COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
IG - 042/CENIPA/2019

OCCURRENCE:	**SERIOUS INCIDENT**
AIRCRAFT:	**PR-AQV**
MODEL:	**ATR-72-212A**
DATE:	**12MAR2019**

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 12MAR2019 serious incident with the ATR-72-212A aircraft model, registration PR-AQV. The serious incident was classified as “[SCF-PP] System/Component Failure or Malfunction Powerplant – Engine Failure on the Ground”.

During the beginning of the takeoff run, still below the decision speed (V1), engine number 2 failed. The crewmembers performed the aborted takeoff procedures and adequately controlled the aircraft, stopping it on the runway.

The damage to the aircraft was slight, being restricted to engine number 2.

All crewmembers and passengers 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 manufactured) and an Accredited Representative of the Transportation Safety Board (TSB) – Canada, (State where the engine was manufactured) were designated for participation in the investigation.

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

ANAC	Brazil's National Civil Aviation Agency
ATR	*Avions de Transport Regional*
BEA	Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile
CA	Airworthiness Certificate
CENIPA	Aeronautical Accident Investigation and Prevention Center
CMA	Aeronautical Medical Certificate
COMAER	Aeronautics Command
CSHSI	Cycles Since Hot Section Inspection
CSN	Cycles Since New
CSO	Cycles Since Overhaul
CVR	Cockpit Voice Recorder
EASA	European Aviation Safety Agency
ECTM	Engine Condition Trend Monitoring
EMM	Engine Maintenance Manual
FC	Flight Cycles
FDR	Flight Data Recorder
FH	Flight Hours
HSI	Hot Section Inspection
HP	High Pressure
HPT	High Pressure Turbine
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IFRA	Instrument Flight Rating - Helicopter
ITT	Interturbine Temperature
LABDATA	Flight Data Recorders Read-out and Analysis Laboratory
LL	Life Limit
PCM	Commercial Pilot License - Airplane
PLA	Private Pilot License– Airplane
PN	Part Number
PPR	Private Pilot License – Airplane
PPH	Private Pilot – Helicopter category
QRH	Quick Reference Handbook
RS	Safety Recommendation
SBKP	ICAO Location Designator – Viracopos International Aerodrome, Campinas - SP
SBRP	ICAO Location Designator – Leite Lopes Aerodrome, Ribeirão Preto - SP
SIL	Service Information Letter

SIPAER	Aeronautical Accident Investigation and Prevention System
SN	Serial Number
TCCA	Transport Canada Civil Aviation
TPR	Aircraft Registration Category of Regular Public Transport
TSB	Transportation Safety Board
TSHSI	Time Since Hot Section Inspection
TSN	Time Since New
TSO	Time Since Overhaul
TWR	Control Tower
UTC	Universal Time Coordinated
VFR	Visual Flight Rules

1. FACTUAL INFORMATION.

Aircraft	**Model:** ATR-72-212A **Registration:** PR-AQV **Manufacturer:** AER - *Aerospatiale* and *Alenia*	**Operator:** *AZUL* Brazilian Airlines S.A
Occurrence	**Date/time:** 12MAR2019 - 2230 UTC **Location:** SBKP - Viracopos International Aerodrome **Lat.** 023°00'25"S **Long.** 047°08'04"W **Municipality – State:** Campinas – SP	**Type(s):** "[SCF-PP] System/Component Failure or Malfunction Powerplant" **Subtype(s):** Engine Failure on the Ground

1.1 History of the flight.

The aircraft started the takeoff from the Viracopos International Aerodrome (SBKP), Campinas - SP, to the Leite Lopes Aerodrome (SBRP), Ribeirão Preto - SP, at 2230 (UTC), in order to carry out regular passenger transport, with five crewmembers and sixty passengers on board.

At the beginning of the takeoff race, when the speed reached about 30kt, the pilots felt a vibration in the aircraft. Next, they noticed changes in the parameters of engine number 2.

The pilots successfully performed the aborted take-off procedure, controlling the aircraft and stopping it on the runway. After its total stop, the Control Tower (TWR) reported the existence of fire in engine number 2. In this way, the crewmembers carried out the procedures of shutting down the engine and fighting the fire, activating the respective fire extinguisher.

The Commander also shutdown engine number 1 and requested the towing of the aircraft to the apron, where passengers disembarked normally.

The aircraft had minor damage.

All crewmembers and passengers left unharmed.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor	-	-	-
None	5	60	-

1.3 Damage to the aircraft.

The damage were restricted to the internal region of engine number 2. The high and low pressure turbine modules were severely damaged. The power turbine modules did not show significant damage.

1.4 Other damage.

None.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Flight Hours		
	Pilot	Copilot
Total	13.200:00	1.651:25
Total in the last 30 days	33:05	40:20
Total in the last 24 hours	00:00	00:00
In this type of aircraft	3.448:20	721:50
In this type in the last 30 days	33:05	40:20
In this type in the last 24 hours	00:00	00:00

N.B.: The data related to the flown hours were provided by the aircraft's operator.

1.5.2 Personnel training.

The pilot took the PPR course at the *Aeroclube do Brasil* - RJ, in 1978.

The copilot took the PPR course at the *Aeroclube do Pará de Minas* - MG, in 2011.

1.5.3 Category of licenses and validity of certificates.

The pilot had the PLA License and had valid AT47 aircraft type Rating (which included the ATR-72-212A model) and IFRA Rating.

The copilot had the PCM License and had valid AT47 aircraft type Rating and IFRA Rating.

1.5.4 Qualification and flight experience.

The pilots were qualified and had experience in the type of flight.

1.5.5 Validity of medical certificate.

The pilots had valid CMAs.

1.6 Aircraft information.

The aircraft, serial number 1195, was manufactured by *AER-Aerospatiale e Alenia*, in 2014, and it was registered in the TPR category.

The aircraft had valid Airworthiness Certificate (CA).

The technical maintenance records were updated.

The initial stages of the investigation process were completed and were duly supported by the airline. As a result of the initial assessments, the Investigation Team found that the same aircraft, PR-AQV, was involved in another aeronautical occurrence on 02MAR2019.

In the event previously studied, the aircraft had a failure in engine number 1, model PW127M, Serial Number (SN) PCE-ED0550, during the initial climb phase for the cruise flight, approximately when crossing 10,000ft of altitude. The engine had a sudden change in parameters and then shutdown in flight.

The event of 02MAR2019 was classified as an Incident by the CENIPA.

However, due to the fact that it involves two occurrences of engine failure in the same aircraft and being within a period of ten days, the CENIPA decided to investigate the factors involved in the failures of both engines, under the scope of a single process.

The PW127M engines, installed in the ATR-72-212A aircraft, operated by *Azul* Airlines, were maintained, in accordance with the requirements established in the ATR Maintenance Review Board Report and in the P&WC Engine Maintenance Manual. The maintenance program adopted by the operator was “On Condition”, characterized by the establishment of maintenance intervals based on the ECTM.

A software developed by Pratt & Whitney Canada, called WebECTM®, allowed the monitoring of the performance of the engines through the analysis of the operation data, among them, the compressor speed, the engine temperature and the fuel flow, this in a scenario where the aircraft's flight conditions were considered, such as the outside air temperature, the flight level and the indicated speed.

The combinations of all this data generated graphs where certain deviations and trends could indicate a degradation in the performance of the engine. The trend analysis is designed to reveal the degree of engine deterioration and a possible need for corrective action.

The monitoring of the engines performance - SN PCE-ED0550 (02MAR2019 Incident) and SN PCE-ED0604 (12MAR2019 Serious Incident), carried out through the WebECTM®, did not reveal a significant trend that indicated the need for further intervention.

Still, in the context of the maintenance actions performed on the engines, the intervals foreseen for the scheduled interventions were taken into consideration; the Hot Section Inspection (HSI) and the Overhaul, as well as the results of the boroscopic inspections, the analysis of the lubricating oil and the components with life limited by cycles or hours of operation. The operator established HSI compliance for every 7,000 Flight Cycles (FC) and Overhaul for every 13,500 FC.

The engine, serial number PCE-ED0550, ran the HSI on 25JAN2016 and it was installed in the PR-AQV aircraft, where it operated 6,051 hours and 5,452 cycles until it failed on 02MAR2019.

The engine, serial number PCE-ED0604, performed the HSI on 29JUL2016 and it was installed in the PR-AQV, where it operated 4,847 hours and 4,374 cycles until it failed on 12MAR2019.

The engines had the following accumulated Flight Hours (FH) and FC history (Figure 1):

Engine Serial Number	PCE-ED0550	PCE-ED0604
TSN - Time Since New (FH)	12.835	12.199
CSN - Cycle Since New (FC)	11.396	10.678
TSO - Time Since Overhaul (FH)	0	0
CSO - Cycle Since Overhaul (FC)	0	0
TSHSI - Time Since Hot Section Inspection (FH)	6.051	4.847
CSHSI - Cycle Since Hot Section Inspection (FC)	5.452	4.374

Figure 1 – Cycles and hours table of the engines.

The High Pressure (HP) Blades, which were installed since the engines were produced, had the following accumulated FH history (Figure 2):

Engine Serial Number	PCE-ED0550	PCE-ED0604
HP Blades	12.835	12.199

Figure 2 - HP Blades hours history.

The parameter of lifetime limit, in the form of Hard Time, established for the replacement of the HP Turbine Blades, was 15,000 FC. However, because of a growing trend of unplanned engine removals, due to abnormal HP Blades behavior, characterized by unexpected failures, the engine manufacturer has instituted a new parameter for its removal.

Through the Service Information Letter (SIL) – N° PW100-183, the value of 3,000 FH was established, in the form of Soft Time, for the removal and disposal of the HP Blades. The reference unit was based on flight hours, due to the failure mode of the blades having been diagnosed as a phenomenon that occurred due to time and temperature. In this context, it was observed that the failures under consideration occurred in engines of the PW127 series with the highest rated power, which operated at higher temperatures.

Being the recommendation to replace the blades in the form of Soft Time, it would occur in cases where there was access to the HP Disk during a shop visit or during an access in the field to perform a balance of the HP Turbine Disk set.

The SIL N° PW100-183, which introduced the 3,000 FH Soft Time parameter for HP Blades, had its first edition on 08APR2017. The third revision of this SIL, dated 20JUL2018, modified the arrangement of the information of the Soft Time parameter contained in the engine maintenance manual. What used to be in chapter 05-20, which dealt with scheduled inspections and maintenance intervals (Engine Maintenance Manual - EMM Chap. 05-20), became part of chapter 72-03 (EMM Chap. 72-03), which dealt with inspection in the hot engine section (HSI Manual).

On the date the HSI were performed on the SN PCE-ED0550 and SN PCE-ED0604 engines, SIL N° PW100-183 had not yet been issued, introducing the 3,000 FH Soft Time parameter for HP Blades. Thus, the only parameter in force for the HP Blades was the Hard Time value of 15,000 FC.

Thus, considering the fact that there is no access to the HP Disk provided for the engines in question, nor any changes in the performance parameters, monitored through the WebECTM®, the operator decided to maintain the operation of the engines installed in the PR-AQV until they reach the 13,500 FC mark for Overhaul.

It should also be noted that, in all the documentation available on the product, no recommendation was identified regarding the management of installation, removal, or permanence of engines in the same aircraft that had as parameters:

• the configuration of applied service bulletins;

• history of inspections carried out and to be carried out; or yet

• the operating time elapsed since its manufacture or since an intervention by HSI or Overhaul.

Consequently, the installation and operation of the SN PCE-ED0550 and SN PCE-ED0604 engines on the PR-AQV aircraft were in full accordance with the airworthiness standards, manuals and guidelines established by the certifying authorities.

1.7 Meteorological information.

Nil.

1.8 Aids to navigation.

Nil.

1.9 Communications.

Nil.

1.10 Aerodrome information.

The Aerodrome was public, managed by *Aeroportos Brasil Viracopos* and operated under VFR and by IFR, during the day and night.

The runway was made of asphalt, with thresholds 15/33, dimensions of 3,240m x 45m, with elevation of 2,170 feet.

The services provided by the Aerodrome ground teams were adapted to the needs of the aircraft, crew and passengers.

1.11 Flight recorders.

The aircraft was equipped with a digital flight data recorder Flight Data Recorder (FDR) L-3, model FA2100 FDR (solid state memory), Part Number (PN) 2100-4245-00, SN 977829, with the capacity of 1024 words (each word has 12 bits).

In addition, it was also equipped with a Cockpit Voice Recorder (CVR) L-3 digital voice recorder, model FA2100 CVR (solid state memory), PN 2100-1020-02, SN 207679, with the capacity of two hours recording, with 4 channels of 30 minutes in high quality and 2 channels of 2 hours of standard quality audio.

Both recorders were operational and were sent to the CENIPA's LABDATA for transcription and analysis.

Regarding the voice communication between the pilots, it was possible to verify that all the procedures related to the preparation of the aircraft for the flight, the taxi procedures for takeoff, as well as the emergency procedures performed, when the engine failure occurred, were followed appropriately.

With regard to communications with the control agencies at the Viracopos Aerodrome, all messages were executed in a clear and correct manner. It is worth noting that the Viracopos TWR acted proactively in informing the crewmembers about the visualization of fire in engine 2 right after the take-off abortion.

With this information, since there was no fire alarm on the instrument panel, the crew performed the procedures provided for the extinguishing of fire in the engine, using the extinguishing bottle.

For a better understanding of the FDR data analyzed and shown in the graphs below, the list of nomenclatures in the Pratt & Whitney Canada Manual follows, noting that number 2, in parentheses, refers to the parameters related to the right engine (SN PCE-ED0604):

- ITT2 - Interturbine Temperature (2)
- NH2 - High Pressure Rotor Speed (2);
- NL2 - Low Pressure Rotor Speed (2);
- NP - Propeller Speed; and
- TQ2 - Torque Shaft Temperature (2);

The FDR data were properly analyzed and, consequently, it was possible to state that:

- all parameters of engine 2, SN PCE-ED0604, proved to be stable and within the normal operating parameters established by the aircraft manufacturer's Operations Manual during the departure and taxi phases;

- when starting the engine acceleration, at 22h13min10sec (UTC), there was a simultaneous drop in the indications of NL2, NP2, TQ2, NH2 and an increase in the indication of ITT2. Such facts pointed to a sudden engine failure causing an abrupt loss of performance (Figure 3);

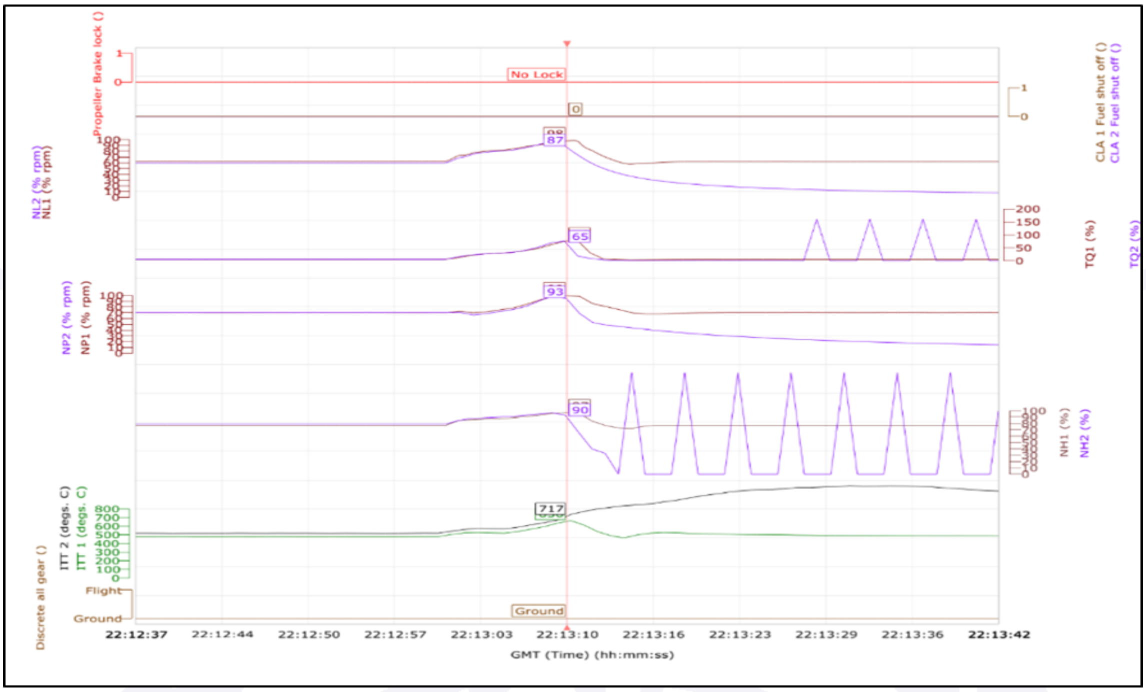


Figure 3 - Graph of engine parameters. Information taken from the FDR.

- the peak of ITT2 reached 1,065ºC, approximately, 25 seconds after the beginning of the engine failure (Figure 4);

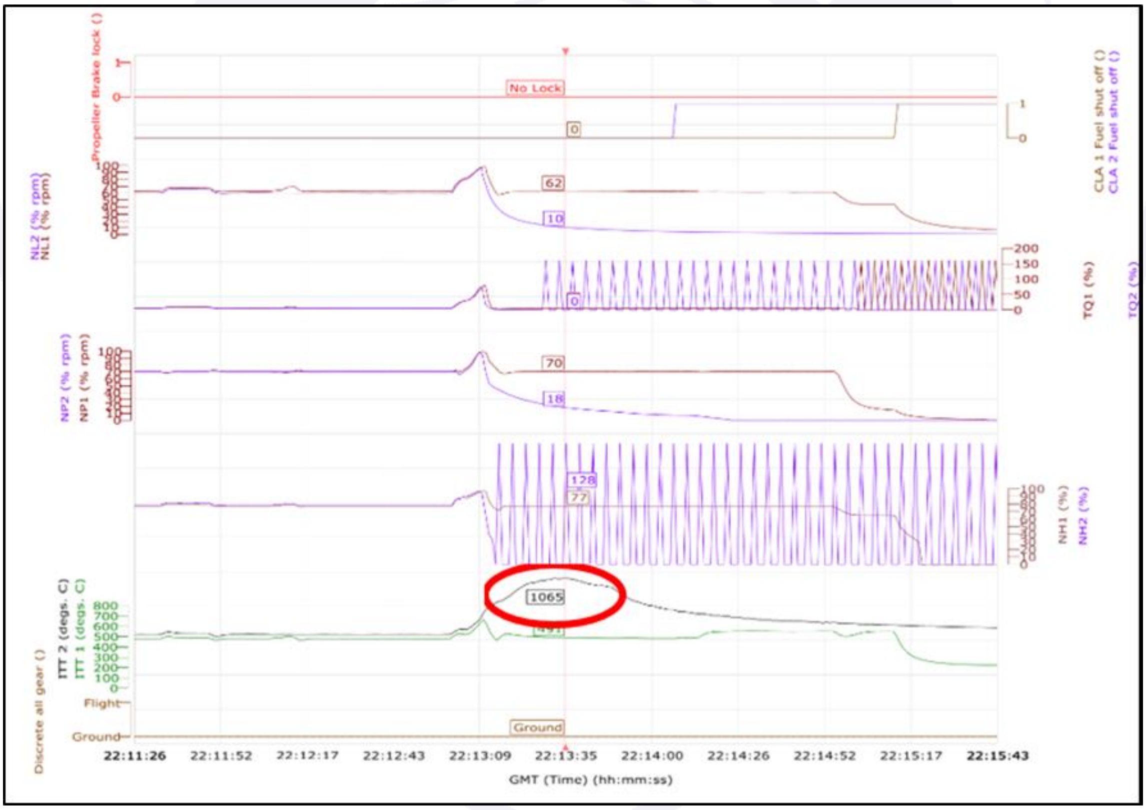


Figure 4 - Graph of engine parameters. Information taken from the FDR.

1.12 Wreckage and impact information.

Nil.

1.13 Medical and pathological information.

1.13.1 Medical aspects.

Not investigated.

1.13.2 Ergonomic information.

Nil.

1.13.3 Psychological aspects.

Not investigated.

1.14 Fire.

There was no flame formation.

The fire in engine number 2, observed by the TWR, occurred due to the detachment of its internal parts that were expelled in incandescent form and were mixed with the portion of the residual fuel that went into combustion in the exhaust duct.

1.15 Survival aspects.

After the aircraft had come to a complete stop on the runway and the shutting down procedures of both engines, the aircraft was towed to the apron, where all passengers were properly disembarked by the aircraft's main door.

1.16 Tests and research.

The SN PCE-ED0550 and SN PCE-ED0604 engines were separated by the Investigation Team and sent to the performance of failure research and issuance of technical report by the manufacturer (Pratt & Whitney), in Canada.

The technical work at the Pratt & Whitney shops took place on 03, 04, 05 and 06JUN2019. In addition to the members of the Investigation Team, accredited representatives of the aircraft's and the engines' manufacturing states were present, as well as advisers indicated by the operator and the aircraft manufacturer.

Bearing in mind that the following analyzes mentioned several internal parts of the engines, below is a longitudinal sectional view of a PW100 series engine for reference (Figure 5).

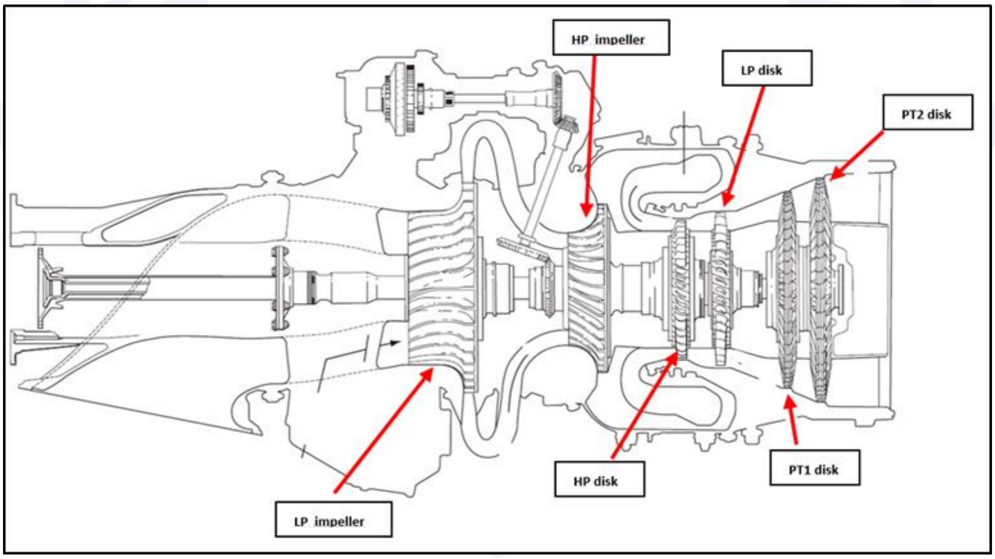


Figure 5 - Longitudinal section view of a PW100 series engine.

The disassembly and analysis of the engines revealed the following:

1. - Engine serial number SN PCE-ED0550 (Incident, 02MAR2019):

• Generally presented separations in all blades of the Power Turbine (PT) Disks 1 and 2, and the Low Pressure (LP) Turbine Disk, in different lengths, caused by the impact of debris (Figures 6 and 7).

Figure 6 - Power Turbine Disks 1 and 2 of the SN PCE-ED0550 engine with all blades fractured.

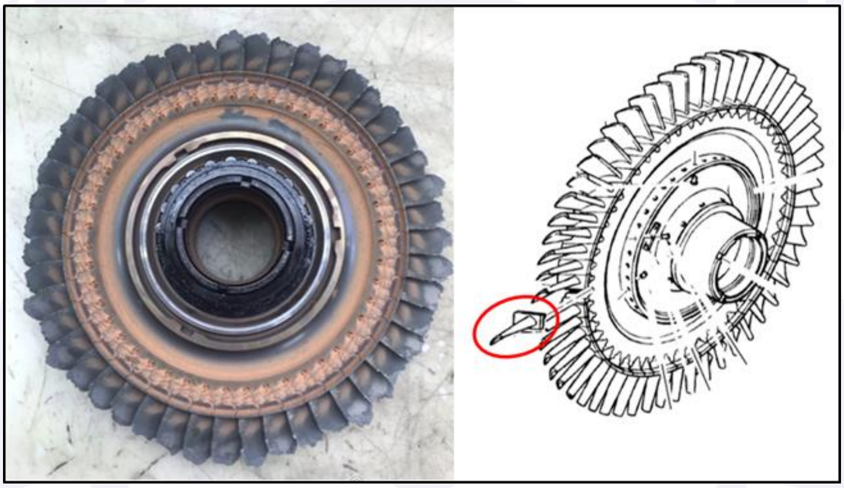


Figure 7 - Low Pressure Turbine Disk removed from the SN PCE-ED0550 engine with all blades fractured at the ends and an intact disk design.

• Most High Pressure Turbine Disk (HPT) blades showed overload fractures near the platform (Figure 8).

Figure 8 - High Pressure Turbine Disk of the SN PCE-ED0550 engine with all blades fractured near the platform and, in most cases, with signs of rupture due to overload.

• The Low Pressure Impeller and High Pressure Impeller showed only material loss at the tops of the blades and small dents. In the stationary elements positioned after the impellers, considering the flow of the gaseous mass, and even immediately before the HP Disk, no signs were found that any particle could have come off them and caused damage to the HP Blades (Figure 9).

Figure 9 - Low Pressure Impeller and High Pressure Impeller of the SN PCE-ED0550 engine without significant damage.

2. PCE-ED0604 SN Engine (Serious Incident, 12MAR2019):

• It did not present significant damages in the blades of the Power Turbine (PT) Disks 1 and 2. The Low Pressure (LP) Turbine Disk presented all the blades fractured in the extremities, caused by impact of debris (Figures 10 and 11).

Figure 10 - Power Turbine Disks 1 and 2 of the SN PCE-ED0604 engine without significant damage.

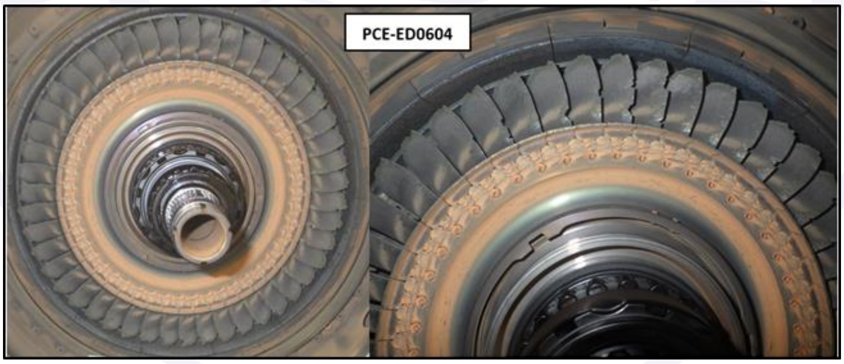
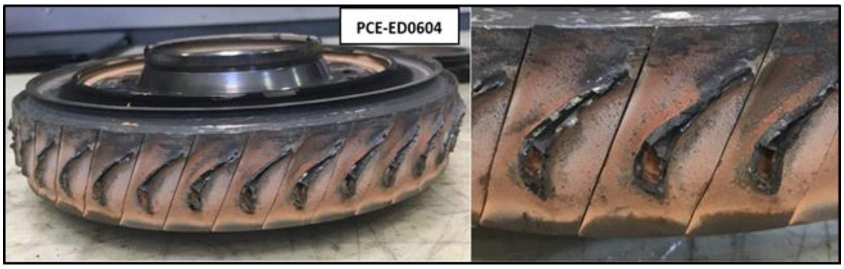


Figure 11 - Low PressureTurbine Disk of the SN PCE-ED0604 engine with all blades fractured at the ends.

The High Pressure Turbine Disk had all blades fractured near the platform, most of them due to overload (Figure 12).



• Figure 12 - High Pressure Turbine Disk of the SN PCE-ED0604 engine.

• Low Pressure Impeller and High Pressure Impeller showed only material loss at the tops of the blades and small dents. In the stationary elements positioned after the impellers, considering the flow of the gaseous mass and, even immediately before the HP Disk, there were no signs that any particle could have come off them and caused damage to the HP Blades (Figure 13).

Figure 13 - Low Pressure Impeller and High Pressure Impeller of the SN PCE-ED0604 engine without significant damage.

Thus, considering the damage found in the rotating components and having the flow of gaseous mass inside the engine as reference, it could be said that the initial failure in both engines occurred in the blades of the High Pressure Turbine Disk.

The damage found in the Low PressureTurbine and in the Power Turbine Disks 1 and 2 were due to the fragments of the blades that detached from the HP Disk and also to the other stationary components of the engine that were after that disk.

The failures of the two engines occurred suddenly. Based on boroscopy observations, oil analysis and Engine Condition Trend Monitoring, there was no indication of the tendency for engine failure or the need for additional maintenance actions.

The Investigation Team sent the High Pressure Turbine Disks of the SN PCE-ED0550 and SN PCE-ED0604 engines to perform examinations in the engine manufacturer’s laboratory, specialized in failure analysis.

The objective was to identify the root cause of the phenomenon and the respective fracture mechanism in the HP Blades, PN 3115601-01, which gave rise to the failure of the first blades and possibly triggered the rupture of the others.

The Laboratory analyzes of the High Pressure Turbine Disks showed the following:

1. - SN PCE-ED0550 engine

• The initial optical inspection of the High Pressure Turbine Disk for this engine did not reveal the presence of a point where the blades fracture could have started. Subsequently, the 38 blades, PN 3115601-01, which constituted the disk, were removed and the dimensional verification found that, in all of them, the fractures were positioned approximately 0.1 inch above the platform (Figure 14).

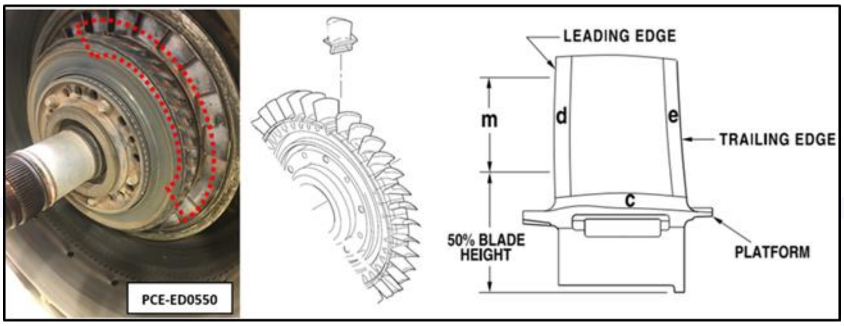


Figure 14 - HPT Disk of SN PCE-ED0550 engine installed and with all fractured blades above the platform (dotted detail). Drawings of part of an intact disk and a blade with theoretical regions.

• The fracture surface presented a rough topography, the fracture angles were acute and the appearance was consistent with fractures caused by overload. It was also found that the thickness measurements of the blades' walls were in accordance with the project specifications (Figure 15).

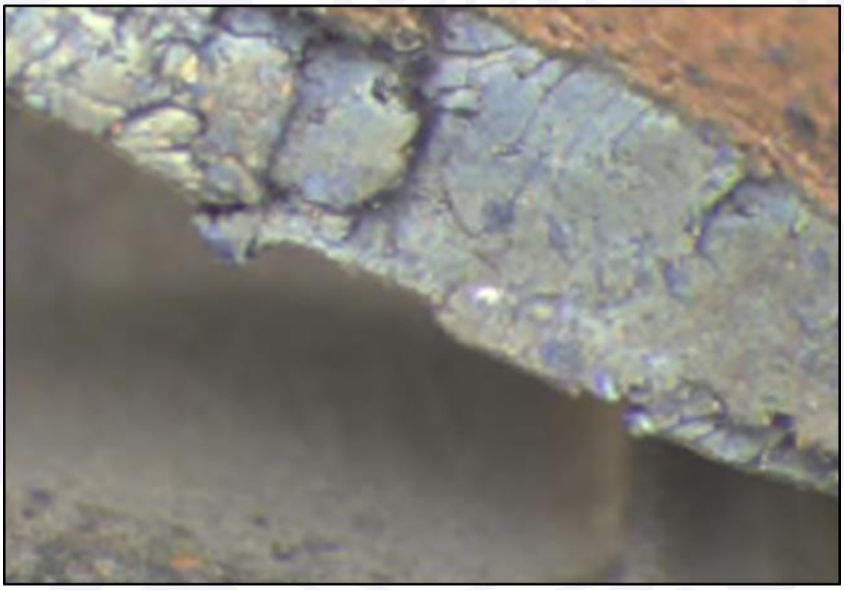


Figure 15 - Fractured surface of one of the HP blades of the SN PCE-ED0550 engine.

• Through a scanning electronic microscope, there was a small, non-significant change in the microstructure of the blades. Using dispersive spectroscopy of energy, it was found that the chemical composition of the main elements of the metallic alloy met the project requirements.

2. - Engine serial number PCE-ED0604

• The 38 HP blades, PN 3115601-01, which constituted the disk, were soon removed and the dimensional verification found that, in all of them, the fractures were positioned approximately 0.1 inch above the platform.

• The blades’ fractures surface presented a rough topography, with sloping regions, whose aspect was consistent with fractures resulting from overload. Except for a blade, which had a small area of its fractured surface with smoothed topography (absence of relief with peaks and valleys that characterized rough topography - Figure 16).

Figure 16 - Fractured surface of one of the HP blades from the SN PCE-ED0604 engine.

• This area indicated cracks caused by material fatigue. The image of the area, observing the white dotted arrows in Figure 17, indicating a direction of propagation and the dotted lines in yellow, indicating the stages of propagation, were compatible with material fatigue.

• Through the scanning electronic microscope, a larger view of the smoothed area of this blade was obtained. There were progression marks that were indicative of the propagation of high cycle fatigue cracks.

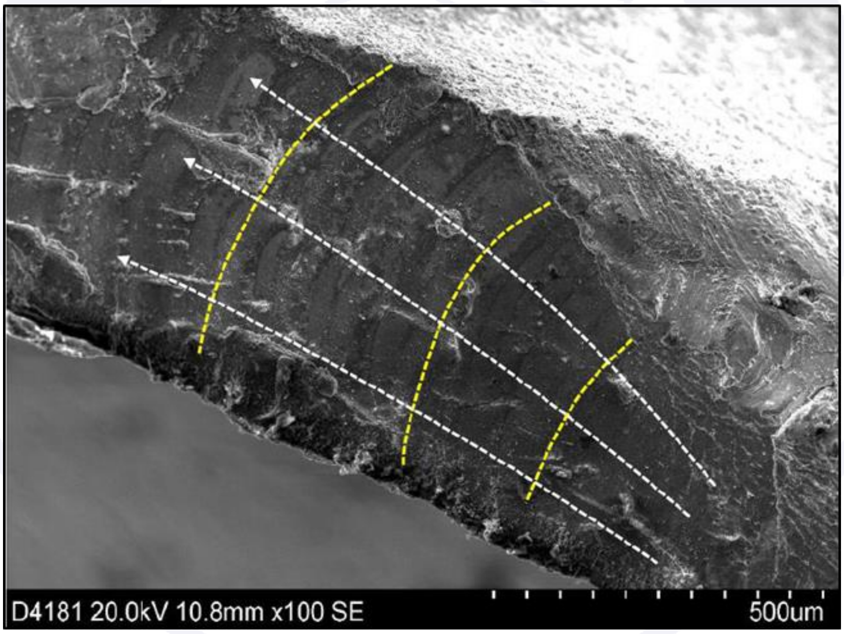


Figure 17 - Smoothed area of the HP blade from the SN PCE-ED0604 engine with fatigue marks.

• Using dispersive spectroscopy of energy, it was found that the chemical composition of the HP blades from the SN PCE-ED0604 engine, referring to the main elements of the metallic alloy, met the project requirements.

A blade in operation on a turbine disk is subject to several stresses, those resulting from the temperature to which it is subjected, as well as those resulting from the circular movement of the disk and the action of gases.

Fatigue, in general, is the designation of a form of failure in which the mechanical elements, which are submitted to repeated cycles of stress and / or deformation, are subjected. The deformations of the mechanical elements resulting from these stresses are not permanent deformations, that is, when the stress is removed, the material returns to its original dimensions. The working stresses are of a lower value than the yield stress, the one that produces permanent deformations.

Considering an element where there is an ongoing fatigue process, three stages can be identified in it: the crack initiation, propagation and structural separation.

Experiments on the behavior of materials, submitted to cyclical efforts, allow to establish reliable parameters, so that the number of cycles to which the item is submitted, without changing its structural characteristics, is used to classify the emergence of a process of fatigue such as “high cycle fatigue” and “low cycle fatigue”.

The number of cycles for the beginning of fatigue classified as “high cycle” depends on the characteristics of the material, such as chemical composition and crystalline arrangement. Basically, events that occur from the interval between 10^2 and 10^4 cycles can be considered high cycle.

The image of a surface formed by a fatigue process can reveal which factor was more significant: the change in the stress level, the chemical reactions, or even the changes in the temperature levels.

High cycle fatigue phenomena, where temperature levels were more significant, tend to be classified as "High Cycle Thermal Fatigue". High cycle fatigue phenomena, where changes (deformations) occurred in the material's microstructure, tend to be classified as Creep (Fluency).

This environment favors changes in the behavior of the materials due to the diffusion process of the atoms, the movement of discrepancies and grain contours, and also the recrystallization of the structure of the material that makes up the blades.

Fluency and Thermo mechanical Fatigue, when they occur in metallic structures and alloys such as blades, culminate in a type of fracture known as a “fragile fracture”. In this type of fracture, the material hardly deforms before fracturing, and the crack propagation process can be very fast, sudden and catastrophic.

Considering a sample space of the PW127 series engines, which use the same design as the HP blades used in the PW127M series, a series of studies and researches, carried out by the engine manufacturer, on the types of premature failures in these HP blades were consulted.

The results of the studies revealed the existence of two predominant modes of failure: Creep and Thermal Mechanical Fatigue, independent or combined.

As for its location on the blade, there was no predominance. There were cases in the area with a fatigue aspect found on the leading edge, in the intermediate region of the airfoil and also on the trailing edge. Still relevant, a case of failure was identified in the area below the platform.

When taking into account the amount of accumulated hours of operation, an interval was not identified where the concentration of failures of HP blades was higher. For example, there were cases of blades that failed since 1,200h, 2,500h, 5,000h and even those with the greatest number of hours of operation with 8,400h and 11,300h.

Regarding the design and manufacture of blades, it is important to note that they are produced with the existence of holes and internal cavities for the passage of air, which, among other functions, are dedicated to the cooling of its structure during the cycles of operation of the engines. The direction of displacement of this air current is from the blade root, through the platform, through the airfoil cavities and out through the trailing edge (Figure 18).

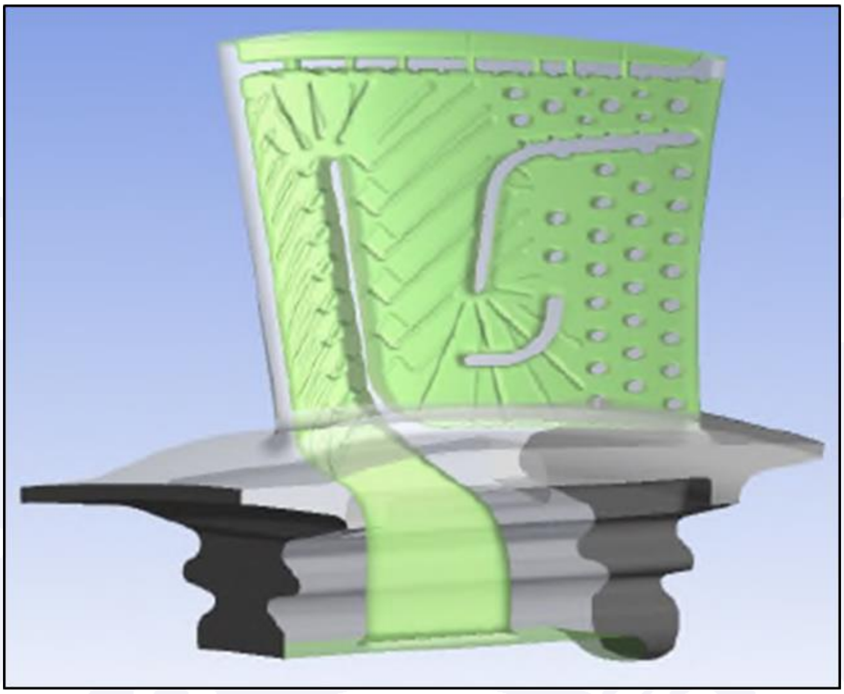


Figure 18 - Visualization of the internal area of an HP blade from a PW100 series engine as a reference for the location of the holes and cavities.

That said, the finding that was most present in the cases investigated by the manufacturer was the obstruction of the cooling holes and cavities. There have been cases of obstruction due to the deposit of material foreign to the engine, such as sand and other solid particles present in atmospheres with industrial waste.

Another situation, which leads to the obstruction of the cavities, is the retention of corrosion residues in the internal area of the cavities, resulting from two main mechanisms: oxidation at high temperature and sulfidation.

Regarding laboratory research on the HP blades of the SN PCE-ED0550 and SN PCE-13 ED0604 engines, due to the high fragmentation of all blades, it was not possible to identify the predominant failure mode, as well as the correct clearance of the cooling cavities.

Still considering the entire group of engines reached in the research, an increase in blades distress was identified (failure or abnormal behavior of the blade structure) characterized by cracks in the leading edge.

These premature failures are related to the high temperature that the blades reached and the time that they were exposed in this temperature condition.

It is also said that boroscopic inspections, performed periodically when the engines were installed in the aircraft, were not effective in identifying processes of premature degradation of the blades' structure.

1.17. Organizational and management information.

Nil.

1.18. Operational information.

The aircraft was within the weight and balance limits specified by the manufacturer and operated in accordance with the operating specifications issued by the Brazilian civil aviation authority.

The flight planning was adequate, obeying all the operational rules standardized in the aircraft manuals.

The crewmembers had valid qualifications, as well as updated and suitable training for the type of flight to be performed. The crew resting parameters, prevised in Brazilian legislation, were obeyed.

All the procedures for preparing the aircraft for the flight, the procedures for boarding passengers, starting the engines, and leaving the taxi for takeoff from the SBKP threshold 15 were performed correctly. The briefings, normal and emergency, were done and carried out as planned.

The pilots demonstrated quickness in the perception of the emergency and performed the procedures prevised in the QRH in a smooth and standardized manner.

Once the SBKP TWR reported the presence of fire in engine 2, the pilots shutdown the engine immediately, triggering the extinguishing bottle, although there was no fire alarm in the cockpit.

All information about the emergency was notified to flight attendants, who acted in a coordinated and serene manner with passengers.

1.19. Additional information.

Nil.

1.20. Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

It was a flight for regular passenger transport, operated by Azul Airlines, which would take off from SBKP to SBRP, on 12MAR2019, at 2230 (UTC).

The Investigation Team initially verified that all operational requirements related to the crewmembers and the aircraft were in accordance with the laws required by the Brazilian civil aviation authority.

All procedures for preparing the aircraft for the flight, the procedures for boarding passengers, starting the engines and leaving the taxi for takeoff from the SBKP threshold 15, as well as the procedures after the engine failure were performed correctly.

Before engine 2 from the PR-AQV aircraft failed, all engine parameters were stable and were within the normal operating indications established by the aircraft manufacturer's Operations Manual during the departure and taxi phases for takeoff.

At the beginning of the takeoff run, when the speed reached about 30kt, the pilots felt a vibration in the aircraft and, at 22h13min10sec (UTC), a simultaneous drop in the indications from engine 2 (SN PCE-ED0604) of NP2, TQ2, NH2 and an increase in the indication of ITT2 were noticed.

Such facts pointed to a sudden engine failure caused by an abrupt loss of performance. The ITT2 peak reached 1,065ºC, approximately, 25 seconds after the beginning of the engine failure.

In the initial stages of the investigation, the Commission found that the same aircraft, PR-AQV, was involved in another aeronautical occurrence on 02MAR2019, with engine number 1 failing (SN PCE-ED0550), thus deciding to investigate the factors involved in both occurrences under the scope of a single investigation.

In both engines, it was identified that the primary cause of their failures came from the HP blades disc.

The examinations carried out on the engines made it possible to identify that, in both, the main elements of the metallic alloy constituting the blades met the project requirements, the wall thickness measurements were in accordance with the specifications and there were no significant changes in their microstructures.

In the case of the SN PCE-ED0604 engine, laboratory tests indicated that the first blade failed due to material fatigue (High Cycle Fatigue). However, regarding the SN PCE-ED0550 engine, the findings did not allow this confirmation.

Researches developed by the engine manufacturer about the premature failures of the HP blades installed in the PW127 models, revealed the existence of two predominant failure modes: Creep and Thermal Mechanical Fatigue.

Both Creep and Thermal Mechanical Fatigue are related to the behavior of materials in an environment where mechanical stresses occur under high temperature conditions.

This environment favors changes in the behavior of the materials due to the diffusion process of the atoms, the movement of discrepancies and grain contours, and also the recrystallization of the structure of the material that makes up the blades.

Fluency and Thermal Mechanical Fatigue, when they occur in metallic structures and alloys such as blades, culminate in a type of fracture known as a “fragile fracture”. In this type of fracture, the material hardly deforms before fracturing, and the crack propagation process can be very fast, sudden and catastrophic.

The severity of the phenomenon is due to the fact that, after a certain moment, the crack becomes so unstable that its propagation occurs even without an increase in the mechanical efforts normally applied.

The mechanical stresses to which the blades are subjected during the operation of the engine, basically, are those of traction and flexion, whose values are due to the speed of rotation of the turbine disk and the flow of the air mass that drives the disk.

These two variables, rotation and airflow, are continuously monitored and controlled by the engine systems according to the required performance. The operating temperature of the engine is also constantly monitored and controlled.

The temperature reached by the HP blades, if they are structurally intact and with their cooling holes and cooling cavities duly unobstructed, will depend on the operating temperature of the engine.

However, in the case of obstruction of the holes and cavities, the cooling will be deficient and the blades will start to work at a temperature above the projected, even if the engine is operating within its normal limits.

It is in this scenario that the granular structure of the blades changes slowly and progressively and, consequently, gradually reduces their load capacity to the point that normal work efforts match the structural capacity of the blades, resulting in premature failure and structural separation.

Among the situations that can lead to the obstruction of the blades cavities is the operation in areas with an atmosphere charged by particles of sand and other solid industrial residues. These micro particles, when penetrating the cavities, are retained, obstructing the air passage and, consequently, they reduce the cooling capacity of the blades.

Another situation, which leads to the obstruction of the cavities, is the retention of corrosion residues in the internal area of the cavities, resulting from two main mechanisms: oxidation at high temperature and sulfidation.

In short, considering that:

• the laboratory results confirmed the nature of the failure, caused by High Cycle Fatigue, in one of the blades of the SN PCE-ED0604 engine HPT blades, even though the engine has the entire inspection program established by the properly executed manufacturer;

• the results of research carried out by the engine manufacturer, regarding the recurring failures of the HP blades installed in the PW127 models, revealed the predominance of High Cycle Fatigue, in the two failure modes: Fluency and Thermo Mechanical Fatigue; and

• the premature fatigue failures revealed are directly associated with the exposure and operation of the blades at temperatures above the limit specified for the item.

It was possible to establish the existence of a relation between the aforementioned results and the inadequacy of the HP blades design, specifically, with regard to the component's internal cooling process.

Insufficient internal cooling is associated with the susceptibility shown by the item with regard to the undesired retention of particles inside the cavities and holes designed to allow the component to cool.

Such particles, trapped in the cavities and orifices, impair the free flow of air through the blades and, consequently, cause the item to operate at a temperature above which the component was designed.

Therefore, the continuous exposure of the blades to these temperatures causes changes in the granular structure of the material, compromising its capacity to support the load, leading the item to a premature catastrophic failure caused by material fatigue.

Finally, it should be noted that the mitigating measures already implemented by the manufacturer, such as reducing the service life of the HP blades, in the form of Soft Time, and monitoring the component's life through boroscopic inspections, were not sufficient to eliminate the cases of HP blades failure of this occurrence.

3. CONCLUSIONS.

3.1 Facts.

a) the pilots had valid CMAs;

b) the pilots had valid AT47 aircraft type Rating (which included the ATR-72-212A model) and IFRA Ratings;

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

d) the aircraft had valid CA;

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

f) the technical maintenance records were updated;

g) the weather conditions were favorable for the flight;

h) the airline was operating in accordance with the operating specifications issued by the Brazilian civil aviation authority;

i) the engine parameters were stable and within the limits of normal operation during the starting phases of the engines and taxi for takeoff;

j) during the takeoff run, approximately 30kt, there was a sudden failure of engine 2 (SN PCE-ED0604), causing an abrupt loss of performance;

k) the pilots performed the take-off abortion procedure successfully, controlling the aircraft and stopping it on the runway;

l) the aircraft had restricted damage to engine number 2;

m) the aircraft, PR-AQV, was involved in another aeronautical occurrence on 02MAR2019 with failure in engine 1 (SN PCE-ED0570), during the climb to cruise flight;

n) the operation of the SN PCE-ED0550 and SN PCE-ED0604 engines in the PR-AQV aircraft was in full agreement with the airworthiness standards, manuals and guidelines established by the certifying authorities;

o) the examinations performed on the SN PCE-ED0550 engine identified a failure in 8 the HP blades, as a primary cause;

p) in the HP blades of the SN PCE-ED0550 engine, the elements of the constituent metallic alloy met the project requirements;

q) due to the high degree of destruction of the blades, it was not possible to identify the fracture mechanism of the SN PCE-ED0550 engine first blade, the one responsible for triggering the failure of the others;

r) the examinations performed on the SN PCE-ED0604 engine identified a failure in 15 the HP blades, as a primary cause;

s) in the HP blades of the SN PCE-ED0604 engine, the elements of the constituent metal alloy met the design requirements;

t) the laboratory results confirmed the occurrence of a failure, caused by High Cycle Fatigue, in one of the blades of the SN PCE-ED0604 engine;

u) the results of research carried out by the engine manufacturer, regarding the premature and recurring failures of the HP blades installed in the PW127 models, revealed the predominance of High Cycle Fatigue, in the two failure modes: Fluency and Thermal Mechanical Fatigue;

v) the continuous exposure of the blades to temperatures above the projected, resulted in changes in the granular structure of the material, leading the item to a catastrophic and premature failure caused by material fatigue;

w) the mitigating measures implemented by the manufacturer were not sufficient to eliminate the cases of failure of the HP blades in operation;

x) the aircraft had minor damage; and

y) all occupants left unharmed.

3.2 Contributing factors.

- **Project – a contributor.**

The project characteristics of the High Pressure Turbine Blades, PN 3115601-01, installed in the Pratt & Whitney Canada engines, model PW127M, SN PCE-ED0604, were not strong enough to not allow premature component failure, caused by a process of High Cycle Fatigue, even if the item is within its lifetime limit and in compliance with all maintenance actions recommended by the engine manufacturer.

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 prior to the publication of this report:

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

IG-042/CENIPA/2019 - 01 Issued on 06AUG2019

Work together with the EASA and the TCCA, in order to reassess the suitability of the parameters and processes established in the service manuals and bulletins for the maintenance of the operational life of the HP blades that equip the PW127M engines, also considering the possibility of changing the Life Limit of the HP Blades.

To the Bureau d'Enquêtes et d'Analyses pour la Securité del l'Aviation Civile (BEA):

IG-042/CENIPA/2019 - 02 Issued on 06AUG2019

Work together with the EASA and the ATR, in order to reassess the suitability of the parameters and processes established in the service manuals and bulletins for the maintenance of the operational life of the HP blades that equip the PW127M engines, also considering the possibility of changing the Life Limit of the HP Blades.

To the Transportation Safety Board of Canada (TSB):

IG-042/CENIPA/2019 - 03 Issued on 06AUG2019

Work together with the TCCA and with Pratt & Whitney Canada, in order to reassess the suitability of the parameters and processes established in the service manuals and bulletins for the maintenance of the operational life of the HP blades that equip the PW127M engines, also considering the possibility of changing the Life Limit of the HP Blades.

Recommendations issued at the publication of this report:

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

IG-042/CENIPA/2019 - 04 Issued on 07/08/2021

Work with Pratt & Whitney Canada to update the parameters and processes established in the service manuals and bulletins for maintaining the operational life of the High Pressure Turbine Blades, PN 3115601-01 that currently equip the PW127M engines, reducing the Life Limit of the HP blades PN 3115601-01.

IG-042/CENIPA/2019 - 05 Issued on 07/08/2021

Work with Pratt & Whitney Canada to implement improvements in the project of the High Pressure Turbine Blades, PN 3115601-01, installed in Pratt & Whitney Canada engines, model PW127M, in order to make them less susceptible to the emergence of fatigue processes High Cycle.

IG-042/CENIPA/2019 - 06 **Issued on 07/08/2021**

Work with Pratt & Whitney Canada to implement the improvements in the project of the High Pressure Turbine Blades, PN 3115601-01, installed in the Pratt & Whitney Canada engines, model PW127M, in order to make them less susceptible to the emergence of High Cycle Fatigue.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

The Investigation Team and Azul Brazilian Airlines identified, in the company's ATR-72-212A fleet, two other PW127M engines (SN PCE-ED0607 and SN PCE-ED0570) installed and operational with an operational life cycle similar to the engines SN PCE-ED0550 and SN PCE-ED0604.

Thus, in order to increase the safety of air operations, the company's maintenance department determined the removal of the aforementioned engines. The SN PCE-ED0607 was removed on 15MAR2019 and the SN PCE-ED0570 was removed on 19MAR2019.

In response to the RS IG-042/CENIPA/2019 - 01, issued on 06AUG2019, ANAC reported that:

- it worked together with the EASA and TCCA to reassess the suitability of the parameters and processes adopted in the service manuals and bulletins for maintaining the operational life of the HPT blades, considering the possibility of changing their life limit;

- Pratt & Whitney Canada reported, through the TCCA, the following mitigating actions regarding the risk of failure of the HPT blades: revision of the limit of the boroscopic inspection in the engine maintenance manual, so as not to allow cracks in the airfoils; introduction of the 3000 hour soft time when the engine is removed for HSI inspection; and proactive work with operators on maintenance awareness and planning. Considering a conservative approach, Pratt & Whitney Canada conducted a risk and reliability analysis of the HPT blades and this analysis indicated that the eventual risk of rupture of the HPT blades from two engines at the same time is below that referenced in Advisory Circular 39-8 Continued Airworthiness Assessments of Powerplant and Auxiliary Power Unit Installations of Transport Category Airplanes. The TCCA agreed with the manufacturer and will continue to assess the issue of the HPT blades regularly during service difficulties meetings with Pratt & Whitney Canada; and

- The EASA reported that the issue of the HPT blades failure is reviewed at airworthiness meetings at regular intervals between the EASA and the aircraft manufacturer.

The BEA reported that it issued a safety recommendation to the EASA and the ATR, requesting preventive measures to limit the risk of a recurrence and the possible consequences of the events mentioned in this report.

It is worth mentioning that, for the purpose of prevention, Security Recommendations IG-042/CENIPA/ 019 - 01, IG-042/CENIPA/2019 - 02 and IG-042/CENIPA/2019 - 03 and the responses were issued during the investigation process, with the information gathered up to that moment. With the end of the investigation, the conclusions presented in this report have been reached and with that, the Investigation Team issued new Safety Recommendations, with the purpose of correcting an inadequacy of the High Pressure Turbine Blades project, PN 3115601-01.

On July 8th, 2021.