COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
IG-032/CENIPA/2017

OCCURRENCE:	**SERIOUS INCIDENT**
AIRCRAFT:	**PT-MZY**
MODEL:	**A320-232**
DATE:	**22FEB2017**

NOTICE

According to the Law nº 7565, dated 19 December 1986, the Aeronautical Accident Investigation and Prevention System – SIPAER – is responsible for the planning, guidance, coordination and execution of the activities of investigation and prevention of aeronautical accidents.

The elaboration of this Final Report was conducted taking into account the contributing factors and hypotheses raised. The report is, therefore, a technical document which reflects the result obtained by SIPAER regarding the circumstances that contributed or may have contributed to triggering this occurrence.

The document does not focus on quantifying the degree of contribution of the different factors, including the individual, psychosocial or organizational variables that conditioned the human performance and interacted to create a scenario favorable to the accident.

The exclusive objective of this work is to recommend the study and the adoption of provisions of preventative nature, and the decision as to whether they should be applied belongs to the President, Director, Chief or the one corresponding to the highest level in the hierarchy of the organization to which they are being forwarded.

This Report does not resort to any proof production procedure for the determination of civil or criminal liability, and is in accordance with Appendix 2, Annex 13 to the 1944 Chicago Convention, which was incorporated in the Brazilian legal system by virtue of the Decree nº 21713, dated 27 August 1946.

Thus, it is worth highlighting the importance of protecting the persons who provide information regarding an aeronautical accident. The utilization of this report for punitive purposes maculates the principle of "non-self-incrimination" derived from the "right to remain silent" sheltered by the Federal Constitution.

Consequently, the use of this report for any purpose other than that of preventing future accidents, may induce to erroneous interpretations and conclusions.

N.B.: This English version of the report has been written and published by the CENIPA with the intention of making it easier to be read by English speaking people. Taking into account the nuances of a foreign language, no matter how accurate this translation may be, readers are advised that the original Portuguese version is the work of reference.

SYNOPSIS

This is the Final Report of the 22FEB2017 serious incident with the A320-232 aircraft, registration PT-MZY. The serious incident was classified as “[SCF-PP] System/Component Failure or Malfunction Powerplant / Engine Failure on the Ground”, “[LOC-G] Loss of Control – Ground and [RE] Runway Excursion.”

During the takeoff run, a failure occurred on the right engine of the aircraft.

The crew aborted the take-off (Rejected Take Off), but during this procedure, the aircraft momentarily exited by the right side of the runway, returning later.

The aircraft had limited damage to the right engine and minor damage to the right wing.

All occupants left unharmed.

An Accredited Representative of the *Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile* (BEA) - France, (State where the aircraft was designed) was designated for participation in the investigation.

An Accredited Representative of the National Transportation Safety Board (NTSB) - USA, (State where the engine was designed) was designated for participation in the investigation.

An Accredited Representative of the Japan Transport Safety Board (JTSB) - Japan (State where components of the engine were designed) was designated for participation in the investigation.

An Accredited Representative of the *Bundestelle für Flugunfallunterschung* (BFU) - Germany, (State where components of the engine were designed) was designated for participation in the investigation.

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

AMM	Aircraft Maintenance Manual
BEA	*Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile*
BFU	*Bundestelle für Flugunfalluntersuchung*
CA	Airworthiness Certificate
CENIPA	Aeronautical Accident Investigation and Prevention Center
CG	Center of Gravity
CI	Investigation Team
CIV	Pilot's Flight Logbook
CM	Registration Certificate
CMA	Aeronautical Medical Certificate
CSO	Cycles Since Overhaul
CVR	Cockpit Voice Recorder
DCTA	Department of Science and Airspace Technology
EGT	Exhaust Gas Temperature
FDR	Flight Data Recorder
HPC	High Pressure Compressor
HPT	High Pressure Turbine
IAE	International Aero Engines
IFR	Instrument Flight Rules
IFRA	Instrument Flight Rating - Airplane
INFRAERO	Brazilian Airport Infrastructure Company
IGV	Inlet Guide Vanes
IPS	Inches Per Second
JAEC	Japanese Aero Engine Corporation
JTSB	Japan Transport Safety Board
LPT	Low Pressure Turbine
METAR	Aviation Routine Weather Report
NTSB	National Transportation Safety Board (USA)
NWS	Nose Wheel Steering
OGV	Outlet Guide Vanes
PCM	Commercial Pilot License – Airplane
PLA	Airline Pilot License - Airplane
PN	Part Number
PPR	Private Pilot License – Airplane
SBCF	ICAO Location Designator - Tancredo Neves Aerodrome, Confins - MG
SBSP	ICAO Location Designator – Congonhas Aerodrome, São Paulo - SP
SCF-PP	Powerplant Failure or Malfunction

SESCINC	Prevention, Rescue and Fire Fighting Service
SIPAER	Aeronautical Accident Investigation and Prevention System
SN	Serial Number
SPECI	Selected Special Aeronautical Weather Report
TCSN	Total Cycles Since New
TPR	Aircraft Registration Category of Regular Public Transport
TOGA	Take-Off/Go Around
TSO	Time Since Overhaul
TTSN	Total Time Since New
TSR	Time Since Repair
TWR-SP	Congonhas Aerodrome Control Tower - SP
UTC	Universal Time Coordinated
VFR	Visual Flight Rules

1. FACTUAL INFORMATION.

Aircraft	**Model:** A320-232 **Registration:** PT-MZY **Manufacturer:** *Airbus Industrie*	**Operator:** TAM Airlines S/A
Occurrence	**Date/time:** 22FEB2017 - 2148 UTC **Location:** Congonhas Aerodrome (SBSP) **Lat.** 23°37'34"S **Long.** 046°39'23"W **Municipality – State:** São Paulo – SP	**Type(s):** "[SCF-PP] System/Component Failure or Malfunction Powerplant; "[LOC-G] Loss of Control – Ground; [RE] Runway Excursion" **Subtype(s):** Engine Failure on the Ground

1.1 History of the flight.

The aircraft was taking off from the Congonhas Aerodrome (SBSP), São Paulo - SP, to the Tancredo Neves Aerodrome (SBCF), Confins - MG, at about 2148 (UTC), in order to carry out regular passenger transport with six crewmembers and 131 passengers on board.

Moments after starting the takeoff run from threshold 17R, a failure on the right engine occurred, followed by a yaw to the side of the engine that failed (right), causing a runway excursion by the right side.

Soon after the engine failure, the crewmembers started the takeoff rejection procedure, getting back to a position close to the center of the runway, where the total stoppage of the aircraft occurred.

The aircraft had limited damage to the right engine and minor damage to the right wing.

All occupants left unharmed.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor	-	-	-
None	6	131	-

1.3 Damage to the aircraft.

Damage occurred in the inner regions of the right engine. That is, in the inner fan case, in two structural elements of the fan set - annulus fillers, in the High Pressure Compressor (HPC), in the High Pressure Turbine (HPT) and Low Pressure Turbine (LPT).

On the right engine reverser, more precisely, on the inside of the left and right sliding bonnets, minor damage occurred due to the fragmented parts of the fan region that were ingested and then pushed.

There were minor damage to the right wing lower surface resulting from impacts of the fragmented small parts of the fan region, precisely on one flap fairing.

1.4 Other damage.

None.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Hours Flown		
	Pilot	Copilot
Total	Unknown	5,200:00
Total in the last 30 days	64:50	65:35
Total in the last 24 hours	00:00	00:00
In this type of aircraft	11,366:35	3,972:45
In this type in the last 30 days	64:50	65:35
In this type in the last 24 hours	00:00	00:00

N.B.: The data related to the flown hours were obtained through information of the Airline operating the aircraft.

1.5.2 Personnel training.

The pilot took the PPR course, in 1973.

The copilot took the PPR course, in 2008.

1.5.3 Category of licenses and validity of certificates.

The pilot had valid PLA License and valid A320 type aircraft and IFRA Ratings.

The copilot had valid PCM License and valid A320 type aircraft and IFRA Ratings.

1.5.4 Qualification and flight experience.

The pilots were qualified and had experience in that kind of flight.

1.5.5 Validity of medical certificate.

The pilots had valid CMAs.

1.6 Aircraft information.

The aircraft, serial number 1628, was manufactured by *Airbus Industrie,* in 2001 and was registered in the TPR category.

The aircraft had valid Airworthiness Certificate (CA).

All technical documentation regarding the aircraft and the engine maintenance was updated.

The aircraft was equipped with IAE (International Aero Engines) engines. The right engine model and version was V2527-A5, serial number V10871.

The engine was manufactured in 2000 and had the following history of hours and cycles:

- total time since new (TTSN) – 42,342 hours;
- total cycles since new (TCSN) – 35,172 cycles;
- time since last overhaul (TSO) – 18,501 hours;
- cycles since last overhaul (CSO) – 15,252 cycles;
- time since last repair (TSR) – 9,606 hours; and
- cycles since last repair (CSR) – 7,252 cycles.

The last major maintenance intervention on the engine, named by the manufacturer as "last major overhaul", occurred in November 2008 and the last repair occurred in February 2012 at a service center of the engine manufacturer.

This engine was installed on the PT-MZY aircraft in October 2016 and thereafter it operated 710 hours and 587 cycles on the aircraft until the serious incident day.

1.7 Meteorological information.

The METAR and the SPECI of SBSP provided the following information:

SPECI COR SBSP 222022Z 33013G26KT 0300 R35/0500D R17/0550D +TSGRRA BKN015 FEW040CB BKN063 20/17 Q1020=

SPECI SBSP 222045Z 06009KT 8000 TSRA BKN025 FEW037CB BKN063 18/16 Q1018=

METAR SBSP 222100Z 07007KT 9999 TSRA SCT021 FEW037CB BKN063 19/17 Q1018=

SPECI SBSP 222118Z 09007KT 9999 -TSRA FEW037CB BKN083 21/17 Q1018 RERA WS R35L

It was verified, therefore, that in the corrected SPECI (COR) of 2022 (UTC), the Aerodrome presented wind conditions ranging from 13kt to 26kt, with 330º of direction. The visibility was of 300m, the ceiling was 1,500ft, being in the presence of storm with heavy rain, hail and clouds of the cumulonimbus type.

The 2045 (UTC) SPECI already had wind with 060º of direction and intensity of 9kt. The visibility increased to 8,000m, the ceiling increased to 2,500ft, keeping the storm scenario with rain, but without the report of hail.

The 2100 (UTC) METAR had wind with 070º of direction and with an intensity of 7kt. The visibility increased to more than 10km, the ceiling went to 6,300ft, still with storm and rain.

The 2118 (UTC) SPECI had wind with 090º of direction and maintaining the intensity of 7kt. The visibility continued to be over 10km, the ceiling increased to 8,300ft, the rain was lighter, but a windshear was reported over threshold 35 L.

As a result of the weather conditions, the runway was wet and there had been a change in the landing and take-off operation from threshold 35 to threshold 17, just before this serious incident.

At the time of the authorization for PT-MZY to take-off, the wind reported by the Control Tower was heading 110º with 6kt.

1.8 Aids to navigation.

Nil.

1.9 Communications.

According to the audio transcriptions obtained through the Cockpit Voice Recorder (CVR), it was verified that there was no technical abnormality of communication equipment between the aircraft and the air traffic controllers.

1.10 Aerodrome information.

The Aerodrome was public, run by the INFRAERO and operated under visual flight rules (VFR) and under instrument flight rules (IFR), in daytime and nighttime.

The Aerodrome had two parallel asphalt runways, with thresholds 17/35, dimensions of 1,940m x 45m and 1,495m x 45m, with elevation around 2,631 feet, according to Figure 1.

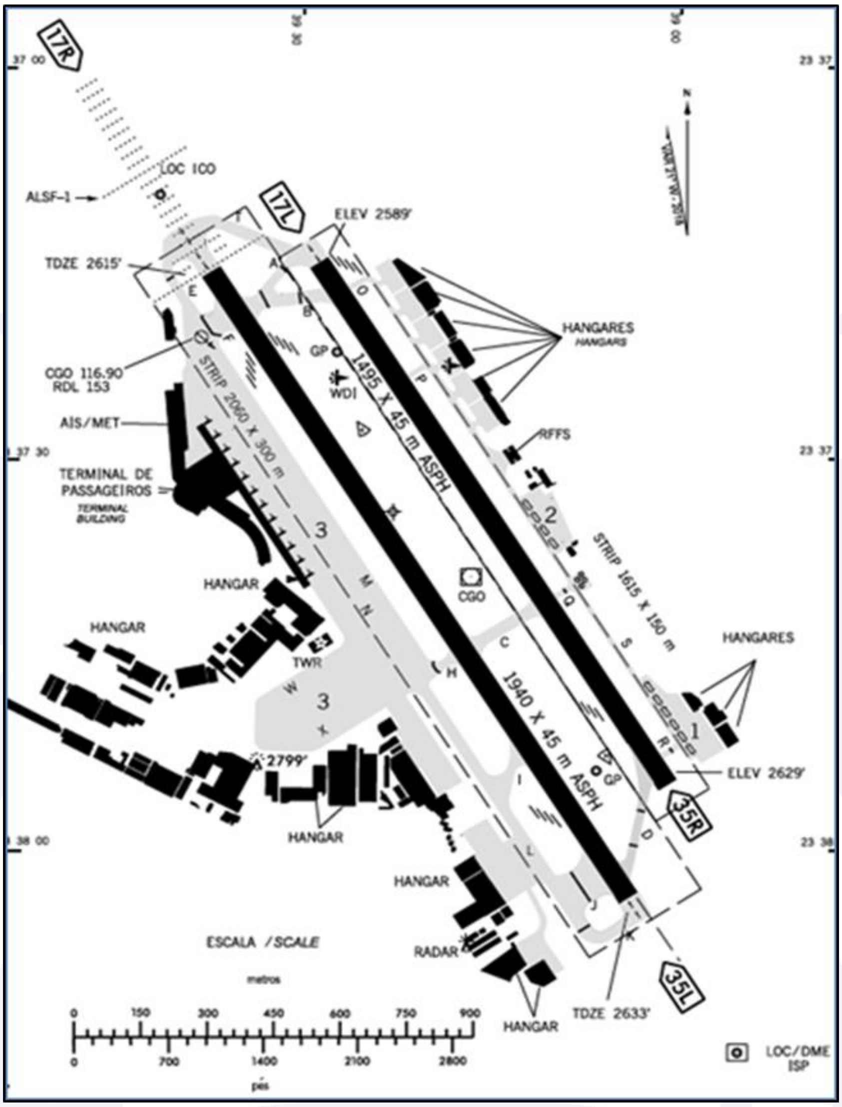

Figure 1 - SBSP Aerodrome Chart.

1.11 Flight recorders.

The aircraft was equipped with a Honeywell Flight Data Recorder (FDR) P/N 980-4700-003, S/N 08611, with processing capacity of 600 parameters. In addition, it was also equipped with a Honeywell Cockpit Voice Recorder (CVR) P/N 980-6022-001, S/N 2959, with two hours recording capability.

Both recorders (flight data and cockpit voice) recorded the occurrence data.

1.12 Wreckage and impact information.

The aircraft exited by the right side and ran about 200m along the runway outside its limits. The right landing gear ran out of the paved surface.

During the runway excursion, there was no collision of the aircraft with any obstacle.

The crewmembers were able to regain control, stopping the aircraft on the asphalt.

1.13 Medical and pathological information.

1.13.1 Medical aspects.

No evidence was found that problems of physiological nature or incapacitation could have affected the flight crew performance.

1.13.2 Ergonomic information.

Nil.

1.13.3 Psychological aspects.

The commander had begun his aviation activities as a pilot in 1979 when he obtained his Private Pilot License. The copilot joined the air activity as a pilot in 2008, when he also obtained his license.

According to information gathered, both the commander and the copilot were considered experienced pilots in the equipment.

Both were off duty the day before the incident. There were no reports of physical or mental fatigue for the flight.

For them, it was an atypical day of operation due to bad weather and the runway being wet. However, the preparation for the flight occurred normally.

It was the first flight that the technical crewmembers held together. According to the copilot's report, the interaction between them in the cockpit occurred normally, a fact that could be verified by the recording of the CVR.

1.14 Fire.

Although the Congonhas Aerodrome Control Tower (TWR-SP) observed a small flame coming out of the aircraft right engine, there were no signs of fire.

The crewmembers realized an increase in the exhaust gas temperature (EGT) of the right engine and performed the shutdown procedure followed by a preventive application of the aircraft engine fire extinguishing agent.

There was the activation of the SESCINC of the Aerodrome and this team proceeded to the preventive cooling of the affected engine, even if there were no signs of fire.

1.15 Survival aspects.

The aircraft was towed from the main runway to the parking area and the disembarkation of passengers and crewmembers occurred without abnormalities.

1.16 Tests and research.

During the engine failure, it was found that fragments of the respective powerplant had come off, stopping near its air intake and exhaust duct. In addition, fragments of the same nature were found on the SBSP runway.

Figure 2 shows an overview of the right engine, where the location of the air intake and the region where the external damage occurred due to the separation of the annulus fillers can be identified.

Figure 2 - Right engine overview, air intake and detail of external damage.

In Figure 3, looking more closely at the affected external region, fan blades, annulus fillers, acoustic panels and guide vanes, all of the right engine can be identified.

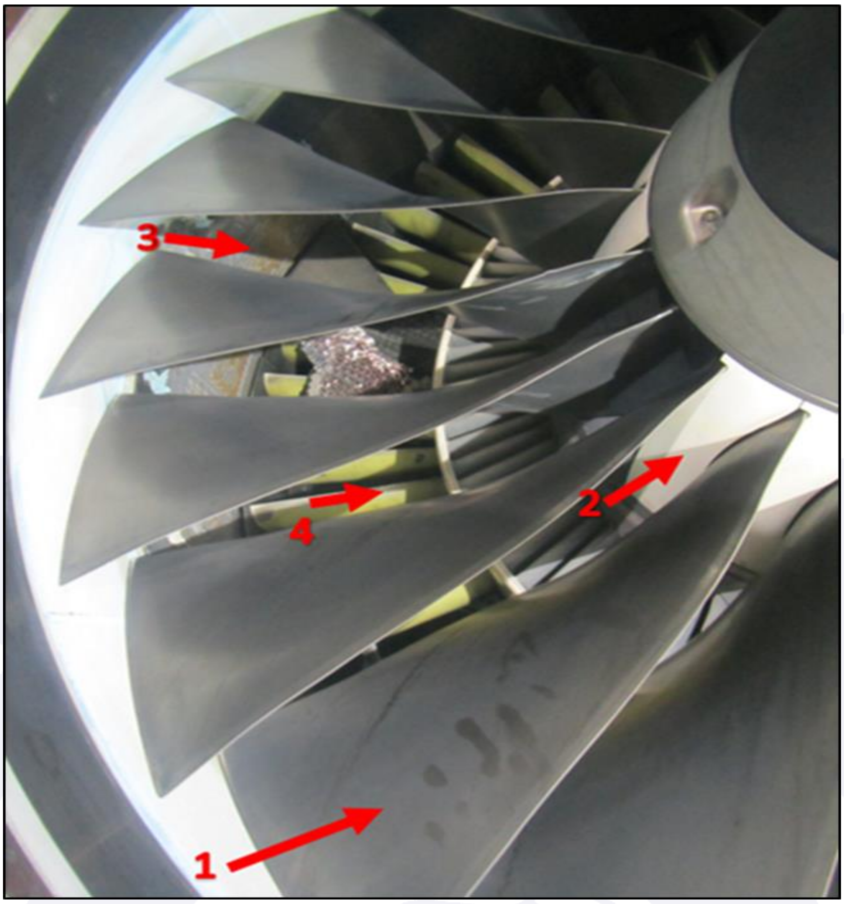

Figure 3 - Right engine, detail of fan blades (1), annulus filler (2), acoustic panels (3) and guide vanes (4).

Because of the material found, a research was oriented in order to know the origin and the context of the detachment of those fragments.

The result of the study concluded that, for the most part, the fragments were part of a component called annulus filler, which is installed in the fan module, between the respective blades.

Based on this information, it was investigated the history of failures in the operating engines IAE V2527, A5 series that had experienced irregularities in operation to which they related to annulus fillers, P/N 5A1710.

Three events were found of separation of annulus fillers. In two of these events, the identified root cause was related to maintenance tasks and in the third case, the root cause was not identified.

Considering the variables related to the manufacture date, serial number, time and total cycles, time and cycles since the Last Shop Visit, it was not possible to establish a connection between these events and the S/N engine failure V10871 (object of these tests) that could make feasible a line of investigative research that related them.

In order to know the verification scenario for this engine module, a research was done on all the documentation related to the execution of preventive maintenance in the engine related to the annulus fillers and their interconnected components. It was found that all the services provided were executed.

In the history of the engine performance data for the last 60 days of operation, it was recorded an EGT margin of 60º C during take-off. The N1 vibration level was 0.50 inch per second (IPS) and the N2 vibration level was 0.40 IPS, all at nominal values, and which remained stable during this period.

It was also found that in the same time interval the engine oil pressure and temperature values were 245 PSI and 105°C respectively.

This history showed that the engine operated in satisfactory conditions, far from marginal operating values, leading to the conclusion that there was no need for unscheduled maintenance for performance recovery.

Initially, fragments of parts and coatings that separated from the engine (annulus fillers, acoustic panels and fan shroud abradable material), along with six blades of the fan disc and two segments of guide vanes stator were analyzed at the DCTA facilities for detecting the following:

- the mechanism of rupture of the two annulus fillers;
- the mechanisms of detachment of the acoustic lining panels from the internal structure of the fan duct; and
- the origin and sequence of impact marks on fan blades and fan exit guide vanes.

In Figure 4, fan blades removed from the engine, which were sent for preliminary analysis at the DCTA, can be identified.

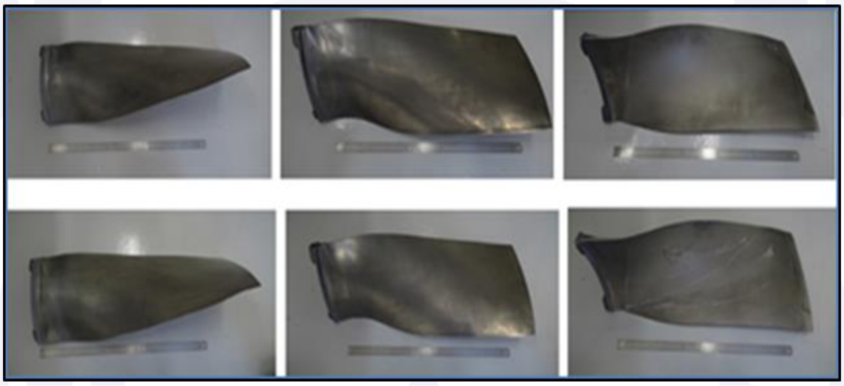

Figure 4 - Set of blades submitted for analysis at the DCTA.

In order to exemplify the damages found in the fan blades, Figure 5 presents a closer look.

Figure 5 - Detail of damage to one of the blades.

Figure 6 illustrates the fan exit guide vanes, which were also submitted for analysis at the DCTA.

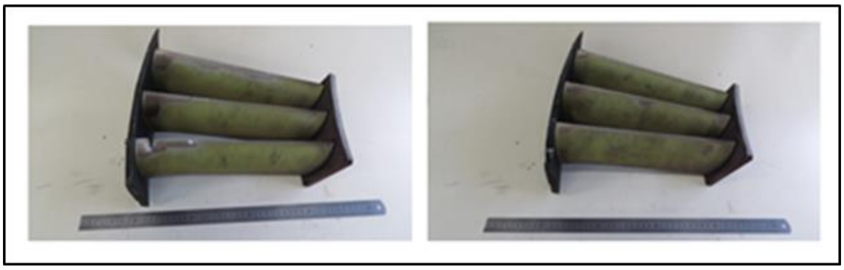

Figure 6 - Segments of fan exit guide vanes sent for analysis.

By means of a visual and stereoscopic analysis, it was observed that the fractures of the annulus fillers, acoustic lining panels and guide vanes occurred from impacts and presented typical characteristics of overload, as shown in Figures 7 to 9.

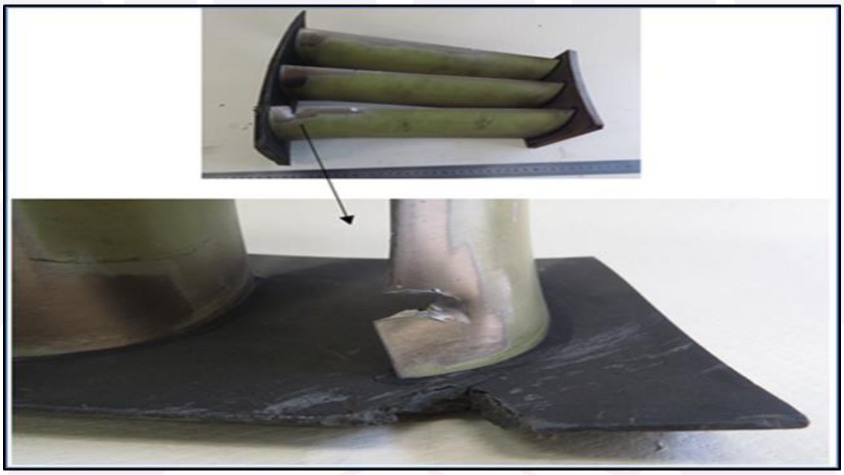

Figure 7 - Damage detail on one of the fan exit guide vanes.

Figure 8 - Annulus filler that separated from the engine.

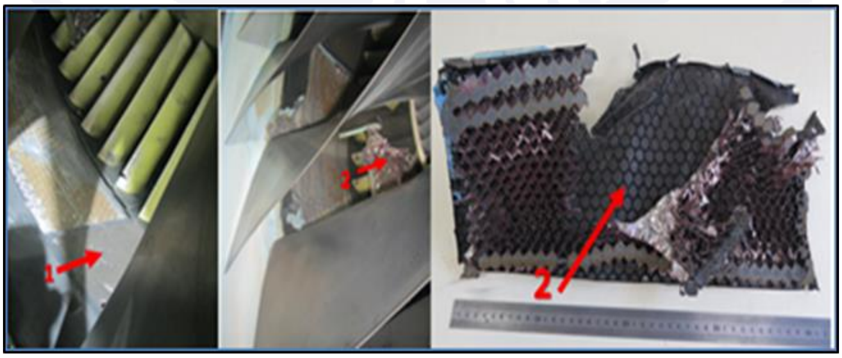

Figure 9 - Acoustic lining panels installed (1) and separated from the frame (2).

For reference and comparison purposes, Figure 10 shows some installed annulus fillers and a whole unit removed.

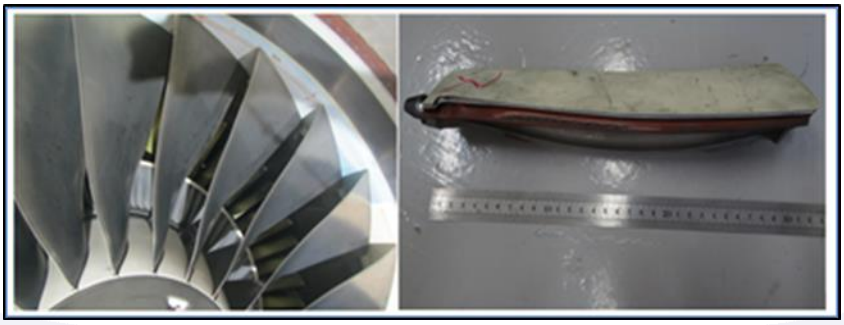

Figure 10 - Annulus fillers installed and a whole unit removed.

The risks found in the parts were also due to impacts on the surface of the material, with no evidence of corrosion or fatigue.

After these tests, the material was re-incorporated into the engine, so that it could be transported for further testing.

Subsequently, the engine was subjected to an analysis in the premises of the manufacturer's service center, in this case MTU Maintenance Ltd. (Figure 11).

Figure 11 - Engine under analysis at the MTU service center.

This analysis was carried out with the participation of representatives of the following investigation authorities: CENIPA, NTSB, BEA and BFU. In addition to these authorities, technical advisors from the manufacturers AIRBUS, IAE, Japanese Aero Engine Corporation (JAEC) and MTU also participated in the analysis. A representative of the aircraft operator also followed the work.

Due to the impossibility of reinstalling some parts and fragments of the engine, without significantly altering its state after the occurrence, they were sent separately, in order to allow a more reliable analysis (Figure 12).

Figure 12 - Parts and fragments of the engine sent separately for analysis.

In the examinations performed, considering the sections (modules) in which the engine was divided for the purpose of analysis, the following was observed:

- FAN module: blades #4 and #5 of the fan disc presented impact marks compatible with the shape of an annulus filler. The white coloration of these marks was also compatible with the color of the annulus filler. Blades #18 and #19 showed small kneading at their trailing edge, about two inches from the end. The fragments of annulus fillers #5 and #6, which were recovered and submitted to analysis, were still with parts of their screws threaded, and also the front and rear attachment posts were incorporated into their structure (Figure 13);

Figure 13 - Annulus filler: post (1) and screw (2). Brands on Blade (3).

- Low Pressure Compressor Module: The low-pressure module had small kneading on the first stage blades as well as the Inlet Guide Vanes (IGV). However, it was not possible to rotate it. This module has not been completely disassembled;

- High Pressure Compressor Module: The high-pressure module presented severe thermal and mechanical damage. Several vanes and blades from 5^{th} to 12^{th} stages were fractured and missing parts of their structures (Figure 14);

Figure 14 - Fractured blades of the high-pressure compressor.

- Diffuser and Combustion Module: in the diffuser housing, there was a large amount of melted wreckage in the form of flakes. These debris were compatible with the shape and the constituent material of the combustion chamber. In the Outlet Guide Vanes (OGV) of the compressor and in all twenty fuel nozzles there were also melted debris (Figure 15);

Figure 15 - Diffuser housing and fuel nozzle with melted debris.

- High Power Turbine Module: all blades of the 2^{nd} stage were fractured in different lengths, as observed in Figure 16. The blades of the 1^{st} stage did not present fractures, but there were melted debris deposited on the leading edges of all of them;

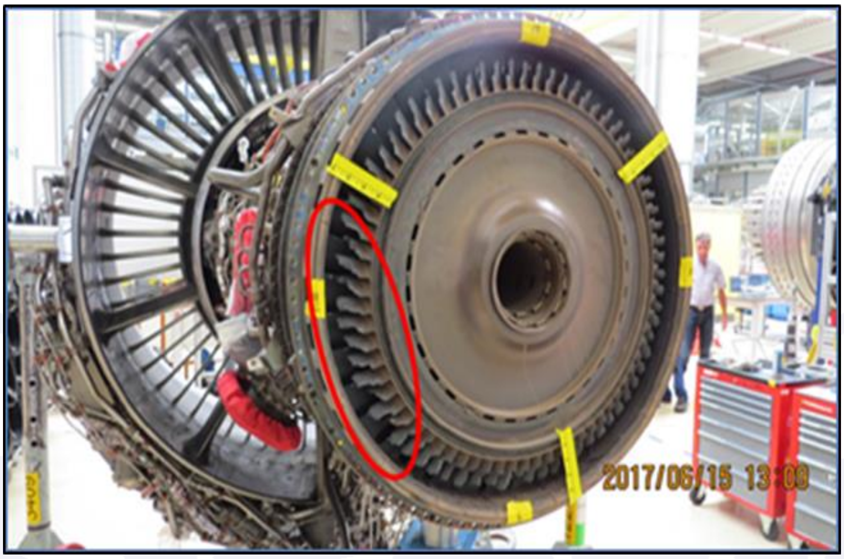

Figure 16 - Fractured 2nd stage blades.

- Low Power Turbine Module: On the first set of vanes, there were melted debris and their trailing edges showed loss of material, according to Figure 17.

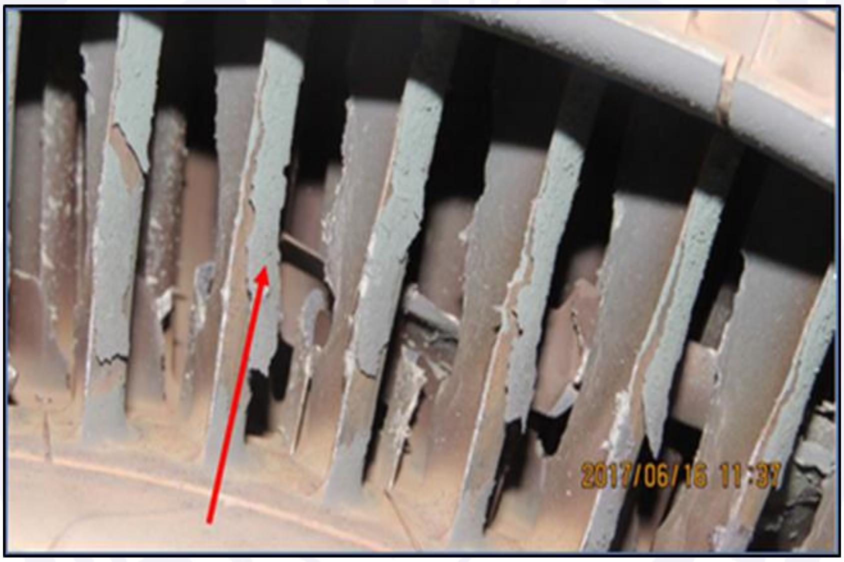

Figure 17 - Melted debris in low power turbine vanes.

There was damage, for loss of material, in all blades of the 1st stage; and

- Accessory Gear Box: there was no need to analyze the accessory gearbox, due to the impossibility of the annulus fillers flow of the debris to reach the interior of this component.

Considering the relative positioning of all the engine components and the dynamics of the air flow (compressed air and bypass air), combustion flow and flue gas flow, it was found that the engine damage occurred from a failure in the structure of two annulus fillers.

The research, from then on, began to focus on these components. In this sense, a structural analysis of the annulus fillers was conducted with the purpose of evaluating the possibility of an atypical mode of internal tension in these components when in service.

At a later date, the results of disassembly and engine analysis being known, the tension distribution was simulated from boundary loading conditions in the theoretical structure of a solid identical to one of the annulus fillers (Figure 18).

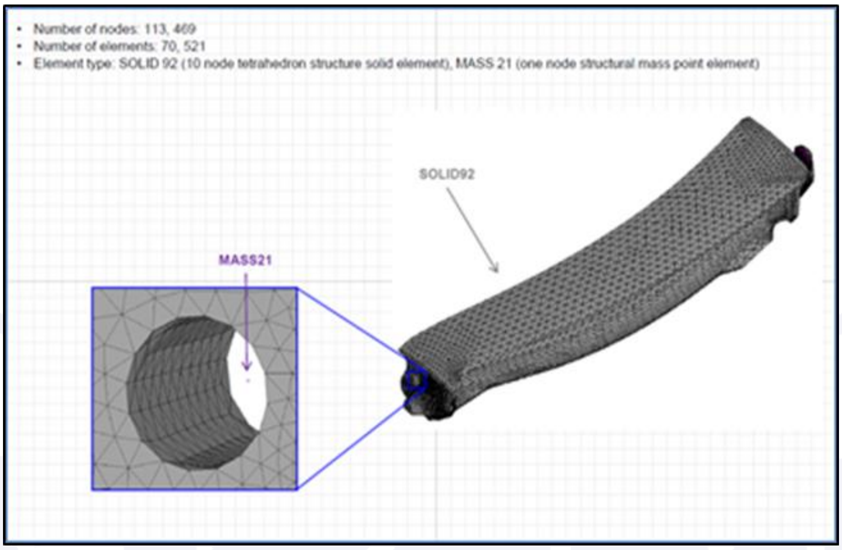

Figure 18 - Solid with the shape of annulus filler used as model for analysis.

When comparing the results of the maximum main tension distribution with the fragments of annulus fillers, which were detached from the engine and which did not receive significant additional impacts, it was possible to verify a similarity between the shape of these fragments and the contour of the areas of the different main tensions, as shown in Figure 19, in the blue, green and yellow colors.

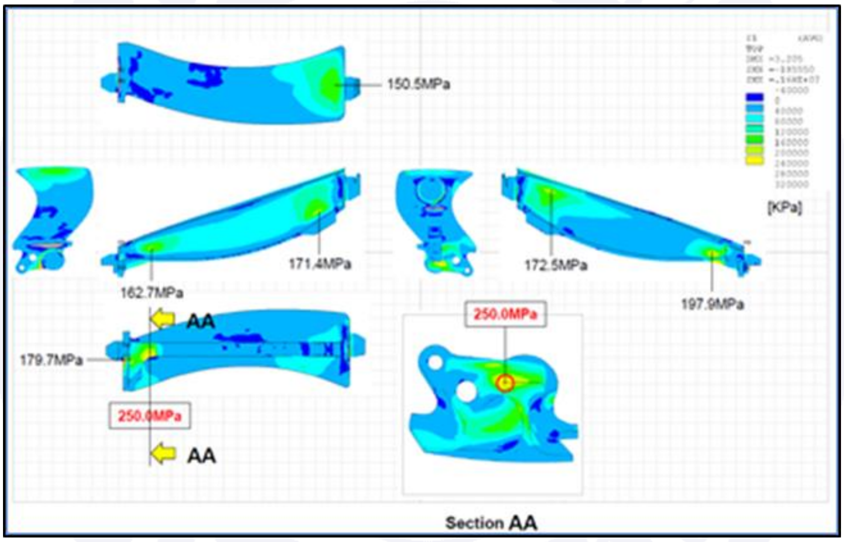

Figure 19 - Result of the maximum main tension distribution.

Finally, in order to deepen the analysis, to the point of knowing the triggering factor of the failure in the structure of the annulus fillers, tests were performed in a specific laboratory for that purpose, located in the premises of the component manufacturer itself.

This work was carried out with the supervision of representatives of the Japanese Investigation Authority, the JTSB, and with the participation of the technical advisors of JAEC, manufacturer of annulus fillers.

In this stage, besides the fragmented annulus fillers, other components of the engine structure connected to them were also analyzed, which are called Fan Module, as shown in Figures 20 and 21.

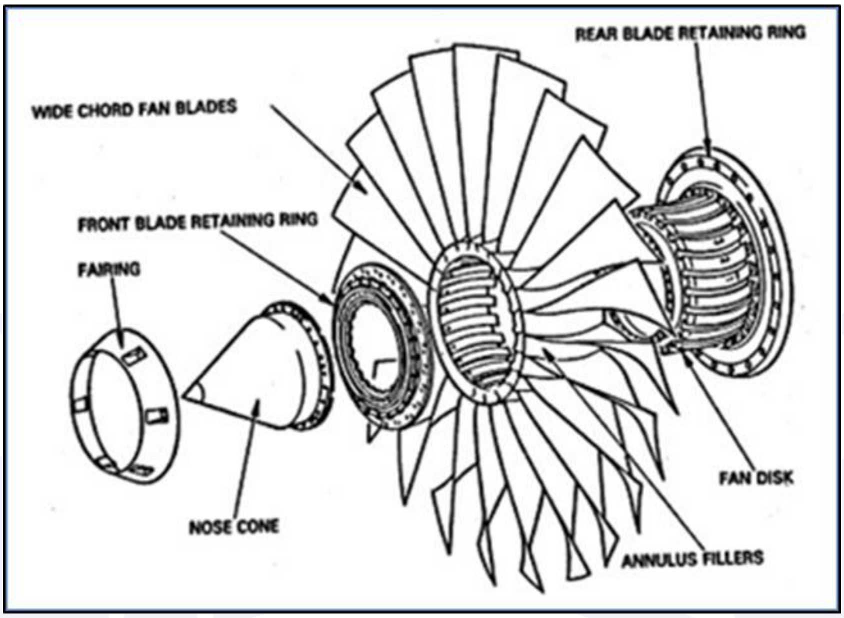

Figure 20 - Overview of the Fan Module components.

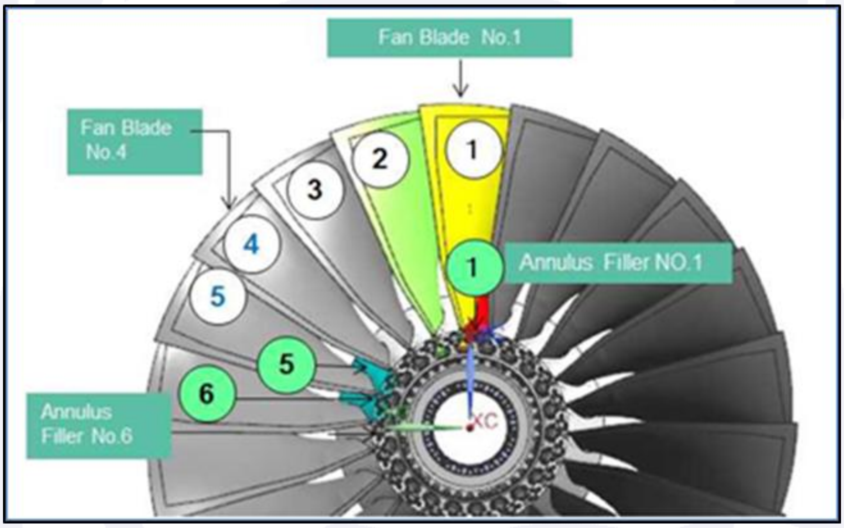

Figure 21 - Reference used to identify the analyzed parts, frontal view.

Specifically, the analyzed pieces were: the front blade retaining ring, the rear blade retaining ring, the fan disk, twenty non-fragmented annulus fillers, two fan blades and a bolt (the fragment of the head of a screw), as shown in Figure 22.

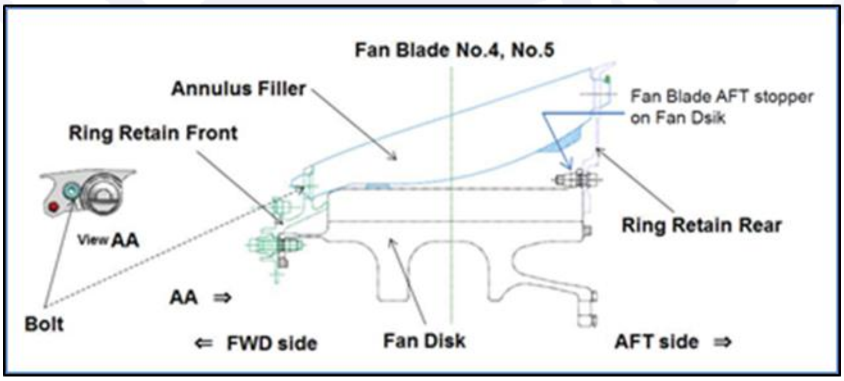

Figure 22 - View in longitudinal section of the parts' set that was analyzed.

The verification of the pieces occurred through visual inspection, besides the use of a scanning electron microscope and a computerized tomograph.

Among the findings in the inspection, the following were highlighted:

- for annulus fillers and rear blade retaining ring, a number of contact marks were identified for the rear attachment points (AFT trunnion) of all annulus fillers with the ring retainer, with the exception of annulus fillers # 4, 5, 6 and 7, as shown in Figure 23.

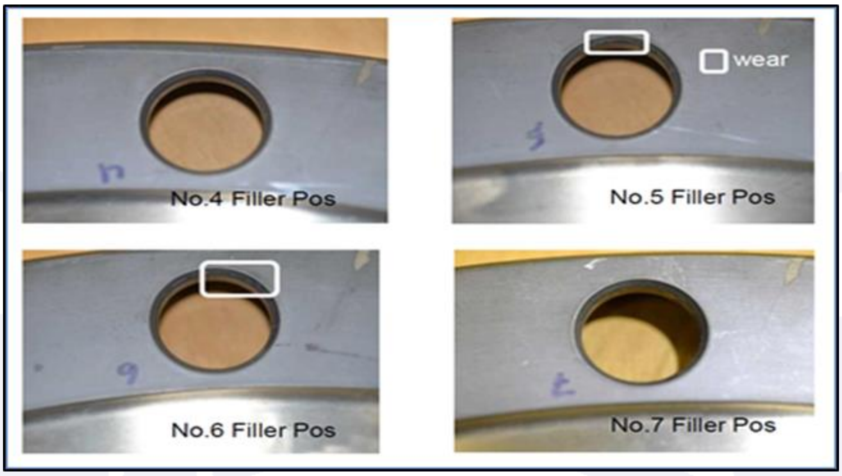

Figure 23 - Plug holes in the rear ring retainer without contact marks of the annulus fillers.

These marks occurred due to the contact with the rear ring retainer by centrifugal force. Based on these marks, it was considered that the relative axial positioning between the rear ring retainer and annulus filler #4, during the engine operation was different from a normal condition (Figure 24).

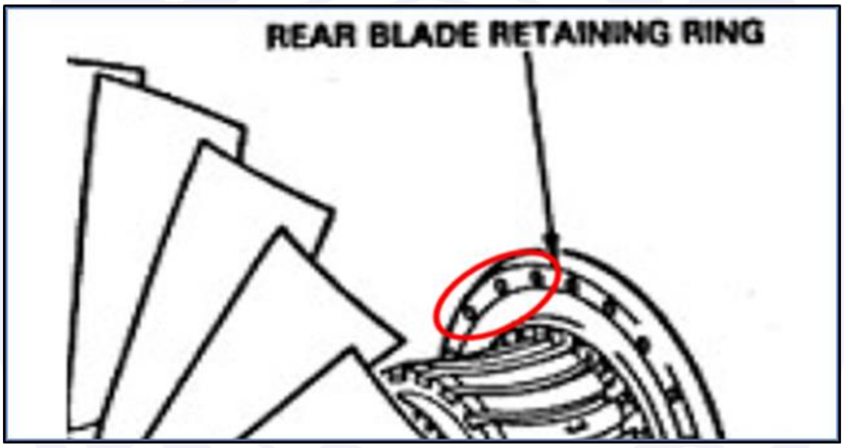

Figure 24 - Detail of the holes location in the rear ring retainer.

This condition was not only due to contact, some load also acted on the spigot of the rear retainer. This could only occur if the annulus filler was forced forward, or if the rear ring was deformed on the backside, or if the annulus filler was deformed so that its axial dimension was shortened. These deformations were not observed in the rear ring retainer nor in annulus filler #4.

Similar conditions were also found in annulus fillers #5 and #7. Marks highlighted as *wear* should not be considered for this analysis as discrepant factors. This is a reference to indicate normal marks that occur during a normal operation.

The annulus fillers #4, 5, 6 and 7 presented contact marks, wear, cracks, fractures and deformations different from those found in other annulus fillers. For purposes of illustration, Figure 25 shows a side view of an annulus filler with its rear trunnion and front trunnion.

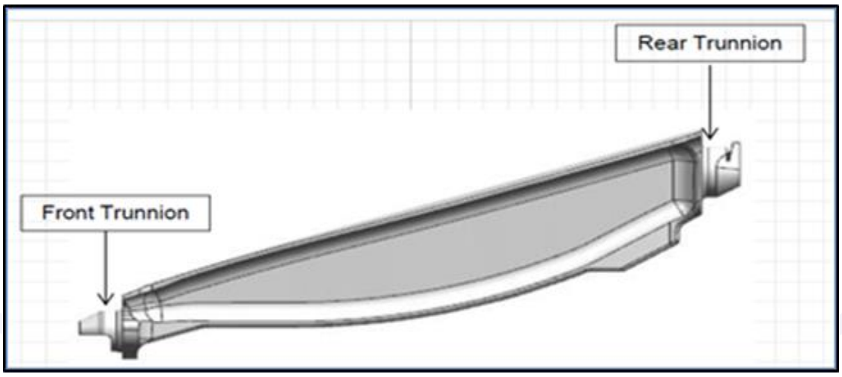

Figure 25 - Side image of an annulus filler for reference.

Figure 26 shows the microscopic image of a crack identified at the rear trunnion of annulus filler #5.

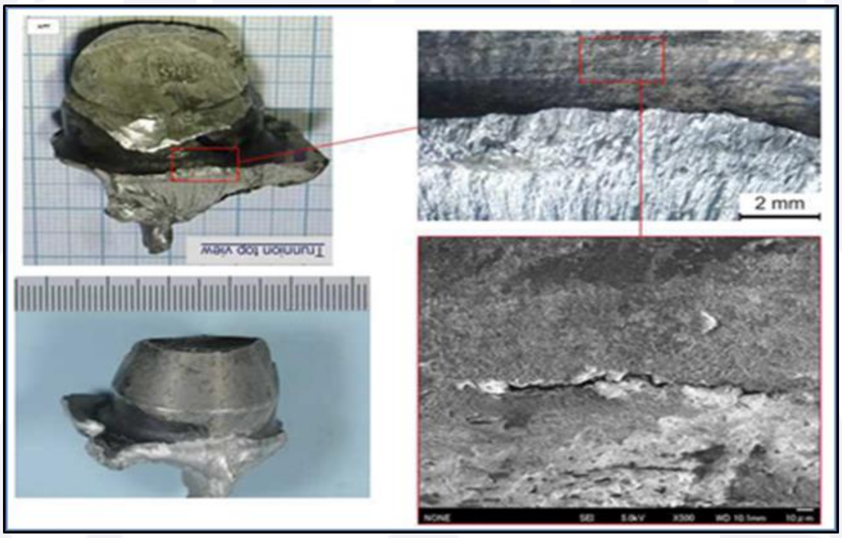

Figure 26 - Crack found at the rear trunnion of annulus filler # 5.

- Regarding the front blade retaining ring, aluminum alloy powder residues were found deposited in the annulus filler #5, as can be seen in Figure 27.

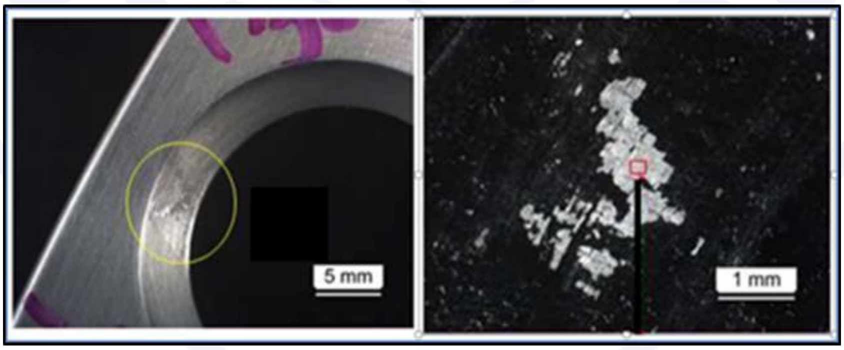

Figure 27 - Aluminum alloy powder waste in the front ring retainer.

The powder was produced by cyclic wear during the engine operation through the contact points of the annulus filler with the front ring retainer (Figure 28).

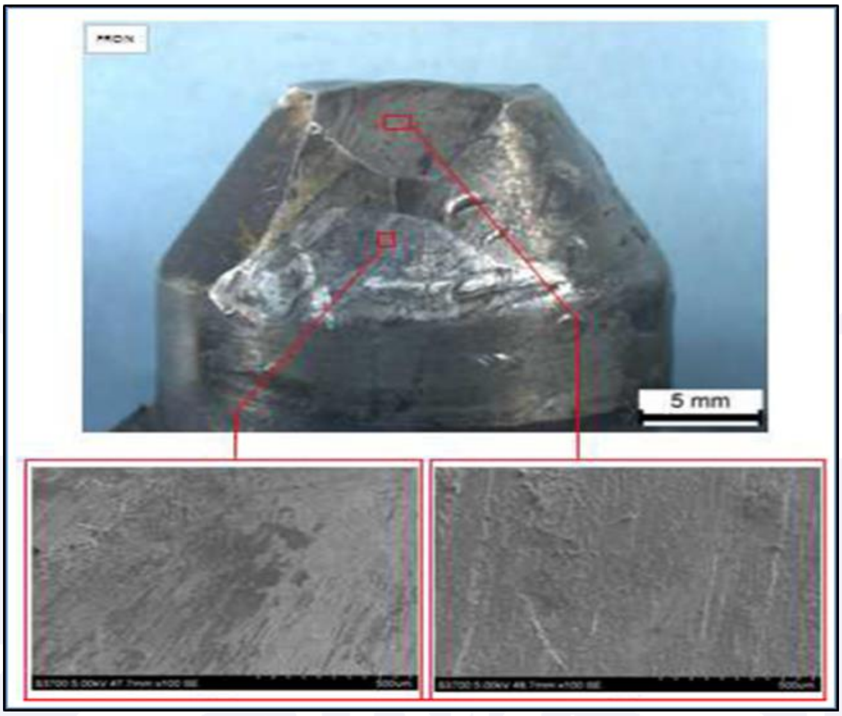

Figure 28 - Contact points of the annulus filler with the front ring retainer.

Yet, according to the analysis of these tests findings, the centrifugal force acting on the annulus fillers is supported by their front and rear attachment and by the fixation screw in the front part.

This force acts only in the radial direction. The stress at the rear attachment point becomes greater if the axial positioning of the force becomes more distant from the center of gravity or if some other attachment point, or fixture, does not fully support its load.

The analysis concluded that no significant stress was identified at the front attachment point of the annulus fillers, in order to constrain the front retaining ring forward and the rear retaining ring back.

Considering all the neighboring elements, an effort could have been made in the retaining rings by means of fan blades in the front direction of the engine. However, the fan blades were mechanically fixed by their own points, front and rear, and there was no evidence of contact of the fan blades with the rings.

Finally, based on this line of reasoning, the deformation of the front retaining ring was considered as a possible situation to have occurred at some point, however, no evidence was observed that the ring was actually deformed.

1.17 Organizational and management information.

No organizational and management information aspects that could have contributed to the serious incident were identified.

1.18 Operational information.

The aircraft was within the weight and balance limits specified by the manufacturer. It carried six crewmembers (two pilots and four flight attendants), 131 passengers and was supplied with 6.914kg of fuel, having a total weight of about 63,300kg, being within the limits of weight and balance.

It had rained heavily on SBSP, so the runways were wet. In addition, due to the modification of the wind conditions, there was a change of runway in the Aerodrome, in the moments that preceded the serious incident. With this change of runway, the operation started to be performed from thresholds 17R and 17L.

The crewmembers were allowed to start the taxi to runway 17R and, until the time of alignment for take-off, everything went on normally.

For take-off, the aircraft was configured with a take-off thrust in "TOGA" (Take-Off / Go Around), with the autobrake armed at maximum position (MAX), with the flaps deflected at 20º, with the slats positioned at 22º (configuration 3) and with the total weight of approximately 63,300 kg.

At the start of the takeoff run, the aircraft traveled a distance of about 100m (from threshold 17R) and reached the speed of approximately 68kt without any apparent change in engine parameters.

Upon reaching this speed, it was possible to hear in the CVR records a noise similar to a burst. Concurrently with this event, the warning message of ENG 2 STALL was registered, indicating a stall condition of the right engine.

Soon after the burst mentioned, the data of the FDR registered a sudden fall of the N1 of the engine 2 (right), accompanied by the gradual increase of EGT of that same engine, besides the registration of the warning messages of ENG 2 FAIL and ENG 2 EGT OVER LIMIT, while the parameters of engine 1 were totally normal.

Simultaneously, the aircraft inadvertently turned to the right.

Upon realizing the turn, the commander applied the left pedal, and momentarily commanded the sidestick to the left, followed by a command on the hand wheels to the same side (left) and with maximum deflection.

In commanding the left pedal, along with the maximum deflection to the left of the hand wheels command, the pilot issued an order to the aircraft ground control system.

Such a system has been programmed so that the change in the angle of the nose wheel (Nose Wheel Steering Angle) obeys a logic that takes into account the speed of the aircraft, as shown in Figure 29.

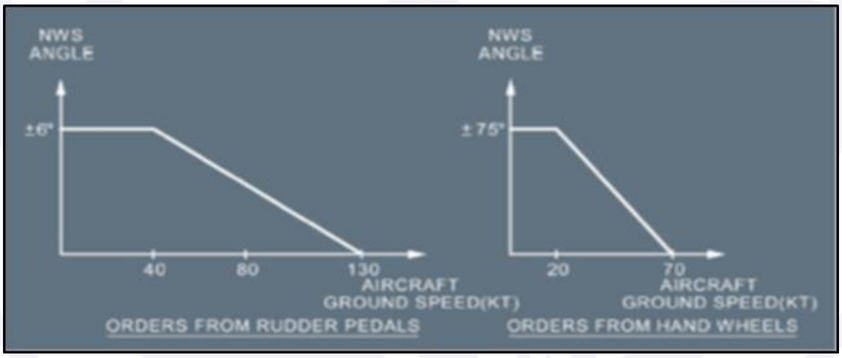

Figure 29 - Graph of the variation of Nose Wheel Steering (NWS) Angle according to the type of command (pedal or hand wheels) by the speed of the aircraft on the ground.

With these commands, a deflection of approximately 10° to the left in the angle of the landing gear was applied.

The power levers were then reduced to idle, thereby initiating take-off rejection, and the left brake was applied in addition to the aforementioned corrections of hand wheels and pedal to the left.

Despite the application of left differential brake, FDR records indicated that, initially, there was a symmetric action of the right and left brakes.

The symmetry in the brake operation was due to the operation of the autobrake.

The logic of the autobrake system predicted that the deflection required in the course of the brake pedals for automatic braking disengagement (when autobrake MAX selected) should be greater than 61º, when only one pedal was actuated or higher than 42º when there was the actuation of two pedals.

Even with the application of all commands to correct the aircraft ground trajectory, it was not possible to prevent the aircraft right landing gear from traveling a few meters off the paved surface of the runway (Runway Excursion Veer Off).

During the stretch that the right landing gear traveled outside the paved surface, there was no collision against obstacles and subsequent analysis of the flight data allowed to conclude that there was no extrapolation of the aircraft structural boundaries because of this runway excursion.

As soon as the aircraft returned fully to the asphalt, the commander applied the reversers, setting the full stop of the aircraft at a position near the centerline, 650 m away from the 17R threshold.

With the aircraft stopped, the copilot started performing the emergency procedures that included cutting off the engines and preventive application of the fire extinguishing agent in engine 2 to contain the increase of EGT of that engine that reached around 755ºC.

In addition to the actions of the crew, the aerodrome firefighters also acted to cool down the aircraft right engine.

1.19 Additional information.

The deflection angle values of the pedals for the disengagement of the autobrake system were not included in the manuals available at the time of the incident. However, Airbus included this information in the update of the Aircraft Maintenance Manual (AMM), issued on 01MAI2019:

> In the LOW and MED modes, the autobrake disconnected if:
>
> - The angular travel of one brake pedal is more than 42 degrees;
>
> - The angular travel of the two brake pedals is more than 9 degrees.
>
> In the MAX mode, the autobrake disconnected if:
>
> - The angular travel of one brake pedal is more than 61 degrees;
>
> - The angular travel of the two brake pedals is more than 42 degrees.
>
> NOTE: The maximum angular travel of a brake pedals is 79.4 degrees.
>
> The pilot can disengage the AUTO BRAKE when he pushes only one pedal..

1.20 Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

This was a scheduled passenger transport flight from SBSP to SBCF.

Until the start of the take-off run, everything went on normally. However, from approximately 68kt the series of events that culminated in the serious incident began.

Upon reaching the speed mentioned, there was a strong boom from the right engine. Such noise could be associated with a classic feature of the phenomenon known as compressor stall.

However, it was subsequently found that the occurrence was not restricted solely to the dynamics of the airflow and that damage occurred in the structure of the engine.

Compressor stall occurs when, for some reason, there is an interruption of the airflow in a jet engine and the engine stops compressing the mass of air, which can cause stagnation of this flow or even its reversal.

In addition to the strong noise, another typical effect of this phenomenon is the emission of backfire, due to the reversal of the airflow.

It is possible that TWR-SP saw this jet of fire motivated by the compressor stall when it reported to have seen signs of fire in the engine of the aircraft.

In the case of the PT-MZY, the heavy noise was caused by the release of the annulus fillers and their impact on the internal structure of the engine. This phenomenon was captured and interpreted by the fault system through the message ENG 2 STALL.

This condition, coupled with a significant rise in engine temperature, made it impossible to produce thrust.

Because it was a twin-engine aircraft, and due to the distance between them, at the moment of loss of power in one of the engines, there was a tendency to turn, due to the momentum resulting from this power asymmetry.

When commanding the left pedal, along with the maximum left deflection of the hand wheels command, the pilot applied a deflection of approximately 10° to the left in the nose gear angle.

Analyzing the graph of Figure 29, it was possible to conclude that the hand wheels command was very ineffective, since the aircraft was little effective, since the aircraft at a speed of 70 kt.

However, in accordance with the logic of the system, the controls (pedal and hand wheels) became more effective in changing the angle of the nose landing gear, as the speed of the aircraft on the ground was reduced.

In this scenario, it was possible to conclude that in the attempt to avoid the excursion of the runway the commands related to the nose landing gear angle change, only became effective, by reducing the speed on the ground.

For this reason, the crew was unable to reverse the initial effect of the inadvertent yaw to the right, to the point of avoiding the runway exit, even though it acted with maximum amplitude in pedal and hand wheel controls.

It was also observed that an attempt was made to apply a differential command to the left brake, in order to increase the effectiveness of the left turn. However, the flight data records showed that, despite the differential application on the left brake, there was, initially, a symmetric braking performance, which did not contribute to the expected correction by the crew.

The symmetry in the brake operation was due to the logic of the autobrake.

At the moment the pilot operated only on the left pedal brake, he deflected the command at about 55º that is, the minimum limit (61º) was not reached for the disengagement of the autobrake with the asymmetric action on the brakes.

As a result, the autobrake remained armed until the moment the aircraft met its driving parameters.

It is inferred, therefore, that the left brake differential control only became effective when the pilot applied a left pedal deflection higher than the 61° required disengaging the autobrake. However, this only happened when the aircraft was already on a return path to the center of the runway after the veer off.

Regarding the analysis of the engine failure itself, it should be clarified that the engine operation data collected and later processed through a software of the monitoring program, considering the last 60 days of operation, presented values that were considered normal for the history of cumulative hours and cycles and for the operating environment of the aircraft.

There was no significant trend of performance degradation that indicated the need for maintenance intervention different from those already scheduled.

The specific maintenance services applied to the FAN Module area were consulted and it was concluded that all the services scheduled for the engine were carried out in compliance with the scheduled deadlines and no maintenance action was pending.

The Investigation Team (CI) interacted with the manufacturer of the aircraft, consulting on the pertinence of issuing an Alert Bulletin, implementing some preventive action that could be performed, in order to previously find a condition of degradation in the structure of annulus fillers. However, no further action was envisaged that could achieve such a purpose.

Therefore, in spite of the execution and monitoring of all maintenance actions planned by both the operator and the maintenance organizations, it is inferred that, at the time of the occurrence, there was no prevised procedure to enable the identification of possible degradation of the affected component.

The first laboratory tests performed on the fan blades, on the fragments of the annulus filler and on the other static structural components revealed that the fractures occurred from impacts and that they presented typical characteristics of overload, with no evidence of corrosion or fatigue.

After these tests, the material was re-incorporated into the engine and, based on this result, the need for a deeper analysis was verified, in order to identify the failure mode of the parts that collapsed and the possible existence of other internal damages arising from this failure.

In the examinations carried out, during the dismantling of the engine at the MTU, it was verified that the fan blades presented impact marks compatible with the form of annulus fillers. As the engine was being disassembled, and considering the sequence of air mass flow, it was found that the internal damage was increasingly severe.

In the Low Pressure Compressor Module, minor damages were found. However, in the next module, the High Pressure, damages were already more significant, with several vanes and blades fractured, in addition to the absence of part of their structures.

In the Combustion Module, there was a large amount of melted debris in the shape of flakes, which was compatible with the shape and constituent material of the combustion chamber itself.

Finally, in the set of vanes of the Turbine Modules, there were also fused debris and their trailing edges presented loss of material. In this final part, the metallic fragmentation with its respective melting became evident, as well as the subsequent adhesion to both rotating and stationary components in the sequence of the gas flow.

These findings confirmed the incidence of high temperatures and the detachment of material from the internal areas, allowing the identification of the sequence in which the metallic material was ingested (fragments of annulus fillers in the majority), and the damage observed in the internal area of the engine.

Once the origin of the material causing the internal engine damage was confirmed, the search was intensified in the annulus fillers.

Tests were performed to verify the theoretical tension condition to which the annulus fillers could be subjected when in normal operation.

Considering the compatibility between the contour areas of the different main tensions obtained in the tension test and the fragments of the annulus fillers that were detached from the engine, there was no evidence of an atypical load on the annulus fillers in operation. That is, they have undergone efforts compatible with those for which they were designed.

However, taking into account the latest tests, those performed in the laboratories of the annulus fillers manufacturer, with the supervision of JTSB representatives, new factors were known and could be considered in the analysis of the conditions triggering the failure of the annulus fillers structure.

According to this latter analysis, tenuous and constant contact marks were identified at the rear attachment points of the annulus fillers with the rear retaining ring, except for the region corresponding to annulus fillers #4, 5, 6 and 7.

The existence of a region with differentiated marks would indicate that the annulus fillers in that area were also subjected to different stresses and the reason for this would be the deformation of the front retaining ring before assembling the set. However, there was no evidence of this deformity prior to the event.

It was found, therefore, that after the separation of the annulus fillers, they collided with the fan blades and the internal structure of the engine air inlet, breaking up and causing parts of the adjacent structures to detach.

Some of these debris were ingested by the engine compressor, passed through the combustion area and turbines, resulting in the breaking of several stationary and rotating elements. There was an excessive increase of the normal temperature of the engine operation, with the consequent casting of these elements. The other part of the debris, which was not ingested by the compressor, passed through the bypass duct and caused minor damage.

The high fragmentation of the annulus fillers, which passed through the fan duct and the submission to the high temperatures of those particles that passed through the combustion areas and turbines, did not allow additional research.

The investigations, however deepened, were not enough to point out the determinant factor for the failure of the annulus fillers, in order to identify if there was already an unfavorable condition in their microstructure before being installed in the engine, or if the submission to further efforts, by a hypothetical deformation of the front retaining ring triggered changes in its structure that culminated in the failure.

3. CONCLUSIONS.

3.1 Facts.

a) the pilots had valid Aeronautical Medical Certificates (CMA);

b) the pilots had valid A320 type aircraft Ratings;

c) the pilots were qualified and had experience in that kind of flight;

d) the aircraft had valid Airworthiness Certificate (CA);

e) the aircraft was within the limits of weight and balance;

f) technical documentation relating to aircraft and engine maintenance was updated;

g) it had rained at the Aerodrome and the runway were wet;

h) there was a change of runway to thresholds 17 just before the PT-MZY started the taxi;

i) the aircraft lined up for take-off at threshold 17R;

j) when reaching about 68kt the CVR registered a strong noise;

k) the noise was succeeded by the warning message of ENG 2 STALL;

l) the aircraft yawed to the right;

m) the flight data recorders registered a decrease of the N1 from engine 2 and the gradual increase of the EGT of this same engine;

n) the parameters of engine 1 remained normal;

o) messages of ENG 2 FAIL and ENG 2 EGT OVER LIMIT were recorded;

p) the pilot commanded left pedal, turned the hand wheels in maximum deflection also to the left and stepped on the left brake to correct the aircraft trajectory;

q) the brakes acted symmetrically because of the autobrake, despite the differential control applied by the pilot to the left;

r) the amplitude of command initially applied by the pilot on the left brake was not enough to desengage the autobrake;

s) the right main landing gear of the aircraft left the paved surface of the runway (veer off);

t) there was no extrapolation of aircraft structural limits during the runway excursion;

u) the crew was able to retake the directional control of the aircraft, stopping it on the asphalt;

v) there was no fire;

w) the crew performed the emergency procedures which included the activation of the right engine fire extinguishing agent;

x) firefighters cooled down engine 2;

y) two engine fan module components, called annulus fillers, were detached and fragmented;

z) part of the debris was ingested by the compressor and turbines and the other part passed through the bypass duct;

aa) the aircraft had limited damage to the right engine and minor damage to the right wing; and

bb) all aircraft occupants left unharmed.

3.2 Contributing factors.

- **Control skills – undetermined.**

Regarding the various attempts to maintain the directional control of the aircraft, after the engine failure on the ground, it was not possible to avoid the side exit of the runway (veer off).

In an attempt to retake the directional control of the aircraft, after inadvertent turning to the right, among other commands, the pilot attempted to use the differential brake technique.

However, the amplitude of application of the left brake pedal was not sufficient to disarm the autobrake and, therefore, this system acted to cause symmetrical braking of the aircraft. However, it is not possible to say that the pilot would avoid runway excursion if he succeeded in the differential application of the left brake.

- **Other - undetermined.**

The investigations, however detailed they may have been, were not enough to point out the determinant factor for the failure of the annulus fillers, in order to identify if there was an unfavorable condition in their microstructure before being installed in the engine, or if the submission to additional efforts by a hypothetical deformation of the front retaining ring triggered changes in its structure that culminated in the failure.

4. SAFETY RECOMMENDATION.

A proposal of an accident investigation authority based on information derived from an investigation, made with the intention of preventing accidents or incidents and which in no case has the purpose of creating a presumption of blame or liability for an accident or incident. In addition to safety recommendations arising from accident and incident investigations, safety recommendations may result from diverse sources, including safety studies.

In consonance with the Law n°7565/1986, recommendations are made solely for the benefit of the air activity operational safety, and shall be treated as established in the NSCA 3-13 "Protocols for the Investigation of Civil Aviation Aeronautical Occurrences conducted by the Brazilian State".

Recommendations issued at the publication of this report:

To the Brazil's National Civil Aviation Agency (ANAC):

IG-032/CENIPA/2017 - 01 **Issued on 08/06/2019**

Evaluate, together with the manufacturer of the IAE V2527-A5 engines, whether all actions planned to maintain the service life of the annulus fillers installed in these engines, such as periodic checks and non-destructive tests, are sufficient to ensure that there are no structural failures in these components during their operation.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

On 01MAR2017, the IAE, the engines manufacturer, issued a notice called IAE NEWSFLASH for all Service Centers that performed maintenance on IAE V2500 engines of all series, describing what occurred and noting that it had been verified the detachment of two annulus fillers, with consequent damage to adjacent areas.

This notice also informed that there was an investigation being conducted by the Brazilian Authority that had the assistance of the NTSB and the IAE support.

The issuance of IAE NEWSFLASH, at the request of the engine manufacturer, has been previously reviewed and approved by the CENIPA.

On 01MAI2019, Airbus updated the AMM with detailed information regarding the deflection angle parameters of the brake pedals for the disengagement of the autobrake system.

On August 6th , 2019.