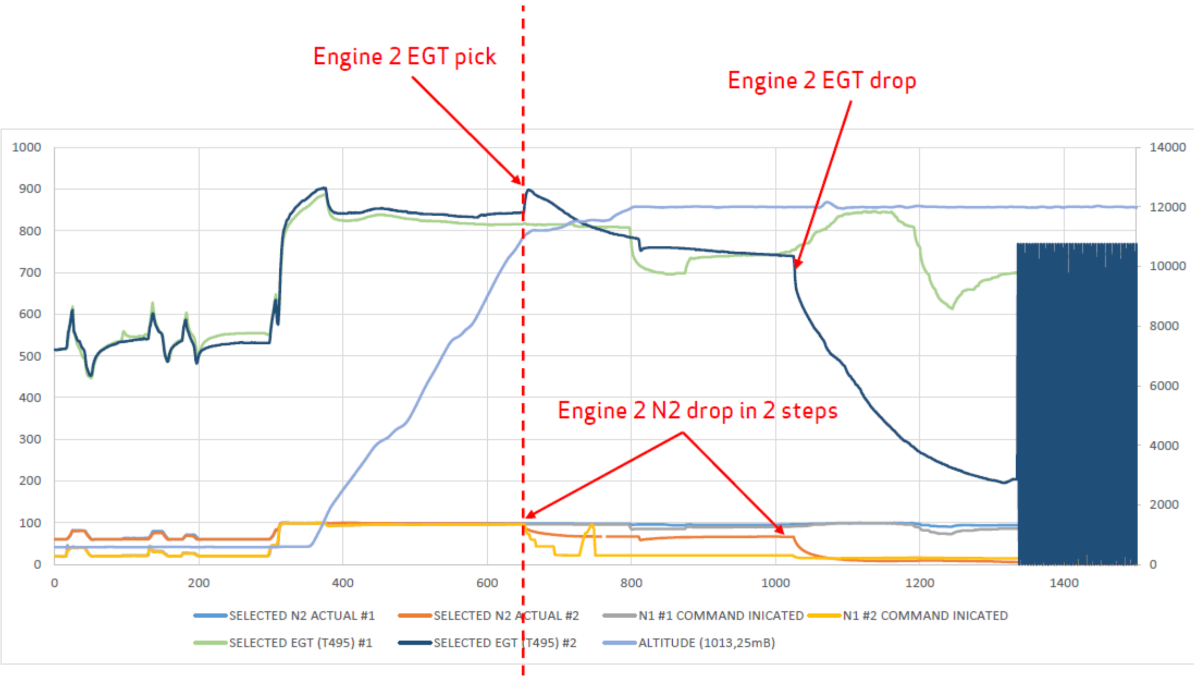

Fig. 32. Both engines graph. Highlighted time of incident (red dashed line) with detailed indications of selected parameters described in the agenda of the graph.
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

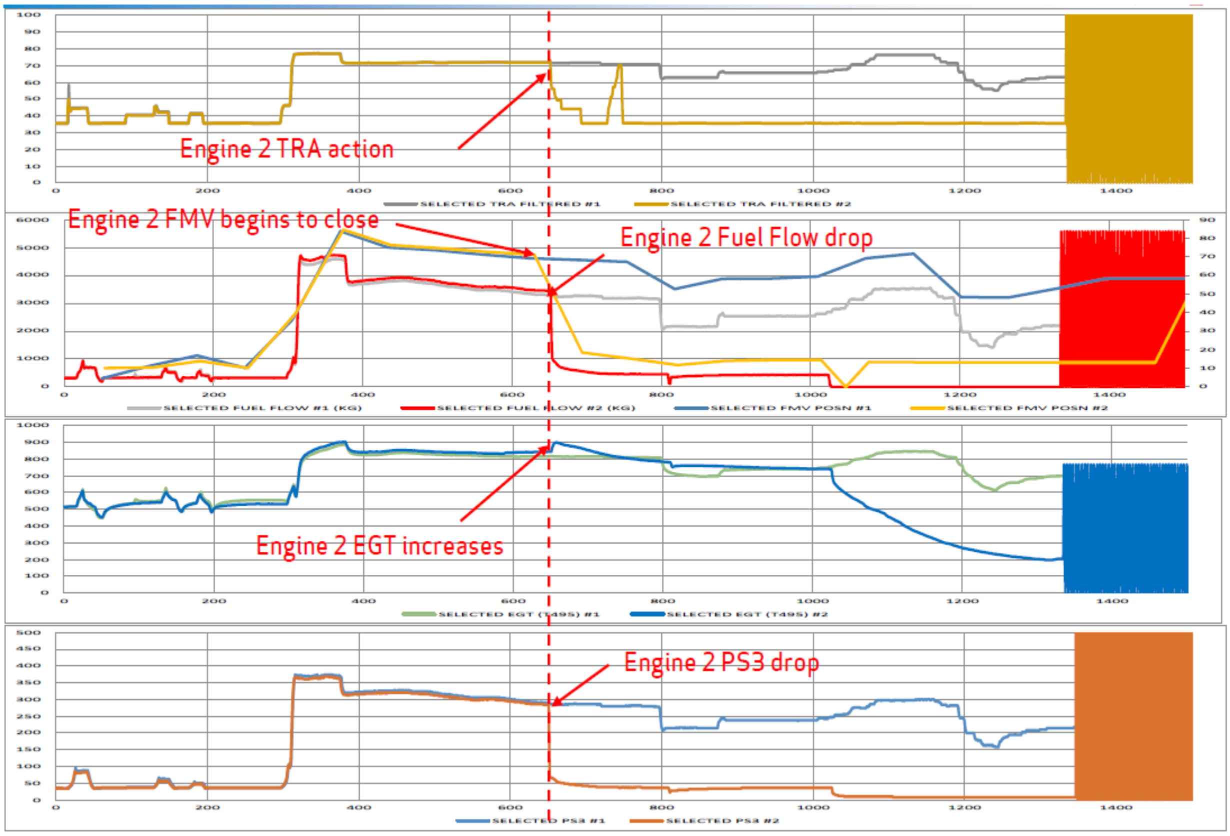

Fig. 33. Both engines graph. Highlighted time of incident (red dashed line) with detailed indications of selected parameters described in the agenda of the graph.
TRA – Throttle Resolver Angle,[9]
FMV – The Fuel Metering Valve,[10]
PS3 - Compressor Discharge Static Air Pressure.[11]
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

[9] **TRA** is a part of delivered parameters to Variable Stator Valve (VSV) system control. VSV system positions the High-Pressure Compressor (HPC) stator vanes to the appropriate angle to optimize HPC efficiency. It also improves the stall margin during transient engine operations.
[10] **FMV** - delivers signal to FADEC system which is a Built In Test Equipment (BITE). This means it is able to detect its own internal faults and also external faults.
[11] **PS3** - delivers signal to FADEC system which is a Built In Test Equipment (BITE). This means it is able to detect its own internal faults and also external faults.

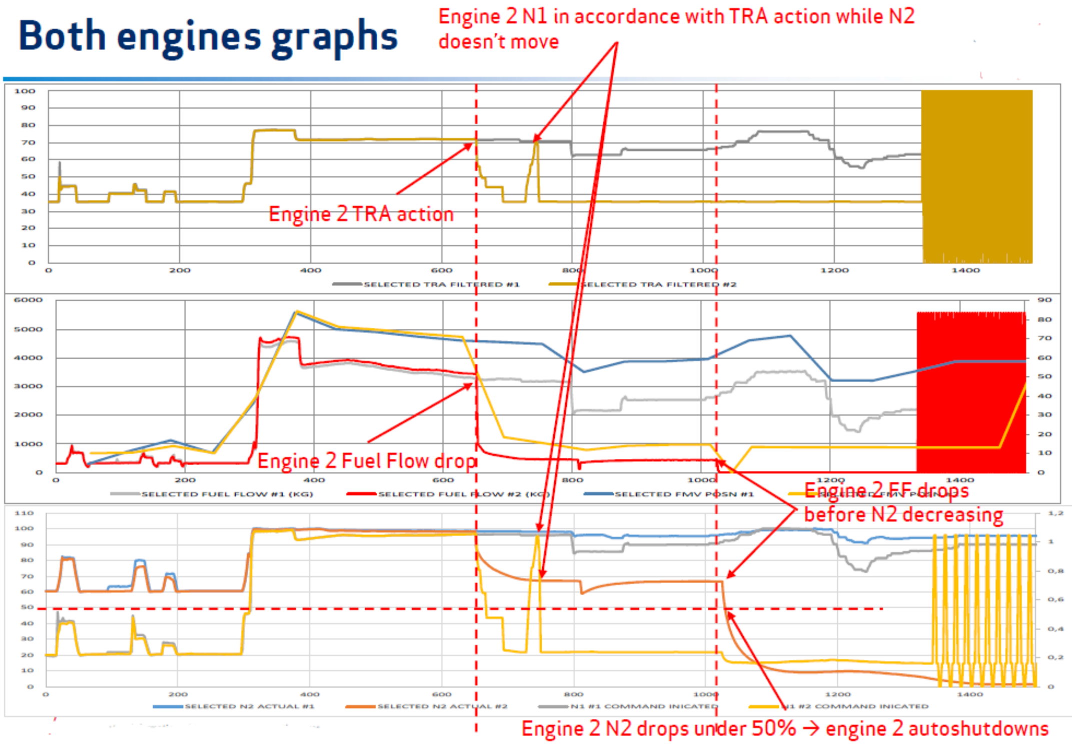

Fig. 34. Both engines graph. Highlighted time of incident (red dashed line) with detailed indications of selected parameters described in the agenda of the graph.
TRA – Throttle Resolver Angle,
N2 – High Pressure Rotor Rotational Speed.
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

Time (secs)	SELECTED N2 ACTUAL #1	SELECTED N2 ACTUAL #2	N1 #1 COMMAND INICATED	N1 #2 COMMAND INICATED	SELECTED VSV POSN #1	SELECTED VSV POSN #2	SELECTED FMV POSN #1	SELECTED FMV POSN #2	SELECTED TRA FILTERED #1	SELECTED TRA FILTERED #2	SELECTED VBV POSN #1	SELECTED VBV POSN #2	SELECTED PS3 #1	SELECTED PS3 #2	SELECTED FUEL FLOW #1 (KG)	SELECTED FUEL FLOW #2 (KG)	ALTITUDE (1013,25mB)	SELECTED EGT (T495) #1	SELECTED EGT (T495) #2	CN1 TRACKED VIB LEFT	CN1 TRACKED VIB RIGHT	CN2 TRACKED VIB LEFT	CN2 TRACKED VIB RIGHT	TN1 TRACKED VIB LEFT	TN1 TRACKED VIB RIGHT	TN2 TRACKED VIB LEFT	TN2 TRACKED VIB RIGHT
648,666	98,62	98,25	96,75	96,79	-1,76	-0,53	68,82	55,69	71,9	71,9	0	-0,16	290	284	3288	3440	10938	816	844	0,44	0,38	0,01	0,12	0,44	0,51	0,07	0,5
648,75	98,62	98,25	96,75	96,8	-1,76	-0,53	68,81	55,62	71,9	71,9	0	-0,16	290	284	3288	3440	10941	816	844	0,43	0,38	0,01	0,12	0,44	0,51	0,07	0,5
648,875	98,62	98,25	96,75	96,8	-1,76	-0,53	68,81	55,52	71,9	71,9	0	-0,17	290	284	3288	3440	10946	816	844	0,43	0,38	0,01	0,12	0,44	0,5	0,07	0,5
649	98,62	98,25	96,75	96,81	-1,76	-0,53	68,81	55,41	71,9	71,9	0	-0,18	290	284	3288	3440	10950	816	844	0,43	0,38	0,01	0,12	0,44	0,5	0,07	0,5
649,125	98,64	98,25	96,75	96,82	-1,76	-0,53	68,81	55,31	71,9	71,9	0	0,29	290	284	3288	3440	10954	816	844	0,43	0,38	0,01	0,12	0,44	0,5	0,07	0,5
649,25	98,66	98,25	96,75	96,83	-1,76	-0,53	68,81	55,21	71,9	71,9	0	0,75	290	284	3288	3440	10959	816	844	0,43	0,38	0,01	0,12	0,44	0,5	0,07	0,5
649,333	98,67	98,25	96,75	96,83	-1,76	-0,53	68,81	55,14	71,9	72	0	1,05	289	284	3288	3440	10962	816	844	0,43	0,38	0,01	0,12	0,44	0,49	0,07	0,5
649,375	98,67	98,25	96,75	96,84	-1,76	-0,53	68,81	55,11	71,9	72	0	1,21	289	284	3288	3440	10964	816	844	0,43	0,38	0,01	0,12	0,44	0,49	0,07	0,5
649,5	98,69	98,25	96,75	96,84	-1,76	-0,53	68,8	55	71,9	72	0	1,67	289	284	3288	3440	10968	816	844	0,43	0,38	0,01	0,12	0,44	0,49	0,07	0,5
649,625	98,7	98,25	96,75	96,85	-1,76	-0,53	68,8	54,9	71,9	72	0	2,13	289	284	3288	3440	10972	817	844	0,43	0,38	0,02	0,12	0,43	0,49	0,07	0,5
649,666	98,71	98,25	96,75	96,85	-1,76	-0,53	68,8	54,87	71,9	72	0	2,28	289	284	3288	3440	10974	817	844	0,43	0,38	0,02	0,12	0,43	0,49	0,07	0,5
649,75	98,72	98,25	96,75	96,86	-1,76	-0,53	68,8	54,8	71,9	72	0	2,59	288	284	3288	3440	10977	817	844	0,43	0,38	0,02	0,12	0,43	0,48	0,07	0,5
649,875	98,73	98,25	96,75	96,87	-1,76	-0,53	68,8	54,7	71,9	72	0	3,05	288	284	3288	3440	10982	817	844	0,43	0,38	0,02	0,12	0,43	0,48	0,07	0,5
650	98,75	98,25	96,75	96,88	-1,76	-0,53	68,8	54,59	71,9	72,1	0	3,52	288	284	3288	3440	10986	817	844	0,43	0,38	0,02	0,12	0,43	0,48	0,07	0,5
650,125	98,75	98,25	96,76	96,87	-1,76	-0,53	68,8	54,49	71,9	72,1	0	3,98	288	284	3289	3440	10990	817	844	0,43	0,38	0,02	0,12	0,43	0,48	0,07	0,5
650,25	98,75	98,25	96,77	96,86	-1,76	-0,53	68,79	54,39	71,9	72,1	0	4,44	288	284	3289	3440	10995	817	844	0,43	0,38	0,02	0,12	0,43	0,47	0,07	0,5
650,333	98,75	98,25	96,77	96,85	-1,76	-0,53	68,79	54,32	71,9	72,1	0	4,74	288	284	3290	3440	10998	817	844	0,44	0,38	0,02	0,12	0,43	0,47	0,07	0,5
650,375	98,75	98,25	96,77	96,85	-1,76	-0,53	68,79	54,29	71,9	72,1	0	4,9	288	284	3290	3440	10999	817	844	0,44	0,38	0,02	0,12	0,43	[illegible]	[illegible]	[illegible]
650,5	98,75	98,25	96,78	96,84	-1,76	-0,53	68,79	54,18	71,9	72,1	0	5,36	288	284	3291	3440	11004	817	844	0,44	0,38	0,02	0,12	0,43	0,47	0,07	0,5
650,625	98,75	98,25	96,79	96,84	-1,76	-0,53	68,79	54,08	71,9	72,1	0	5,82	288	284	3292	3440	11008	817	844	0,44	0,38	0,02	0,12	0,43	0,47	0,07	0,51
650,666	98,75	98,25	96,79	96,83	-1,76	-0,53	68,79	54,05	71,9	72,1	0	5,97	288	284	3293	3440	11009	817	844	0,44	0,38	0,02	0,12	0,43	0,47	0,07	0,51
650,75	98,75	98,25	96,8	[illegible]	[illegible]	-0,53	68,79	53,98	71,9	72,1	0	6,28	288	284	3293	3440	11012	817	844	0,44	0,38	0,02	0,12	0,43	0,46	0,07	0,51
650,875	98,75	98,25	96,8	96,82	-1,76	-0,53	68,78	53,88	71,9	72,1	0	6,75	288	284	3294	3440	11017	817	844	0,45	0,38	0,02	0,12	0,43	0,46	0,07	0,51
651	98,75	98,25	96,81	96,81	-1,76	-0,53	68,78	53,77	71,9	72,1	0	7,21	288	284	3295	3440	11021	817	844	0,45	0,38	0,02	0,12	0,43	0,46	0,07	0,51
651,125	98,75	97,08	96,82	96,8	-1,76	0,16	68,78	53,67	71,9	72,1	0	7,67	288	257	3295	3437	11023	817	846	0,45	0,37	0,02	0,12	0,43	0,47	0,07	0,51
651,25	98,75	95,91	96,83	96,8	-1,76	0,86	68,78	53,57	71,9	72,1	0	8,13	288	230	3295	3435	11026	817	849	0,45	0,36	0,02	0,13	0,43	0,48	0,07	0,51
651,333	98,75	95,13	96,83	96,79	-1,76	1,32	68,78	53,5	71,9	72,1	0	8,44	288	213	3295	3433	11027	817	851	0,45	0,35	0,02	0,13	0,43	0,48	0,07	0,51
651,375	98,75	94,73	96,84	96,79	-1,76	1,55	68,78	53,47	71,9	72,1	0	8,59	288	204	3295	3432	11028	817	852	0,45	0,35	0,02	0,13	0,43	0,49	0,07	0,51
651,5	98,75	93,56	96,84	96,78	-1,76	2,24	68,78	53,36	71,9	72,1	0	9,05	288	177	3295	3429	11030	817	854	0,44	0,34	0,02	0,13	0,42	0,49	[illegible]	[illegible]
651,625	98,75	92,39	96,85	96,77	-1,76	2,93	68,77	53,26	71,9	72,1	0	9,51	288	150	3295	3426	11032	817	856	0,44	0,33	0,02	0,14	0,42	0,5	[illegible]	[illegible]
651,666	98,75	92,01	96,85	96,77	-1,76	3,16	68,77	53,23	71,9	72,1	0	9,67	288	141	3295	3426	11033	817	857	0,44	0,33	0,02	0,14	0,42	0,51	0,06	0,51
651,75	98,75	91,22	96,86	96,77	-1,76	3,63	68,77	53,16	71,9	72,1	0	9,98	288	124	3295	3424	11034	817	859	0,44	0,32	0,02	0,14	0,42	0,51	0,06	0,51
651,875	98,75	90,05	96,87	96,76	-1,76	4,32	68,77	53,06	71,9	72,1	0	10,44	288	97	3295	3421	11037	817	862	0,44	0,31	0,02	0,15	0,42	0,52	0,06	0,51
652	98,75	88,88	96,88	96,75	-1,76	5,01	68,77	52,95	71,9	72,1	0	10,9	288	70	3295	3418	11039	817	864	0,44	0,3	0,02	0,15	0,42	0,53	0,06	0,51
652,125	98,75	88,58	96,85	95,7	-1,76	5,7	68,77	52,85	71,8	72,2	-0,01	11,36	288	70	3294	3186	11042	817	866	0,44	0,3	0,02	0,15	0,42	0,53	0,06	0,51
652,25	98,75	88,28	96,83	94,64	-1,76	6,39	68,77	52,75	71,8	72,3	-0,01	11,82	288	70	3293	2954	11045	817	867	0,44	0,3	0,02	0,15	0,42	0,53	0,06	0,51
652,333	98,75	88,08	96,81	93,94	-1,76	6,85	68,76	52,68	71,7	72,4	-0,01	12,13	288	69	3293	2800	11047	817	868	0,43	0,3	0,02	0,15	0,42	0,53	0,06	0,51
652,375	98,75	87,98	96,8	93,59	-1,76	7,09	68,76	52,65	71,7	72,5	-0,02	12,28	288	69	3292	2722	11048	817	869	0,43	0,3	0,02	0,15	0,42	0,53	0,06	0,51
652,5	98,75	87,69	96,78	92,53	-1,76	7,78	68,76	52,54	71,6	72,6	-0,02	12,74	288	69	3291	2489	11052	817	870	0,43	0,3	0,01	0,15	0,42	0,53	0,06	0,51
652,625	98,75	87,39	96,76	91,48	-1,76	8,47	68,76	52,44	71,6	72,7	-0,03	13,21	288	69	3290	2257	11055	817	872	0,43	0,3	0,01	0,15	0,42	0,53	0,06	0,51
652,666	98,75	87,29	96,75	91,13	-1,76	8,7	68,76	52,41	71,5	72,8	-0,03	13,36	288	69	3290	2181	11056	817	873	0,43	0,3	0,01	0,15	0,42	0,53	0,06	0,51
652,75	98,75	87,09	96,73	90,42	-1,76	9,16	68,76	52,34	[illegible]	[illegible]	[illegible]	13,67	288	68	3289	2025	11058	817	874	0,42	0,3	0,01	0,15	0,42	0,53	0,06	0,51
652,875	98,75	86,8	96,71	89,37	-1,76	9,85	68,76	52,24	71,4	73	-0,04	14,13	288	68	3289	1793	11061	817	875	0,42	0,3	0,01	0,15	0,42	0,53	0,06	0,51
653	98,75	86,5	96,69	88,31	-1,76	10,55	68,76	52,13	71,4	73,1	-0,04	14,59	288	68	3288	1560	11064	817	877	0,42	0,3	0,01	0,15	0,42	0,53	0,06	0,51
653,125	98,73	86,41	96,66	87,26	-1,76	11,24	68,75	52,03	71,4	71,4	-0,05	15,21	288	68	3286	1492	11066	817	878	0,42	0,29	0,01	0,16	0,42	0,52	0,06	0,5

EGT #2 begin to move up
Zone de graphique
Fuel Flow #2 begin to move down
Beginning of TRA action

Fig. 35. Engine data in time frame with indication of EGT begin to move up, beginning of TRA action and Fuel Flow of Eng. 2 beginning to move down.
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

Time (secs)	SELECTED N2 ACTUAL #1	SELECTED N2 ACTUAL #2	N1 #1 COMMAND INICATED	N1 #2 COMMAND INICATED
1024,75	96,25	66,62	91,5	20,97
1024,875	96,25	66,62	91,5	20,8
1025	96,25	66,62	91,5	20,62
1025,125	96,25	65,88	91,5	20,45
1025,25	96,25	65,12	91,5	20,28
1025,333	96,25	64,63	91,5	20,17
1025,375	96,25	64,38	91,5	20,11
1025,5	96,25	63,62	91,5	19,94
1025,625	96,25	62,88	91,5	19,77
1025,666	96,25	62,63	91,5	19,71
1025,75	96,25	62,12	91,5	19,59
1025,875	96,25	61,38	91,5	19,42
1026	96,25	60,62	91,5	19,25
1026,125	96,25	60,16	91,57	19,16
1026,25	96,25	59,69	91,64	19,08
1026,333	96,25	59,38	91,69	19,02
1026,375	96,25	59,22	91,71	18,99
1026,5	96,25	58,75	91,78	18,91
1026,625	96,25	58,28	91,85	18,82
1026,666	96,25	58,13	91,87	18,79
1026,75	96,25	57,81	91,92	18,73
1026,875	96,25	57,34	91,99	18,65
1027	96,25	56,88	92,06	18,56
1027,125	96,28	56,44	92,13	18,48
1027,25	96,31	56	92,2	18,39
1027,333	96,33	55,71	92,25	18,33
1027,375	96,34	55,56	92,27	18,3
1027,5	96,38	55,12	92,34	18,22
1027,625	96,41	54,69	92,41	18,13
1027,666	96,42	54,54	92,44	18,1
1027,75	96,44	54,25	92,48	18,05
1027,875	96,47	53,81	92,55	17,96
1028	96,5	53,38	92,62	17,88
1028,125	96,52	53	92,62	[illegible]
1028,25	96,53	52,62	92,62	17,77
1028,333	96,54	52,38	92,62	17,73
1028,375	96,55	52,25	92,62	17,71
1028,5	96,56	51,88	92,62	17,66
1028,625	96,58	51,5	92,62	17,6
1028,666	96,58	51,38	92,62	17,58
1028,75	96,59	51,12	[illegible]	[illegible]
1028,875	96,61	50,75	92,62	17,49
1029	96,62	50,38	92,62	17,44
1029,125	96,62	50,05	92,62	17,38
1029,25	96,62	49,72	92,62	17,33

Engine 2 shutdown

Zone de g

Fig. 36. Engine data in time frame with indication of Eng. 2 shutdown.
Source: Analysis of Flight Data Monitoring. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

The Analysis of the Data shows that:

- At 649 seconds after take-off, engine 2 VBV began to open,
- At 651 seconds after take-off, engine 2 EGT began to move up to 898°C at 657 seconds after take-off (under AMM limit). And, in the same second, engine PS3 began to move down.
- In the same time, at 652 seconds after take-off, engine 2 fuel flow drop can be observed at the end of climb.
- At 653 seconds after take-off, TRA action is observed on the engine 2.

- It was also observed an engine 2 TRA action up, few seconds later (around 75 seconds later versus first TRA action) without other parameters move (N2, Fuel Flow).
- At 1028 seconds after take-off, the engine 2 fuel flow dropped definitely a second time and noted engine 2 auto shutdown (at 1029 seconds after take-off).

Conclusion:
Consequently, as in a short time (around 2 seconds), VBV opened, EGT increased, PS3 and Fuel Flow dropped, it confirms the engine suffered a stall.
In addition, it was noted, despite it was observed a TRA action, N2 and Fuel Flow parameters did not come back in normal situation and it may be considered that, engine stall was non-recoverable.
As fuel flow dropped without coming back in normal situation after TRA action attempt, after analysis it suspects fuel package (FMV, HMU[12], fuel pump) can be one of root cause of this event.

Observation:
Master lever parameter was not provided in the analyzed excel flight data.

Additional technical analysis and propulsion observations.
Aircraft takeoff/rotation at 00:07:55 from the beginning of recording[13].
Time markers:

- First time marker (yellow)[14] is when Eng. 2 speeds starts dropping – 00:12:51.
    - PS3 decreases from 248 PSI to 68 PSI, then continues to decrease.
    - EGT increases from 844°C to 898°C, then starts to decrease.
    - Variable Bleed Valve (VBV) opens (goes from 0 degrees to 34 degrees).
    - Variable Stator Vane (VSV) closes (goes from -0.5 degrees to 26 degrees).
    - Fuel flow around 7584 PPH and begins to decrease.
    - HPT vibe slightly fluctuated (decreased then started to increase). However, all engine vibe was less than 1.0 units.
    - Controlling regulator (fuel scheduling) differences between engines.
        - Engine 1 controlling regulator = 3 (N1/N2 speed control).
        - Engine 2 controlling regulator = 9 (PS3 Acceleration Limit).
- Second time marker (blue) is when Engine 2 fail signal is set – 00:15:48.
    - PS3 is steady around 30-36 PSI.
    - EGT is steady around 760ºC.
    - Fuel is still flowing around 816 PPH.

[12] HMU – Hydromechanical Unit – (component of FADEC system) which converts electrical signals from the Electronic Control Unit into hydraulic pressure to drive engine`s valves and actuators.
[13] All times in this section are based on recorded by Flight Data Recorder. Time 00:00:00 start of recording.
[14] See all related diagrams below the analysis.

- Third time marker (maroon) is when the Engine 2 start lever is moved to CUTOFF – 00:19:05.
- Fourth time marker (red) is when the flight crew attempts a restart – 00:28:35.
  - Starter air valve opened at 00:28:35 and start lever RUN at 00:28:49 (~14 seconds after SAV open).
    - N2 was at 23% when start lever RUN.
  - Engine 2 accelerated to 61% N2, then started to slowly decrease.
- Fifth time marker (brown) is when the flight crew aborts start attempt, start lever to CUTOFF – 00:31:10.
  - Engine 2 had decreased to 56% N2 when start lever was moved to CUTOFF.

Other observations:

- Before the failure, Engine 2 was using more fuel than Engine 1 and EGT was a slightly higher (roughly 20 degrees higher on average).
- Engine 2 failure, and subsequent N2 behavior during attempted restart, appears consistent with HPT blade failure observed in the CFM56-7B engine.
- Engine 1 appears to respond normally during flight.
  - Fuel flow matches FMV position, which tracks with the thrust levers/TRA.
  - Vibe within limits, no exceedances.
  - Running at ~ 90% N1 for remainder of flight.
- A/T was disengaged about 2 minutes before the engine #2 speed started to drop.
- For both engines, EEC[15] was in normal mode and had no faults, and there were no exceedances.

[15] **Electronic Engine Control** (EEC)Each engine has a full authority digital EEC. Each EEC has two independent control channels, with automatic channel transfer if the operating channel fails. With each engine start or start attempt, the EEC alternates between control channels. The EEC uses thrust lever inputs to automatically control forward and reverse thrust. N1 is used by the EEC to set thrust in two control modes: normal and alternate. Manual selection of the control mode can be made with the EEC switches on engine panel. The full rated take-off thrust for the installed engine is available at a thrust lever position less than the forward stop. Fixed or assumed temperature derated take-off thrust ratings are set at thrust lever positions less than full rated take-off. The maximum rated thrust is available at the forward stop. The EEC limits the maximum thrust according to the airplane model.

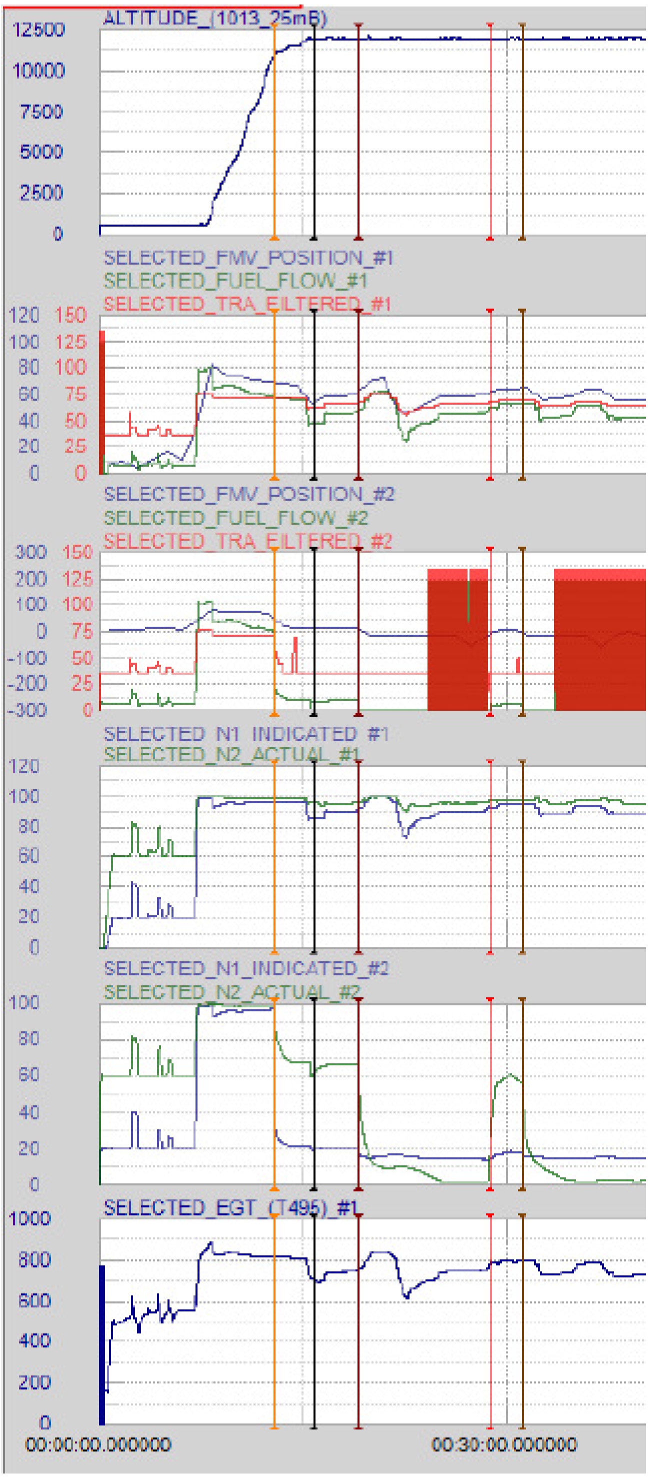

Fig. 37. Flight data overview 1/2.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

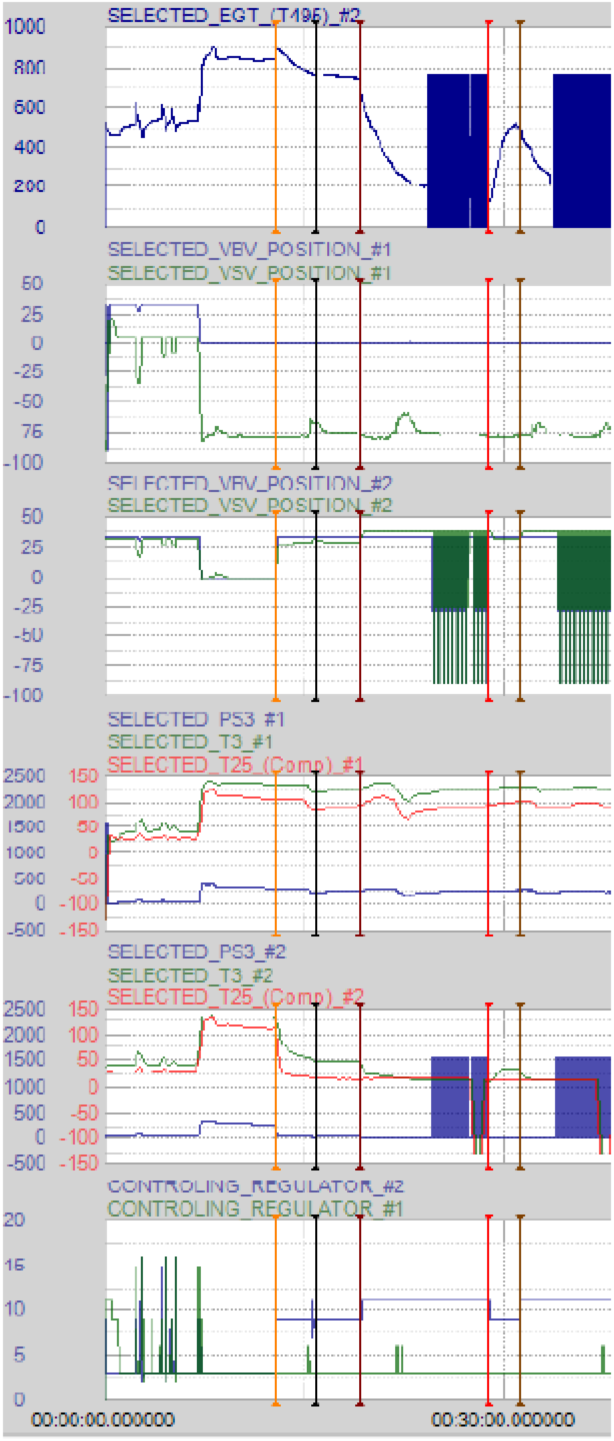

Fig. 38. Flight data overview 2/2.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

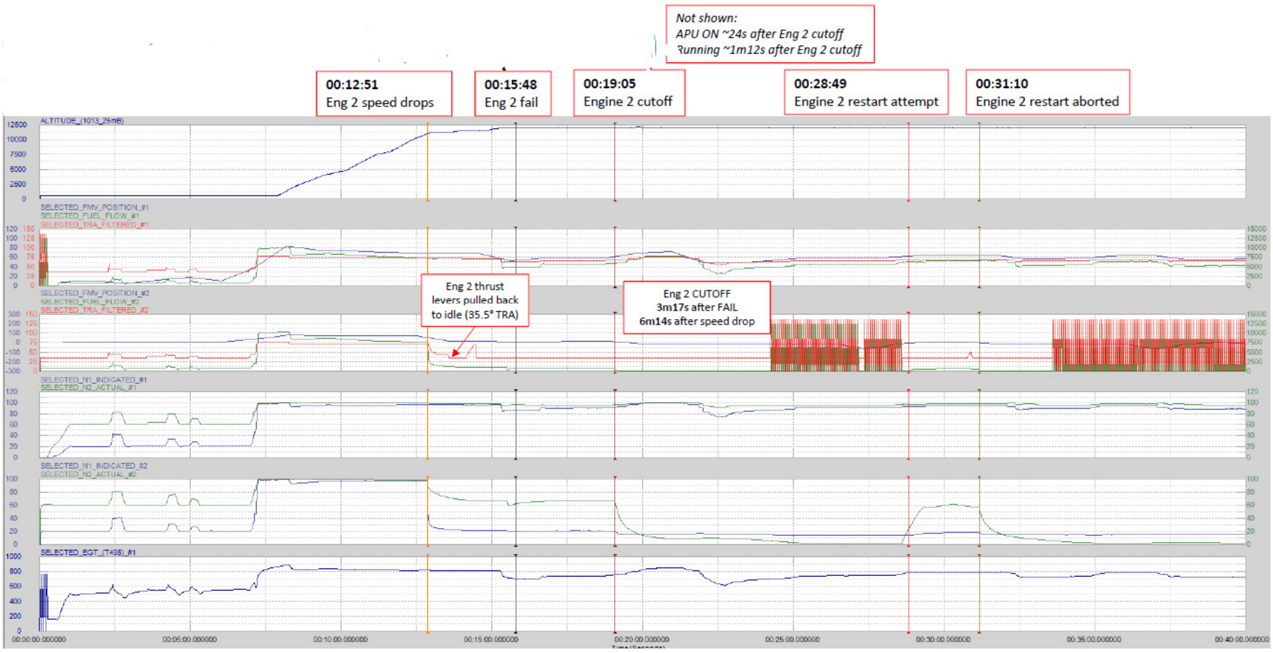

Fig. 39. Zoomed – in view 1/2.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

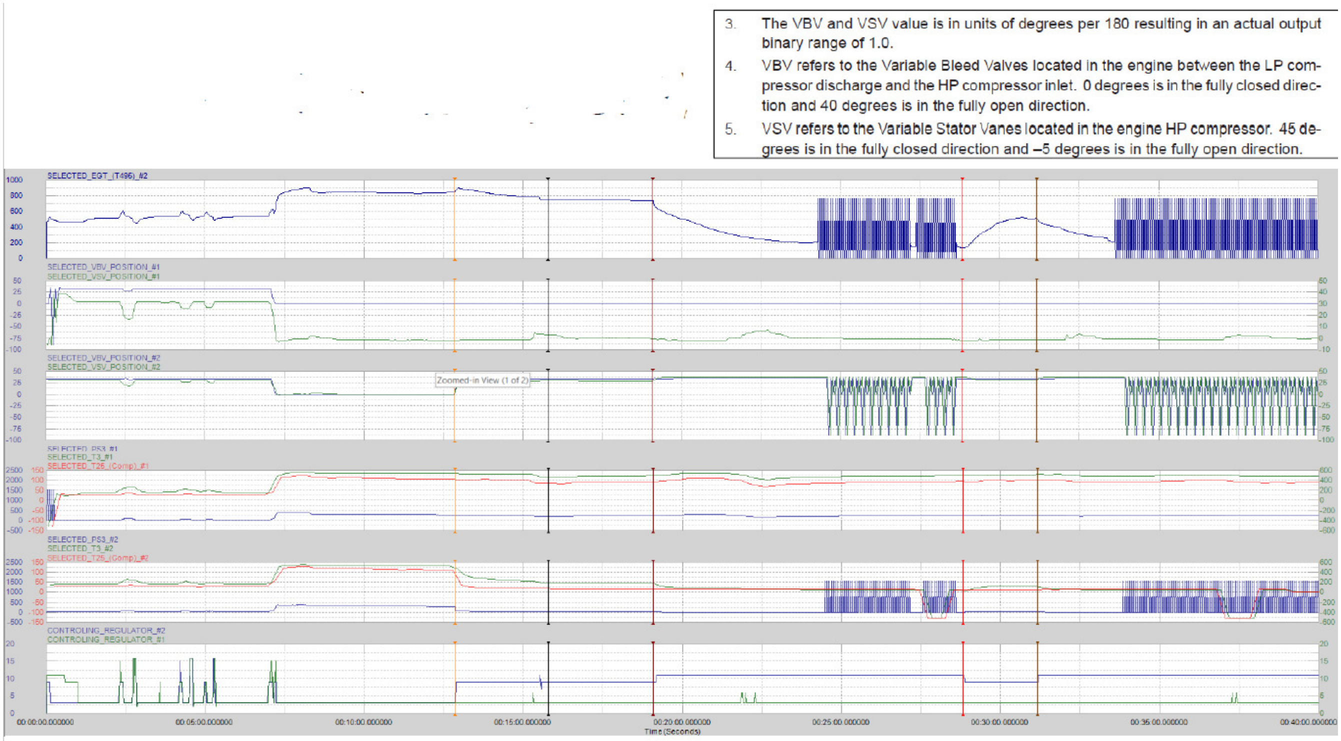

Fig. 40. Zoomed – in view 2/2.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

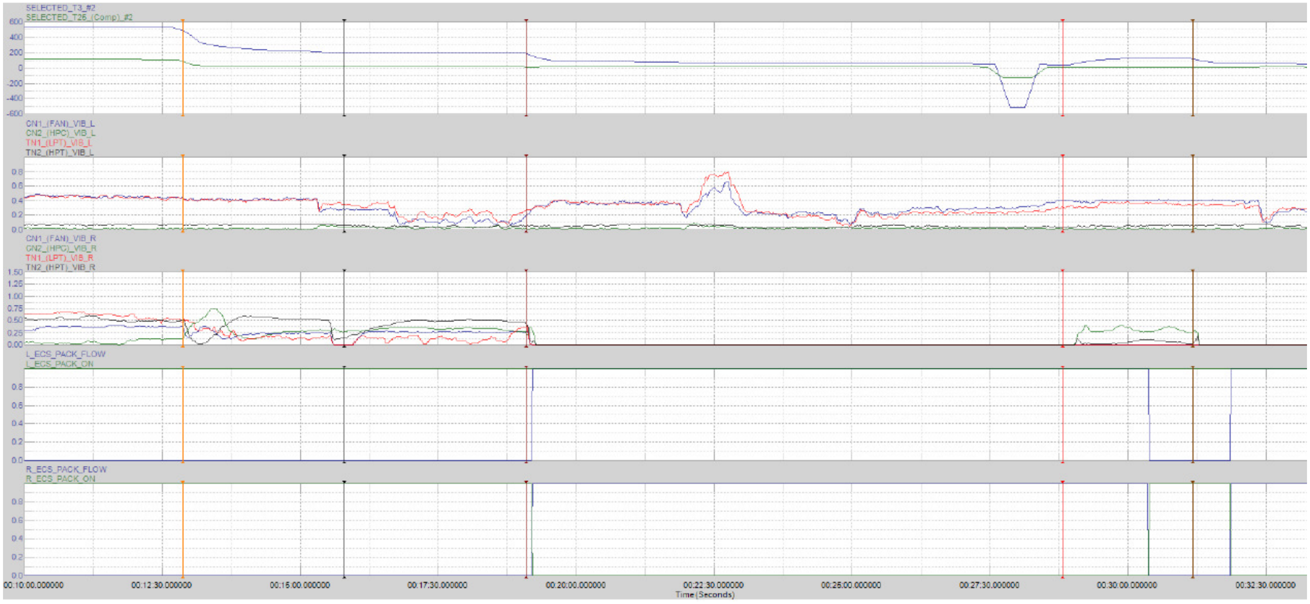

Fig. 41. Vibrations.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

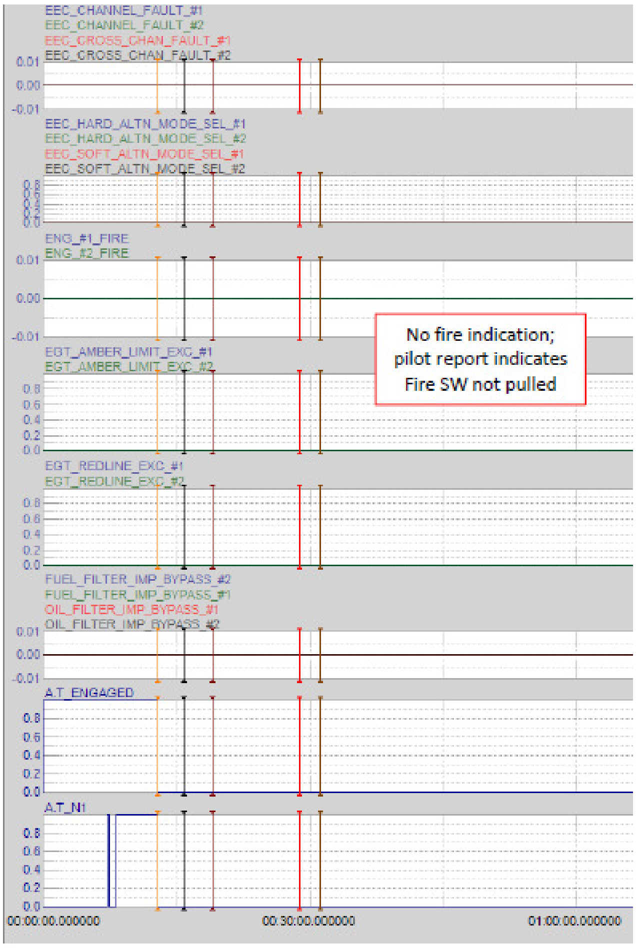

Fig. 42. EEC operated in normal mode with no EEC faults A/T disengaged during the flight.
Source: Propulsion summary. ENTER AIR CFM56-7B
AIRCRAFT SP-ENU - ESN 874306, Engine position 2, Event from August 15th, 2022.

Analysis of technical documentation.

Operator delivered technical documentation of the aircraft. Analysis of mentioned documentation shows that at 14:35 qualified engineer and at 14:36 commander of the flight signed off document and both certified that the work specified, except as otherwise specified, was carried out in accordance with Part-145 and in respect to that work the aircraft/component is considered ready for release to service. Plane was fully serviceable. Engineer uplifted 3 quarts of oil to Eng. 1 and Eng. 2. Total oil for departure: Eng. 1: 18 quarts and Eng. 2: 18 quarts. Hydraulic fluid on departure: System A: 90%, System B: 92%. Crew oxygen for departure: 1450PSI. Fuel for departure: 18 570kg (left wing tank: 3810kg, right wing tank: 3800kg, center tank: 10 960kg).
Last Pre-Departure check: the 15th of August 2022, at 14:35.
Last 48hr check completed: the 15th of August 2022, at 01:48.
Last Weekly check completed the 9th of August 2022, at 23:45.

Weight and balance analysis.

All parameters related to weight and balance within the limit.

3. CONCLUSIONS

3.1. Findings

1) Aircraft fully serviceable for departure with completed and valid pre-departure, 48 hours and weekly check.
2) Flight and cabin crew were rested and planned according to FTL.
3) Both pilots with valid license, and type rating.
4) Both pilots with Class 1 Medical Certificate with VDL limitations - correction for defective distant vision).
5) Weight and balance within the limit.
6) For departure FO was PF and captain was PM.
7) Flight crew identified engine failure as severe damage and decided to complete QRH NNC. 8.2. Engine Fire or Engine Severe Damage or Separation.
8) No fire was detected.
9) After engine fail pilots switched, they role. Captain became of PF and FO became PM.
10) Flight crew declared PAN-PAN distress signal.
11) Flight crew completing NNC. 8.2. Engine Fire or Engine Severe Damage or Separation omitted point 4 from the check list: Engine Fire Switch (affected engine)…confirm…pull.
12) After completing NNC 8.2. (not in full), flight crew decided to restart engine in flight.

13) Engine #2 failed to restart.
14) Initially the flight crew intended to land on EPGD.
15) ATC advised crew that EnterAir OPS Officer is suggesting diverting to EPWA.
16) Flight crew completed QRH NNC 7.32 One Engine Inoperative Landing check list.
17) Flight crew delayed landing to burn fuel and reduce weight, however 737 flight crew training procedures provide guidance to safely perform an overweight landing[16].
18) Flight crew diverted to EPWA in lieu of selecting other potentially closer suitable airports.
19) Flight crew declared MAY-DAY emergency signal.
20) Plane landed safely in EPWA.
21) Flight time 3 hours and 41 minutes.
22) 10 min. and 45 sec. after departure flight data recorders indicated deviations from standard engine parameters indications engine #2 (altitude 11 159ft).
23) Post event BSI showed a single HPT blade with a liberated airfoil.
24) HPT blade number 80 (PN 1957M10P01, SN BWHN9B01) exhibits airfoil separation at ~15% radial span.
25) Metallurgical evaluation shows the prime blade initiated cracks in the airfoil leading edge cavity at the internal crossover rib hole. Cracks propagated in LCF forward and aft on the convex and concave airfoil surfaces to airfoil separation. Finding is consistent with previous CFM56 field experience for this HPT blade configuration.
26) Engine #2, HPT Blade #80 fractured at ~15% span, while multiple HPT blades and downstream hardware were damaged due to impact from the liberated debris.
27) Blade #80. Multiple blades were damaged due to impact from the liberated airfoil debris.
28) HPT Blade #80 showing airfoil liberation.
29) Blade #75 and blade #38 show worst-case lead edge oxidation.
30) HPT Blade operational history shows opportunities were missed to detect LE cracking.
31) M10P01 blades were operated in India environment ~9600 FC, where SB 72 0886 recommends 800 cycle repeat BSI intervals after component repair.
32) BSI views provided by customer are not optimal to detect LE cracking at the convex gill row 1 location.
33) SB 72-0886 recommends internal crossover rib inspection per RD 150 1551 prior to 2013 repair. Inspection not performed as per mentioned SB.

[16] Based on 737 Flight Crew Training Manual – Boeing provides guidance how to safely complete an overweight landing.

3.2. Causes of the incident and contributing factors:

1) The cause of the engine failure and related damage was a rupture of the main blade of the SNBWHN9B01.

Circumstances conducive to the occurrence:

1) Based on the analysis of the Borescope Test Report of June 13, 2022, which was the last BSI test of a high-pressure turbine (performed after 234 cycles) before the occurrence of IFSD, the most likely was that in the BSI test of main blade SNBWHN9B01 was used incorrect angle of view - which is recommended by the producer (justification described in the analysis).
2) No recommended RD 150-1551 study has been performed. Based on the repair records from Plant No. 23 in Singapore, it was concluded that RD 150-1551 was not tested. By State from the 2013 repair, the plant responsible for the major repair of the high-pressure turbine blades (Plant No. 23 in Singapore) has provided repair records for HPT 1957M10P01 blades installed in the 874306 engine (the engine that failed). According to the data contained, a complete set of 80 blades was repaired, of which 25 blades were repaired, including the main separated blade SN BWHN9B01. The remaining 55 blades were scrapped for various reasons. Among the reasons for scrapping the blades, the requirement to meet the conditions of the RD 150-1551 repair document was not given.

4. SAFETY RECOMMENDATIONS

Nor formulated.

THE END

Investigator-in-Charge

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Signature on original