COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
A-119/CENIPA/2018

OCCURRENCE:	**ACCIDENT**
AIRCRAFT:	**PR-GGD**
MODEL:	**737-8EH**
DATE:	**16JUL2018**

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 16JUL2018 accident with the 737-8EH aircraft model, registration PR-GGD. The accident was classified as “[SCF-NP] System/Component Failure or Malfunction Non-Powerplant – with Landing Gear”.

During landing, the cabin crew heard an abnormal noise. When conducting the post-flight inspection, the maintenance team identified a leakage of hydraulic fluid and the breakdown of a component of the right main landing gear.

The aircraft had substantial damage.

All the occupants left unharmed.

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

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

AD	Airworthiness Directive
ADC	Aerodrome Chart
ANAC	Brazil's National Civil Aviation Agency
CA	Airworthiness Certificate
CENIPA	Aeronautical Accident Investigation and Prevention Center
CMA	Aeronautical Medical Certificate
CMM	Component Maintenance Manual
CSI	Cycles Since Installation
CSN	Cycles Since New
CVR	Cockpit Voice Recorder
DGCA	Directorate General of Civil Aviation
EQA	Equipment Quality Analysis
FAA	Federal Aviation Administration
FAP	Final Approach Point
FDR	Flight Data Recorder
FSO	Shop Service Sheet
GPS	Global Positioning System
HRC	Hardness Rockwell C
IFR	Instrument Flight Rules
IFRA	Instrument Flight Rating - Airplane
KSI	Thousand pounds per square inch
METAR	Aviation Routine Weather Report
MEV	Scanning Electron Microscope
MLG	Main Landing Gear
MOQA	Maintenance Operations Quality Assurance
NDB	Non-Directional Beacon
NLG	Nose Landing Gear
NTSB	National Transportation Safety Board (USA)
OM	Maintenance Organization
OPR	Operation Problem Report
OS	Service Order
OTM	Over Tempered Martensite
PCM	Commercial Pilot License – Airplane
PF	Pilot Flying
PLA	Airline Pilot License – Airplane
PM	Pilot Monitoring
PN	Part Number

PPR	Private Pilot License – Airplane
PRI	Private Aircraft Registration Category - Instruction
PUH	Historic Public Aircraft Registration Category
RH	Right Hand
RS	Safety Recommendation
RWY	Runway
SB	Service Bulletin
SBCF	ICAO Location Designator - Tancredo Neves Aerodrome, Belo Horizonte - MG
SBSP	ICAO Location Designator – Congonhas Aerodrome, São Paulo, SP
SEM	Scanning Electron Microscope
SN	Serial Number
SOPM	Standard Overhaul Practices Manual
TBO	Time Between Overhaul
TPR	Aircraft Registration Category of Regular Public Transport
TSI	Time Since Installation
TSN	Time Since New
TWR	Aerodrome Control Tower
UTC	Universal Time Coordinated
VFR	Visual Flight Rules

1. FACTUAL INFORMATION.

Aircraft	**Model:** 737-8EH **Registration:** PR-GGD **Manufacturer:** Boeing Company	**Operator:** Gol Airlines S.A
Occurrence	**Date/time:** 16JUL2018 - 2200 UTC **Location:** Tancredo Neves Aerodrome (SBCF) **Lat.** 19°37'28"S **Long.** 043°58'19"W **Municipality – State:** Belo Horizonte – MG	**Type(s):** "[SCF-NP] System/Component Failure or Malfunction Non-Powerplant" **Subtype(s):** With Landing Gear

1.1 History of the flight.

The aircraft took off from the Congonhas Aerodrome (SBSP), São Paulo - SP, to the Tancredo Neves Aerodrome (SBCF), Belo Horizonte - MG, at about 2100 (UTC), in order to carry out regular passenger transport, with six crewmembers and 136 passengers on board.

During landing, at the moment of touch, a loud noise was heard by the cabin crew. The aircraft taxied by its own means to the apron, where passengers disembarked normally.

When conducting the post-flight inspection, the maintenance team identified a leakage of hydraulic fluid and the breakdown of a component of the right main landing gear.

The aircraft had substantial damage. All occupants left unharmed.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor	-	-	-
None	6	136	-

1.3 Damage to the aircraft.

After landing, during an inspection by the maintenance team, damage was found to the Aft Pressure Bulkhead sealant and in the hydraulic pipes causing fluid leakage (Figure 1).

Figure 1 - Leakage of hydraulic fluid on the right landing gear.

Subsequently, damage was identified to the right landing gear assembly and the corresponding wing stringer. Figures 2 and 3 show the location of the main components of the landing gear damaged in the occurrence.

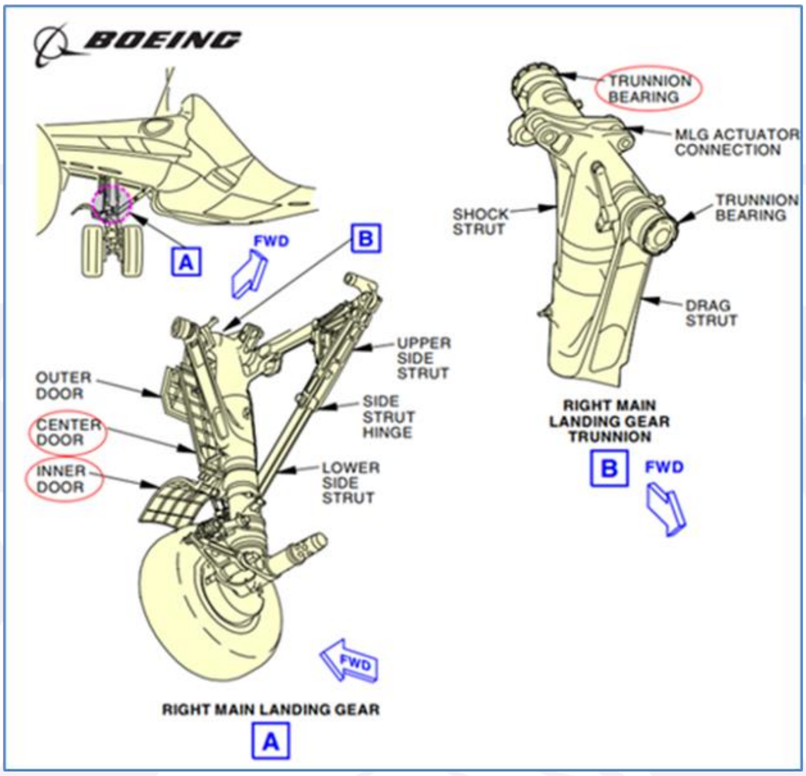


Figure 2 - Location of the damaged components (red circles) of the right main landing gear.
Source: adapted from the Boeing Maintenance Manual.

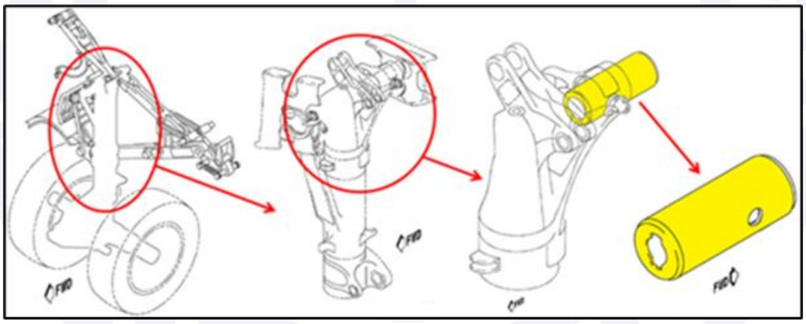


Figure 3 - Place of installation of the aft trunnion pin (yellow).
Source: adapted from the Boeing Maintenance Manual.

The damage to the aft trunnion pin, the aft trunnion bearing and the wing structure (stringer) are shown in detail in Figures 4, 5 and 6, respectively.

Figure 4 - Aft trunnion pin fractured.

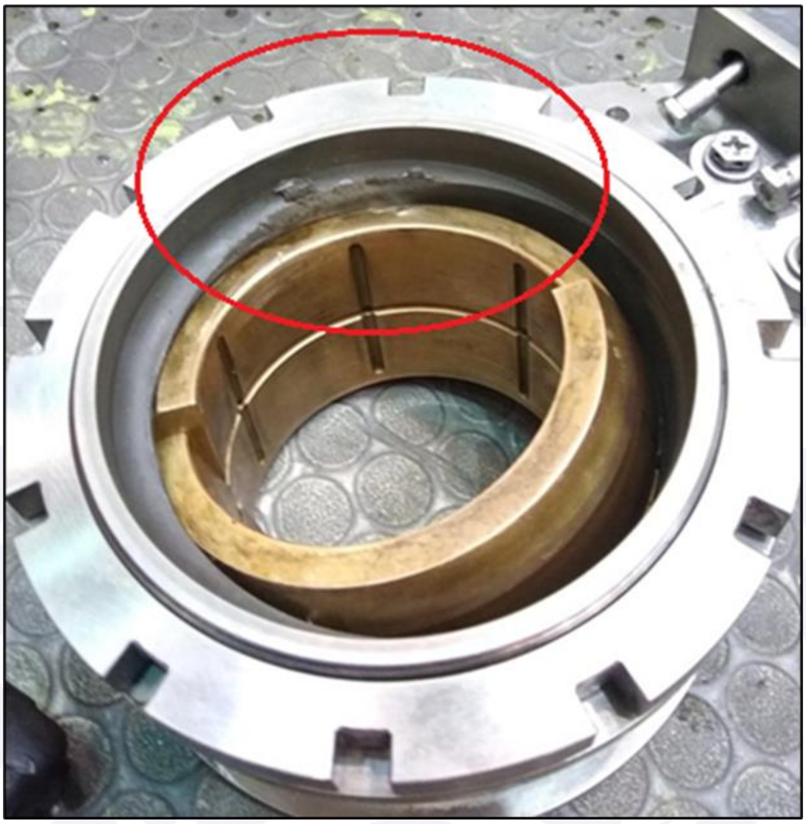


Figure 5 - Damage to the aft trunnion bearing.

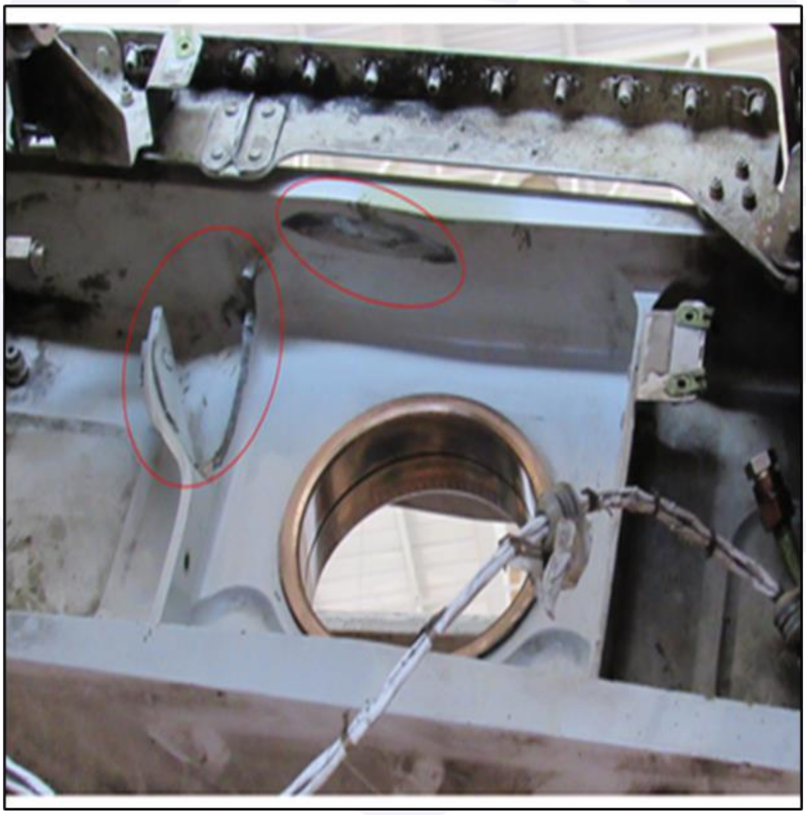


Figure 6 - Damage to the wing structure (stringer), highlighted.

A part of the fractured aft trunnion pin was located on the SBCF runway.

1.4 Other damage.

None.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Flight Hours		
	Pilot	Copilot
Total	19.400:00	6.800:00
Total in the last 30 days	69:00	10:50
Total in the last 24 hours	01:10	01:10
In this type of aircraft	12.589:10	6.292:30
In this type in the last 30 days	69:00	10:50
In this type in the last 24 hours	01:10	01:10

N.B.: The data related to the flown hours were obtained through information from the Airline operating the aircraft and were complemented by the crewmembers themselves.

1.5.2 Personnel training.

The pilot took the PPR course at the Pernambuco Aeroclub – PE, in 1987.

The copilot took the PPR course at the Jundiaí Aeroclub – SP, in 2003.

1.5.3 Category of licenses and validity of certificates.

The pilot had the PLA License and had valid B739 aircraft type Rating (which included the 737-8EH model) and IFRA Rating.

The copilot had the PCM License and had valid B739 aircraft type Rating (which included the 737-8EH model) 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 34275, was manufactured by Boeing Company, in 2008, and it was registered in the TPR category.

The aircraft had valid Airworthiness Certificate (CA).

The technical maintenance records were updated.

The last inspection of the aircraft, the "Weekly Check" type was carried out on 16JUL2018 by the maintenance organization Gol Airlines (0411-01/ANAC), with the aircraft having flown 08 hours and 53 minutes after the inspection.

The last major inspection of the aircraft, the "Check A" type was carried out on 11APR2018 by the maintenance organization Gol Airlines (0411-01/ANAC), with the aircraft having flown 810 hours and 24 minutes after the overhaul.

Landing Gear System Description

The 737 aircraft has a tricycle landing gear with an air/oil type damper. The landing gear provides support for the aircraft during static conditions and ground maneuvers. The landing gear system consists of the MLG, the NLG and their corresponding doors. The MLG and NLG can be extended and retracted during the aircraft operation.

The two main landing gear (MLG) absorb landing forces and hold most of the airplane weight, when the airplane is on the ground. The MLG also transmits the braking forces to the airplane structure.

The main gear shock strut is the primary supporting member of the landing gear. The shock strut consists of an integral drag strut, an outer cylinder, and an inner cylinder. When the MLG extends or retracts, the shock strut rotates about two trunnion bearings and pins at the top of the shock strut's outer cylinder.

Each pin extends through a trunnion bearing and support fitting in the wing and beam assembly. Trunnion cross-bolts keep the trunnion pins from backing out during landing gear operation.

The installation of the aft trunnion pin on the MLG shock strut is shown in Figure 3.

History of the Main Landing Gear installed on the aircraft

- MLG installed on the right side of the aircraft during the occurrence:

. Part Number (PN) 161A1100-54;

. Serial Number (SN) MAL05154Y2498;

. Time Since New (TSN): 36,591 hours;

. Cycles Since New (CSN): 24,939 cycles;

. Time Since Installation (TSI): 6,834 hours;

. Cycles Since Installation (CSI): 3,969 cycles;

. Date of Installation: 20AUG2016; and

. Date of Manufacture: 21JAN2008.

This landing gear set was installed on another aircraft (PR-GGB), being removed on 27APR2016 for the first general overhaul, with 20,970 cycles on that occasion.

The maintenance requirements for the landing gear assembly were:

- Life Limit: 75,000 cycles; and

- Time Between Overhaul (TBO): 21,000 cycles or 3,650 days (approximately 10 years).

Part of the MLG set (PN 161A1100-54 / SN MAL05154Y2498) was the aft trunnion pin, PN 161A1192-13 and SN E4798, being a part made of 4340M steel alloy, 275-300ksi.

Description of the Overhaul of the Landing Gear System

For the research related to the landing gear revision process and, in particular, the aft trunnion pin, the following documentation was used:

- Component Maintenance Manual (CMM) 32-00-05: Repair of High-Strength Steel Landing Gear Parts, Revision 13, from 01JUL2017. Owned by The Boeing Company;

- CMM (with illustrated parts list) 32-11-09: Main Landing Gear Installation Components, Revision 33, from 01JUL2018. Owned by The Boeing Company;

- Standard Overhaul Practices Manual (SOPM) 20-10-02: Machining of Alloy Steel Revision 45, from 01NOV2017. Owned by The Boeing Company;

- SOPM 20-10-04: Grinding of Chrome Plated Parts Revision 22, from 01MAR2016. Owned by The Boeing Company;

- SOPM 20-20-01: Magnetic Particle Inspection Revision 31, from 01MAR2016. Owned by The Boeing Company;

- SOPM 20-20-02: Penetrant Methods of Inspection Revision 26, from 01MAR2016. Owned by The Boeing Company; and

- Service Bulletin (SB) Number 737-32-1448, Revision 1, of 29MAY2015. Owned by The Boeing Company.

The SOPM 20-10-04, Revision 22, from 01MAR2016, dealt with the process of grinding the chrome layer of the parts that were covered with this type of coating. It is noteworthy that the SOPM 20-10-04 was applicable for parts with a chrome layer covering, not only to the aft trunnion pin.

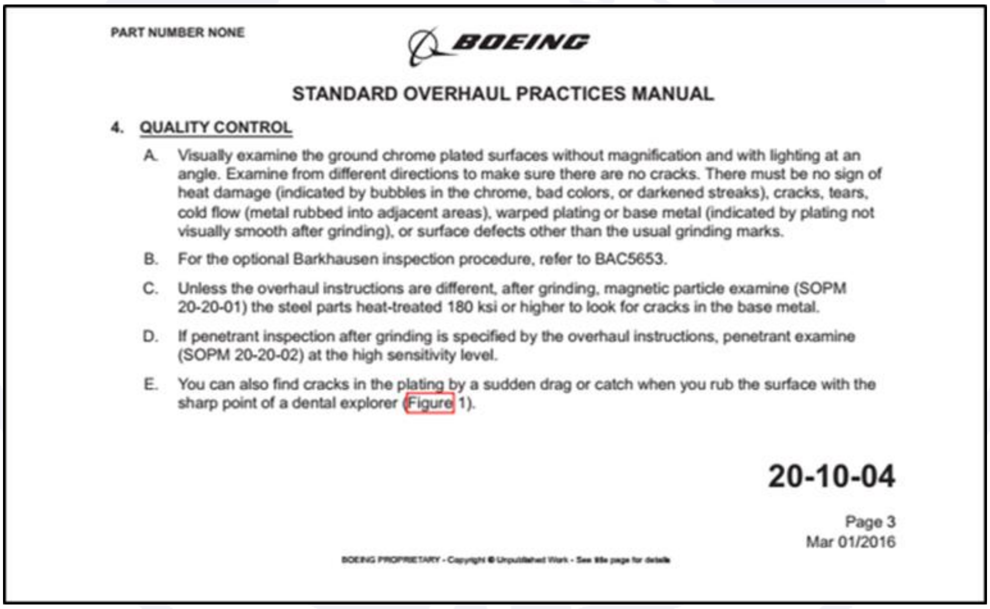
The SOPM was divided into the following sections:

1. Introduction: This section provided general information about the chrome layer grinding procedure.

2. Grinding Procedures: this section provided information for grinding the chrome layer. Among this information was: cleaning of the part surface, care with the grinding stone, cooling of the part, criteria of intrusion of the part in the grinding stone, speed and specifications of the stone, besides general care to be observed during the grinding.

3. Post Grind Bake for Aluminum: this section included cooking procedures in an oven or in boiling water for aluminum parts with a chrome coating (this section is not applicable to the aft trunnion pin).

4. Quality Control: this section provided guidance on quality control after grinding the chrome layer. These procedures are briefly described in the sequence (Figure 7).


PART NUMBER NONE

BOEING

STANDARD OVERHAUL PRACTICES MANUAL

4. QUALITY CONTROL

A. Visually examine the ground chrome plated surfaces without magnification and with lighting at an angle. Examine from different directions to make sure there are no cracks. There must be no sign of heat damage (indicated by bubbles in the chrome, bad colors, or darkened streaks), cracks, tears, cold flow (metal rubbed into adjacent areas), warped plating or base metal (indicated by plating not visually smooth after grinding), or surface defects other than the usual grinding marks.

B. For the optional Barkhausen inspection procedure, refer to BAC5653.

C. Unless the overhaul instructions are different, after grinding, magnetic particle examine (SOPM 20-20-01) the steel parts heat-treated 180 ksi or higher to look for cracks in the base metal.

D. If penetrant inspection after grinding is specified by the overhaul instructions, penetrant examine (SOPM 20-20-02) at the high sensitivity level.

E. You can also find cracks in the plating by a sudden drag or catch when you rub the surface with the sharp point of a dental explorer (Figure 1).

20-10-04

Page 3
Mar 01/2016

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Figure 7 - Quality control procedure after grinding the chrome layer.
Source: SOPM 20-10-04 from the Boeing Company.

Item A refers to the visual inspection, in order to observe if the part has no signs of cracks, heat damage (indicated by bubbles in the chrome and / or strange coloring), cracks, grooves, non-uniformity in the coating, among others.

Item B deals with the optional examination by the Barkhausen inspection procedure. In summary, this examination is performed using a sensor and an equipment called Barkhausen. The assembly is capable of applying a magnetic field to the part. The pulse of the magnetic field is captured by the equipment and differences in the properties of the part and defects are detected in the Barkhausen inspection. It is necessary to calibrate the equipment.

Item C mentions the examination for magnetic particles in steel parts with heat treatment and tensile strength of 180ksi or above, in order to observe cracks in the base metal, carrying out this procedure unless there are different general overhaul instructions.

The magnetic particle examination uses the property of magnetic lines in an applied field to pass through the metal more easily than the air. A defect in or near the surface of the metal alters the distribution of the magnetic flux and some lines must come out of the surface of the metal. The field intensity is increased in the area of the defect and opposite magnetic poles occur on each side of the defect. Fine magnetic particles applied to the part are pulled into these regions and form a pattern around the defect.

Item D mentions the examination by penetrating liquid after rectification with the high sensitive level, if specified in other general review procedures. This examination uses the property of a liquid to enter a defect that is open on the surface of the part. Fluorescent penetrants are examined under ultraviolet light, which highlights the accumulation of liquid in a crack.

No specifications or guidelines were found in the other landing gear review manuals analyzed for the examination by penetrating liquid.

In addition to the other inspections, an examination can be performed using an inspection instrument for crack detection (Figure 8).

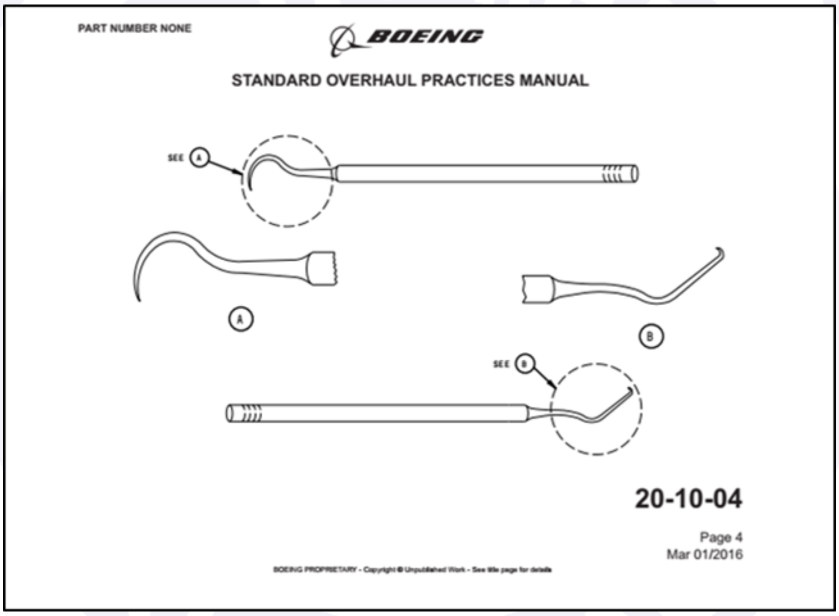

Figure 8 - Inspection and quality control instrument for chrome grinding.
Source: SOPM 20-10-04 from the Boeing Company.

5. Application of Wiped-on Primer: this section included procedures for applying Primer in order to increase corrosion resistance. The Primer should be applied after machining the chromium layer and performing finishing procedures, such as cadmium layer application.

6. Rework: this section provided instructions for removing the chrome layer through machining. This method is an alternative to the usual method provided for in SOPM 20-30-02, which uses chemical removal of the chromium layer.

Execution of the General Review Services

The MLG review, PN 161A1100-54, SN MAL05154Y2498, was carried out by the company TAP *Manutenção e Engenharia Brasil* S.A. (TAP-ME), Maintenance Organization Certificate (COM) n°0112-01, issued by the ANAC.

The TAP-ME was approved to perform a general review on the MLG PN 161A1100-54, as stated in its List of Capabilities, Review 77, of 22NOV2017. In conjunction with the general review, it was expected a compliance with SB 737-32-1448.

The first step of the General Review consisted of the preliminary inspection of the landing gear assembly for obvious damage to the component, missing parts and other observations, according to the Inspection Record Form referring to the Service Order (OS) n°10261058. No significant discrepancies were found in the preliminary steps of the landing gear inspection.

Then, the disassembly, cleaning, painting removal and identification of the controlled items that comprised the MLG were performed, as detailed in the MLG Shop Service Sheet (FSO) PN 161AF1100-54, SN MAL05154Y2498. Among the items that comprised the landing gear, there was the aft trunnion pin PN 161A1192-4, SN E4798.

The repair procedures carried out on the aft trunnion pin, PN 161A1192-4, SN E4798, were recorded in two FSO's and in a sheet called Operation Problem Report (OPR).

The FSO contained the procedures prevised in the overhaul of the aft trunnion pin. After performing each procedure, the fields with the parameters and results of the task were filled in, when pertinent, dated and signed by the person responsible for carrying out the task.

The tasks related to the initial inspection, registered with the FSO, are shown in Figure 9 below, together with the inspection provided for in SB 737-32-1448:

Nº	DESCRIPTION OF THE OPERATION	DATE
001	Stress relief for 4 hours at 190°C ± 10°C Oven in: **23:15** hrs. Day: **18/05/16** Oven out: **03:15** hrs. Day: **19/05/16**	19MAY2016
002	Visual Inspection and superficial corrosion removal. Result: **No Indication**	24MAY16
003	Magnetic Particle Inspection Result: **No Cracks**	27MAY16
004	Dimension inspection and repair decision. Repair: **(x) Yes**. **( ) No.** Inspection per SB 737-32-1448 Result: (x) There are no areas with of loose or missing chrome plate and/or corrosion. Program the repair as necessary. ( ) There are areas with of loose or missing chrome plate and/or corrosion. Identify the damaged area(s) and repair it as necessary. Damaged area: **Bubbles on Chrome**	27MAY2016

Figure 9 - Initial inspections of the aft trunnion pin SN E4798.

The first task performed on the aft trunnion pin was the procedure called “stress relief”. This procedure consisted of heating and consequent expansion of the part, thus reducing residual stresses resulting from the operation of the landing gear assembly, when installed on the aircraft.

The initial inspections (visual and by magnetic particles) did not indicate the presence of defects in the aft trunnion pin SN E4798. In the detailed inspection prevised in SB 737-32-1448, carried out three days later, a defect was identified, described as “chromium bubbles" which, according to the OM mechanics, represented a sign of internal corrosion on the pin.

Thus, we proceeded to the procedures for removing the chromium layer protection, inspections before and after machining the base metal, stress relief and shot peening. The procedures are transcribed in Figures 10 and 11:

Nº	DESCRIPTION OF THE OPERATION	DATE
005	Strip chrome plate from the indicated areas. (x) Diameter "1"	31MAY2016
006	Perform Nital Etch inspection. Result: **No Burns**	31MAY2016
007	Magnetic Particle Inspection Result: **No Cracks**	01JUN2016
008	Inspect, measure and note Diameter "1": **3.2390" – 3.2385"**	01JUN2016

Figure 10 - Procedures for removing the chromium layer and inspecting the base metal.

The removal of the chromium layer was performed chemically, by immersing the part in sodium hydroxide and sodium carbonate solution.

The Nital-Etch inspection consisted of immersing the part in a nitric acid solution. This inspection was able to identify damage by excessive temperature in the base metal of the part.

Nº	DESCRIPTION OF THE OPERATION	DATE
009	Machine the indicated diameters as necessary to remove damages/corrosion. (x) Diameter "1" minimum: **3.2180"**	02JUN2016
010	Inspect, measure and note. Diameter "1": **3.2327" – 3.2333"**	02JUN2016
011	Stress relief for 4 hours at 190°C ± 10°C Oven in: **10:00** hrs Day: **03/06/16** Oven out: **14:00** hrs Day: **03/06/16**	03JUN2016
012	Perform Nital Etch inspection. Result: **No Burns**	06JUN2016
013	Magnetic Particle Inspection Result: **No Cracks**	07JUN2016
014	Shot peening the indicated areas. Shot size: 0.016"/0.033". Intensity: 0.014"/0.018" A2 (x) Diameter "1" ( ) Diameter "6"	08JUN2016

Figure 11 - Machining of the base metal of the pin and subsequent procedures.

After the removal of the chromium layer, an inspection called Nital-Etch was performed. Basically, this inspection consisted of applying a chemical compound (the OM used nitric acid with an anti-smut additive) that would highlight the areas where heating and changing the crystalline structure of the base metal of the aft trunnion pin occurred.

Through the measurements recorded in items 008 and 010, it was possible to verify the removal of about 0.006” (six thousandths of an inch), the pin being above the minimum design dimensions, as it could be verified by comparing the values of items 009 and 010.

Then, due to the machining procedure carried out, the aft trunnion pin was taken for stress relief procedures, Nital-Etch inspection and inspection for magnetic particles.

In the records contained in the FSO, inspections did not identify burns and cracks in the base metal of the AF trunnion pin SN E4798. Then, the shot peening procedure was carried out, which aimed to increase the surface resistance of the piece.

After the completion of these procedures, the pin was taken to the galvanic bath in order to redo the protective covers of chromium and cadmium. Galvanic baths can introduce hydrogen into the internal structure of the pin, making it fragile. Thus, it was necessary to take the piece to the oven in order to remove the hydrogen particles. This procedure is known as “hydrogen relief” and could be done in a single step, after two galvanic bath processes, provided that certain criteria of the manual are obeyed.

The procedures were recorded as follows (Figure 12):

Nº	DESCRIPTION OF THE OPERATION	DATE
015	Apply chrome plate. Diameter “1” design: **3.2480” / 3.2490”** Diameter “1”: **3.2327”** Chrome plate thickness: **0.011”** (Expected) Diameter “1” + Chrome Plate: **3.2437”** Plating control. Tank in – **16:30** hrs Date: **10/06/16** Tank out – **09:30** hrs Date: **11/06/16** Hydrogen relief bake for 23 hours at 190°C ± 10°C Oven in: **12:30** hrs Date: **11/06/16** Oven out: **00:30** hrs Date: **12/06/16**	13JUN2016
016	Apply cadmium plate. Note: Do not apply on areas with Chrome Plate Plating control. Tank in – **12:45** hrs Date: **11/06/16** Tank out – **12:55** hrs Date: **11/06/16** Hydrogen relief bake for 23 hours at 190°C ± 10°C Oven in: **13:00** hrs Date: **11/06/16** Oven out: **12:00** hrs Date: **12/06/16** ----------------------------------	13JUN2016
017	Inspect, measure and note Diameter “1”: **3.243” – 3.244”** Chrome plate insufficient ----------------------------------	14JUN2016
018	Galvanic Plate Machining Description: **The chrome plate thickness at the Diameter “1” did not reach the thickness required. Actual thickness 0.007” to 0.005”** ----------------------------------	14JUN2016

Nº	DESCRIPTION OF THE OPERATION	DATE
019	Check the noted operation problem on the item above and evaluate the solution. If necessary, contact Engineering. Notes: **Remove the Chrome Plate, inspect and apply a new Chrome plate**	14JUN2016

Figure 12 - Galvanization procedures.

In the FSO records, it was observed that the period in which the part remained in the galvanic bath for the application of cadmium (item 016) was contained in the period in which the part was in the oven for hydrogen relief (item 015), being the realization of these procedures, simultaneously, inconsistent.

The galvanic bath required double registration, with one responsible for the execution of the procedure and another for the verification.

In the application of the chromium layer, it was observed that the final design diameter of the pin was not reached, that is, the thickness of the chromium layer obtained by the galvanic process was insufficient.

As a solution to the condition found, it was decided to remove and reapply the chromium layer.

The following are the records of the actions taken (Figure 13):

Nº	DESCRIPTION OF THE OPERATION	DATE
020	Strip chrome plate from the indicated areas. (x) Diameter “1”	15JUN2016
021	Inspect, measure and note Diameter “1”: **3.2325” – 3.2330”**	15JUN2016
022	Apply chrome plate. Diameter “1” design: **3.2480” / 3.2490”** Diameter “1”: **3.2325” – 3.2330”** Chrome plate thickness: **0.011”** (Expected) Diameter “1” + Chrome Plate: **3.2483” – 3.2484”** Plating control. Tank in – **19:00** hrs Date: **15/06/16** Tank out – **21:00** hrs Date: **15/06/16** Hydrogen relief bake for 23 hours at 190°C ± 10°C Oven in: **23:00** hrs Date: **15/06/16** Oven out: **11:00** hrs Date: **16/06/16**	16JUN2016

Figure 13 - Procedures performed for the second application of the chromium layer.

It was found that the time recorded for the second application of the chromium layer (item 022) was significantly less than that of the first. It is noteworthy, again, that this procedure was carried out with double verification.

In interviews carried out during the investigation, the possibility of carrying out a chromium application on top of another layer of chromium was denied, alleging an error in registration in the FSO.

Then, the chromium layer grinding procedure was planned (Figure 14), in order to make the part uniform for installation in the landing gear assembly. In addition to grinding, there were measurement and inspection procedures for magnetic particles.

Nº	DESCRIPTION OF THE OPERATION	DATE
023	Grind the indicated diameters. Superficial finish 32 RMS (x) Diameter “1” to: **3.2480 / 3.2490”**	18JUN2016
024	Locally remove remaining sharp edges from chrome plate. Use a hand-held grinding stone. ATTETION: Do not touch base metal	18JUN2016
025	Inspect, measure and note Diameter “1”: **3.2483” – 3.2484”** Actual Chrome Plate thickness: **0.008” – 0.007”**	20JUN2016
026	Magnetic Particle Inspection Result: **No Cracks**	20JUN2016

Figure 14 - Chromium layer grinding procedure.

In a visit made to the OM during the investigation, no differences were found between the machines and the equipment used by it for grinding the chrome layer (item 025) and those recommended by the manuals.

The inspection by magnetic particles did not identify any cracks in the chromium layer. There are no records of other quality control inspections carried out by the OM.

After the task described in item 026 of Figure 14, in addition to the application of corrosion preventive compounds, procedures prevised in SB 737-32-1448 were carried out, the final assembly and installation of the landing gear.

1.7 Meteorological information.

The conditions were favorable for the visual flight.

The METAR of the SBCF provided the following information:

METAR SBCF 162100Z 06006KT 9999 FEW045 20/10 Q1024=

METAR SBCF 162200Z 03005KT 9999 FEW045 19/11 Q1024=

Therefore, it was found that near the time of the occurrence, the visibility was above 10km and there were few clouds at 4,500ft. The wind had an intensity between 5kt and 6kt.

The Control Tower (TWR) of Confins reported to the crew a wind with a direction of 060º and intensity of 5kt, with an altimeter adjustment of 1025hPa, when the PR-GGD aircraft was in the final approach.

1.8 Aids to navigation.

All navigation and landing aids operated normally when the aircraft approached.

1.9 Communications.

According to the analysis of the audios obtained through the CVR of the PR-GGD, 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, managed by the BH Airport concessionaire (CCR Group, Zurich Airport and Infraero) and operated under VFR and by IFR, during the day and night.

The runway was made of asphalt, thresholds 16/34, dimensions of 3,000m x 45m, with an elevation of 2,713 feet (Figure 15).

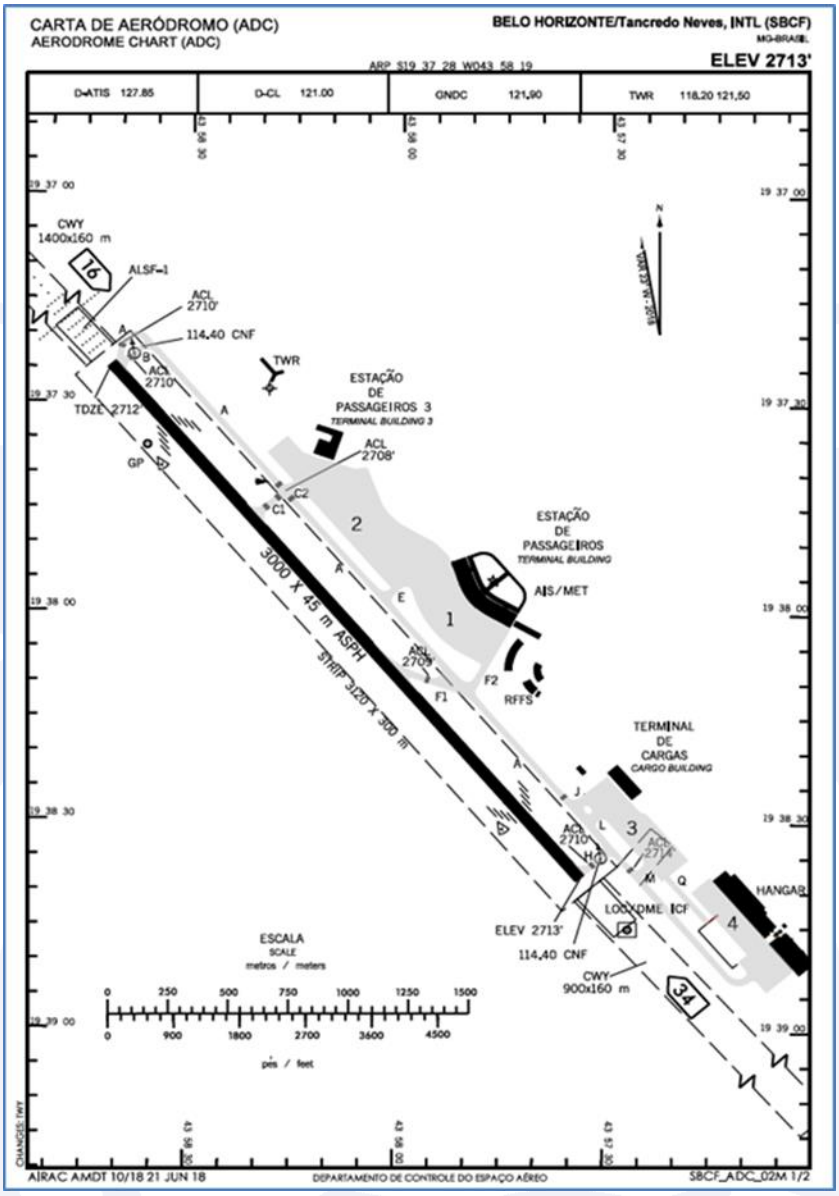

Figure 15 - SBCF Aerodrome Chart.

1.11 Flight recorders.

The aircraft was equipped with a Honeywell Flight Data Recorder (FDR), model SSFDR (solid state memory), PN 980-4700-042, SN 13754, with a capacity of 256 words (each word has 12 bits), thus performing a 256x12 reading every second (words per second).

In addition, it was also equipped with a Honeywell CVR, model SSCVR (solid state memory), PN 980-6022-001, SN 10011, with a capacity for two hours of recording.

Both flight data and cabin voice recorders recorded data related to the occurrence, which could be used in the investigation.

1.12 Wreckage and impact information.

Nil.

1.13 Medical and pathological information.

1.13.1 Medical aspects.

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

1.13.2 Ergonomic information.

Nil.

1.13.3 Psychological aspects.

The commander was described as a very cautious professional and the copilot as attentive and zealous in his operation.

According to the information obtained from the commander and copilot, they presented themselves for that day's flight in the late afternoon. The commander did the briefing and nothing in particular was mentioned to the other crewmembers in relation to the aircraft.

The commander was in the Pilot Monitoring (PM) function and the copilot was in the Pilot Flying (PF) function. The commander chose to assign the São Paulo-Confins leg to the copilot because, whenever possible, he prioritized giving flight opportunities to the copilots. That would be, according to him, one of the easiest contexts to operate in that flight leg that they should fulfill.

Both reported that the flight went normally. They considered it a fast flight because they were involved with various activities on board, such as filling out documents and preparing for the next landing.

When approaching for landing, the crewmembers carried out the briefing, as recommended. They also reported that the interaction in flight was smooth.

The commander monitored the flight at all times and, on landing, followed the speed and height parameters, having not observed any indication of variation that could compromise the operation of the aircraft.

In his professional history, the copilot reported that he had never had experience with hard landing or tail strike. The crewmembers returned to the flight after three days off. He reported that he lived close to the airport and, as the presentation was not early, he was able to rest and report to the flight without problems or complications.

1.14 Fire.

There was no fire.

1.15 Survival aspects.

Nil.

1.16 Tests and research.

The aft trunnion pin, PN 161A1192-13, SN E4798, was analyzed in the Boeing Company's EQA laboratory, with the presence of representatives from the CENIPA, the NTSB, the operator and the aircraft manufacturer.

The two portions of the aft trunnion pin were identified with the numbers 1 and 2, with the number 1 being the front and the number 2 the rear (Figure 16).

Figure 16 - Aft trunnion pin fractured.

The transversal section and fracture area of part 1 are shown in Figures 17 and 18.

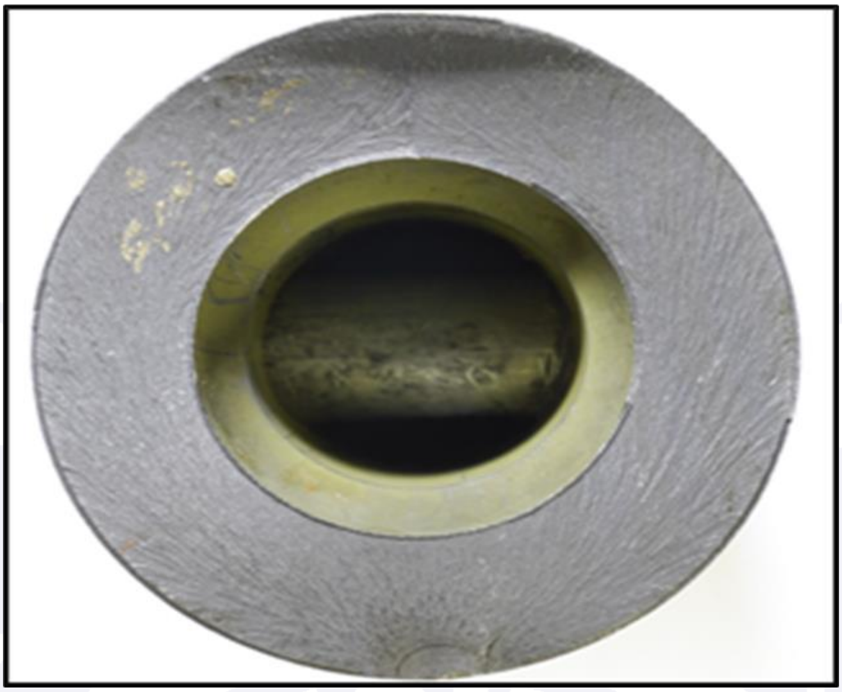

Figure 17 – Fractured face of part 1 of the aft trunnion pin.

Figure 18 - Detail of the part 1 fracture of the aft trunnion pin.

The transversal section and fracture area of part 2 are shown in Figures 19 and 20.

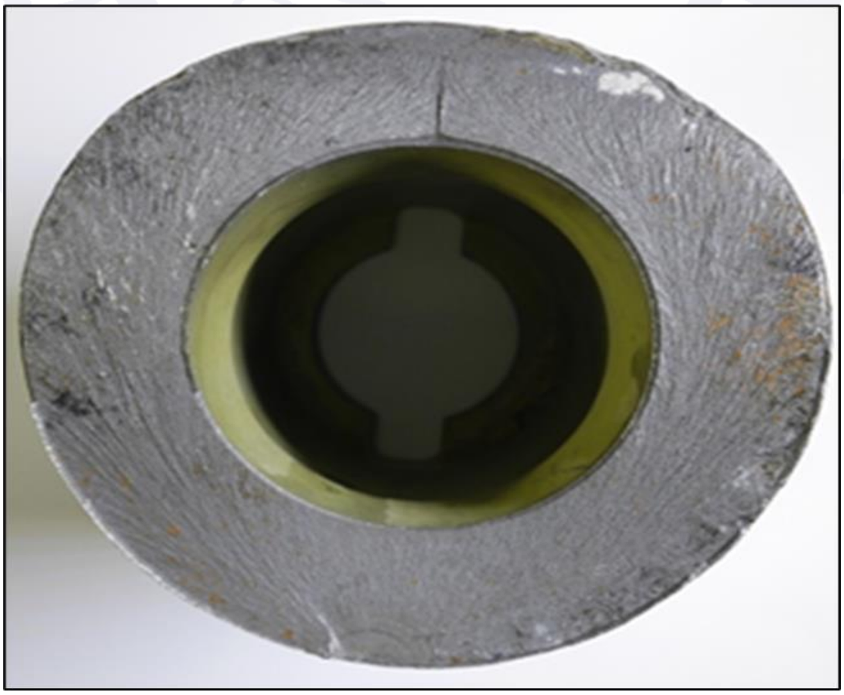

Figure 19 - Fractured face of part 2 of the aft trunnion pin.

Figure 20 - Detail of the part 2 fracture of the aft trunnion pin.

Initially, an inspection by the Barkhausen method was carried out on the two portions of the aft trunnion pin. This examination uses equipment that generates a magnetic pulse capable of identifying changes in the crystalline structure of the part caused by thermal damage.

The Barkhausen inspection was performed using a portable device shown in Figure 21, however, the results were considered inconclusive.

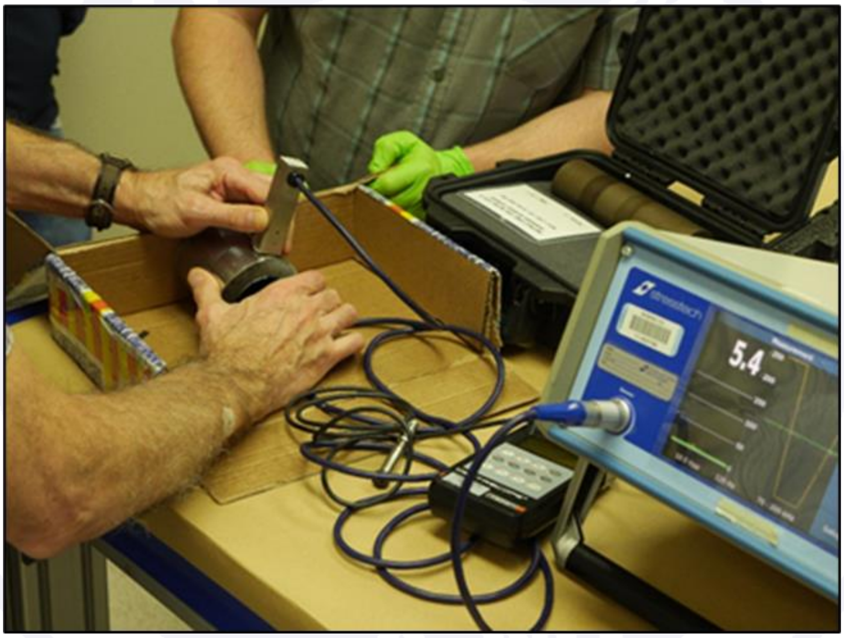

Figure 21 - Barkhausen inspection.

Then, an inspection by magnetic particles was performed, where the part was covered by a liquid containing small magnetic particles and, then, a magnetic field was applied on it, in the longitudinal and transversal directions. In places where there was a crack, there would be an accumulation of particles that could be observed visually.

No significant cracks were found in the inspection by magnetic particles in the two halves of the analyzed pin.

The presence of coverage by non-magnetic material (chromium), which limits the effectiveness of the inspection by magnetic particles, and the existence of the transversal wall plug (red arrow in Figure 22) can alter the magnetic flux, making it difficult to identify cracks.

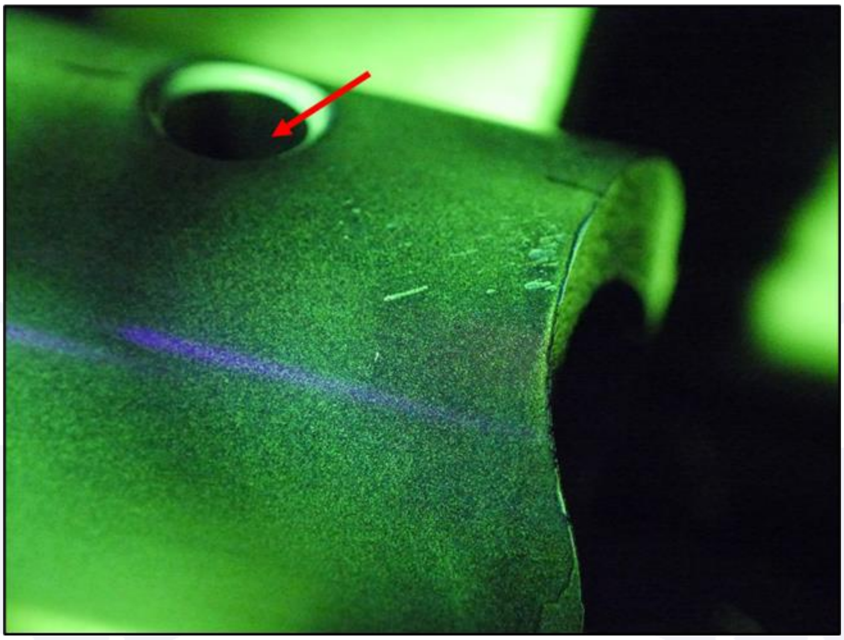

Figure 22 - Inspection by Magnetic Particles.

Then, a penetrating liquid inspection was performed. In this inspection, the part is covered by a liquid that accumulates in the irregularities of the part, facilitating the visualization of cracks.

According to the SOPM 20-20-02 Penetrant Methods of Inspection, there are five levels of sensitivity (ultra-low, low, medium, high and ultra-high). For the analysis of the two portions of the fractured pin, the high level was used.

The inspection by penetrating liquid revealed several accumulations along the entire fracture diameter. In particular, a crack indicative was found in an area of approximately 1.0 pol² close to the region shown in Figure 23 and Figure 24.

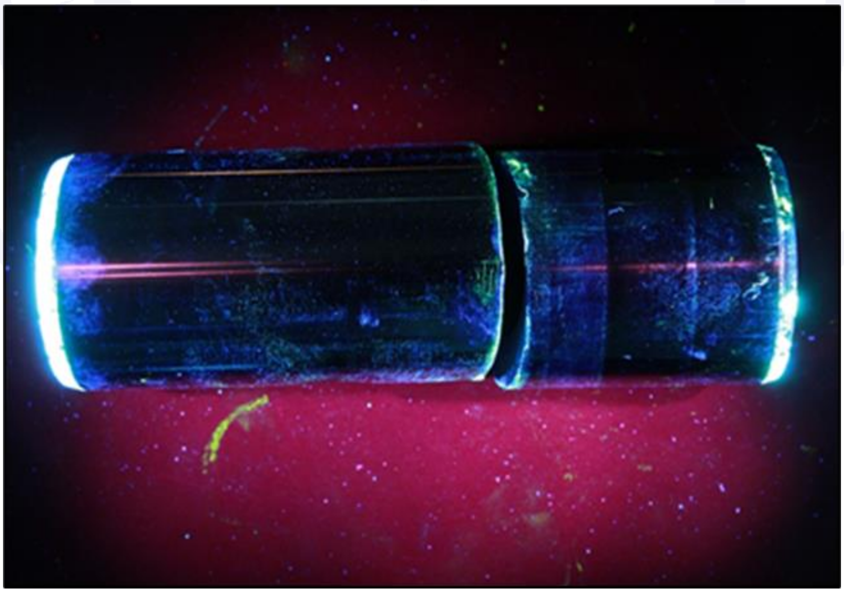

Figure 23 - Overview of the penetrating liquid inspection on the aft trunnion pin.

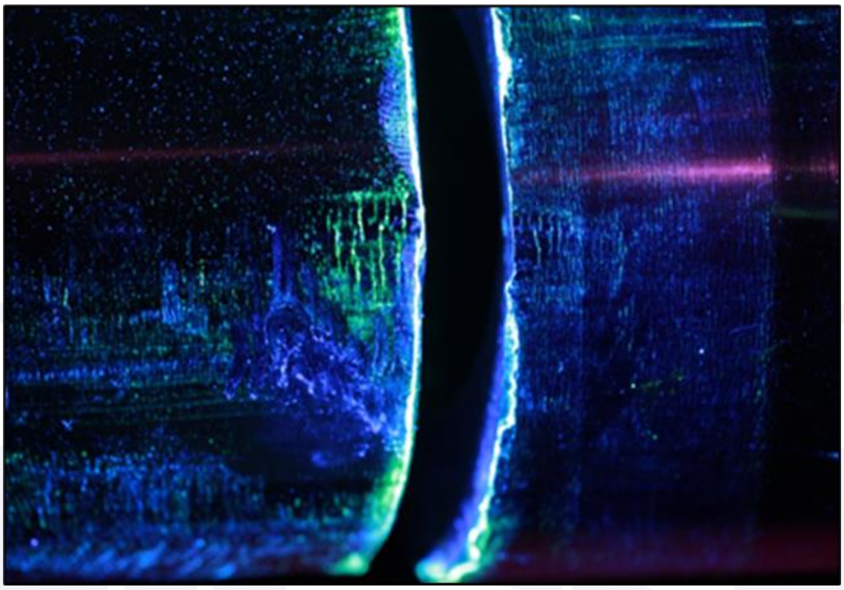

Figure 24 - Detail of the inspection by penetrating liquid in the aft trunnion pin.

The larger part of the aft trunnion pin was cut (Figure 25), in order to allow analysis in the Stereoscope and in the MEV or SEM.

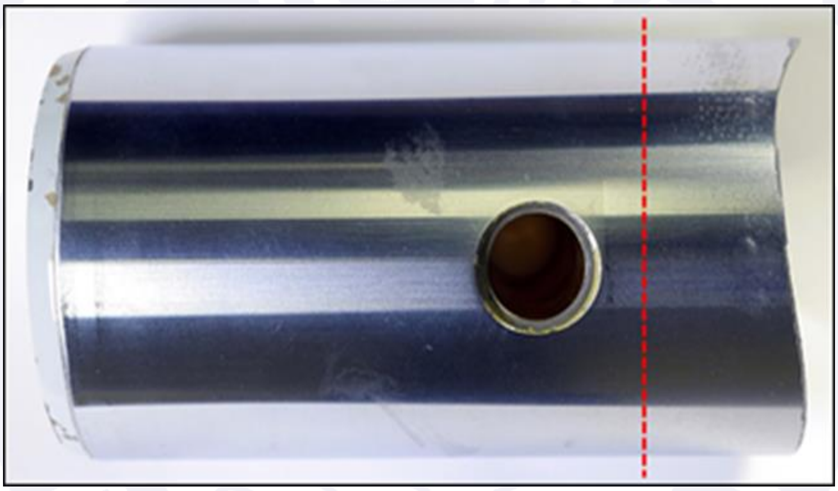

Figure 25 - Section of the major portion of the aft trunnion pin.

In conjunction with the SEM exams, analyzes were performed on the stereoscope that allowed the following observations to be made about the fracture characteristics:

- two intergranular crack start points, with dimensions of about 0.025 inches;

- the first crack portion showed stable growth with fatigue characteristics, approximate dimensions of 0.15 inches (about 20% of the pin section's thickness);

- the remaining portion showed unstable but cyclical growth, with characteristics of ductile fracture. Approximate dimension of 0.30 inches (about 40% of the pin section's thickness); and

- the final fracture showed characteristics of ductile and abrupt fractures.

These characteristics were illustrated below in Figure 26.

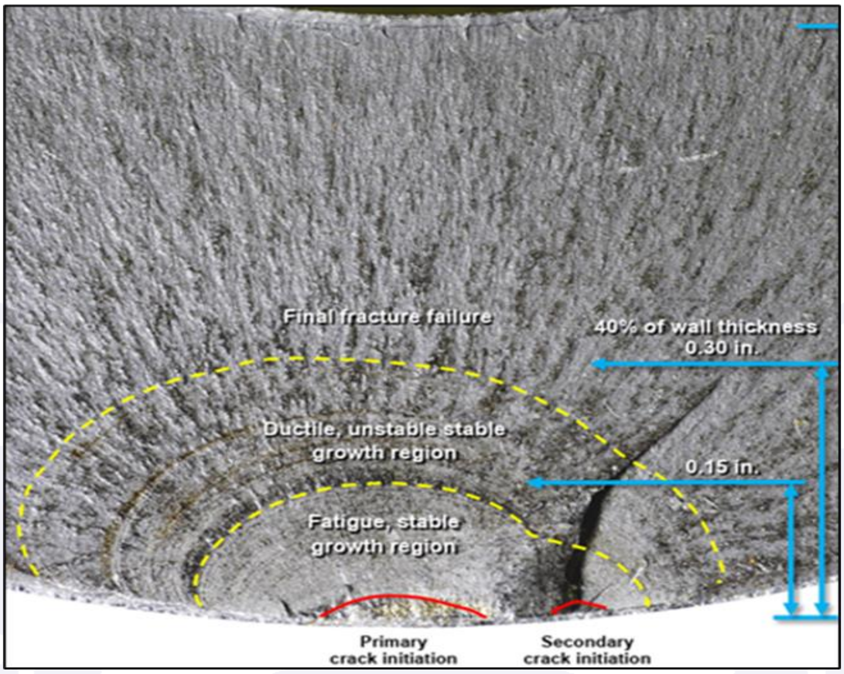

Figure 26 - Fracture characteristic of the aft trunnion pin SN E4798.

Then, a new inspection by magnetic particles was carried out on the sectioned portion of the pin, since the conformation of the aft trunnion pin fixing wall plug on the landing gear could have interfered with the magnetic field generated during the first inspection.

A crack was observed on the surface of the pin with characteristics similar to those observed in the inspection by penetrating liquids (Figure 27).

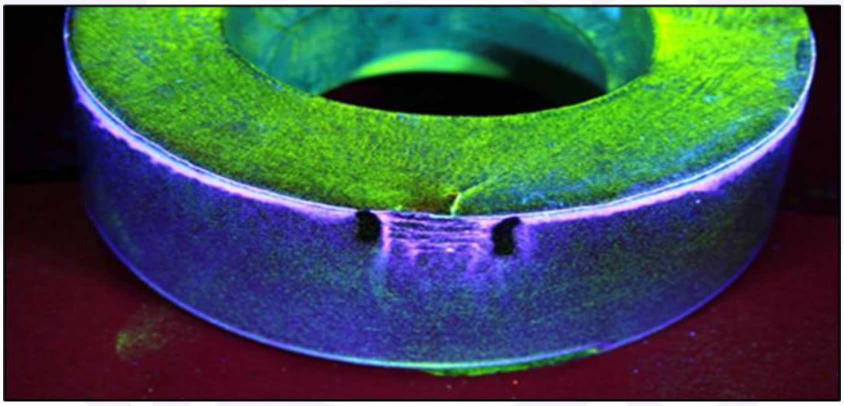

Figure 27 - Inspection by magnetic particles in the sectioned portion of the aft trunnion pin.

A new cut was made in the sectioned portion, in order to conduct metallographic examinations in the fracture region, as shown in Figure 28, below.

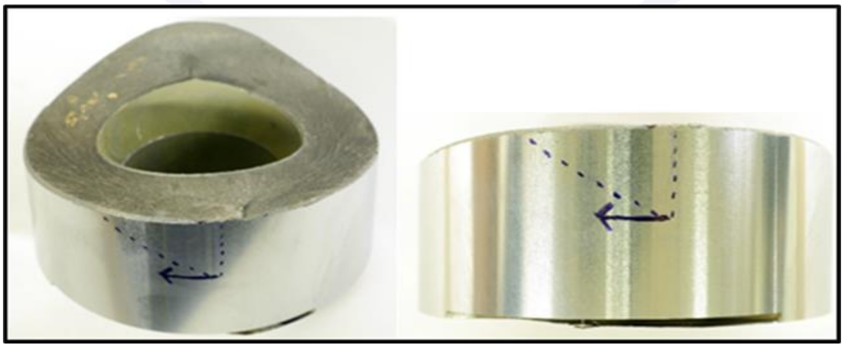

Figure 28 - Cut performed for metallographic examinations.

A sample was prepared, from the cut of Figure 28, for metallographic analysis visualized in Figure 29.

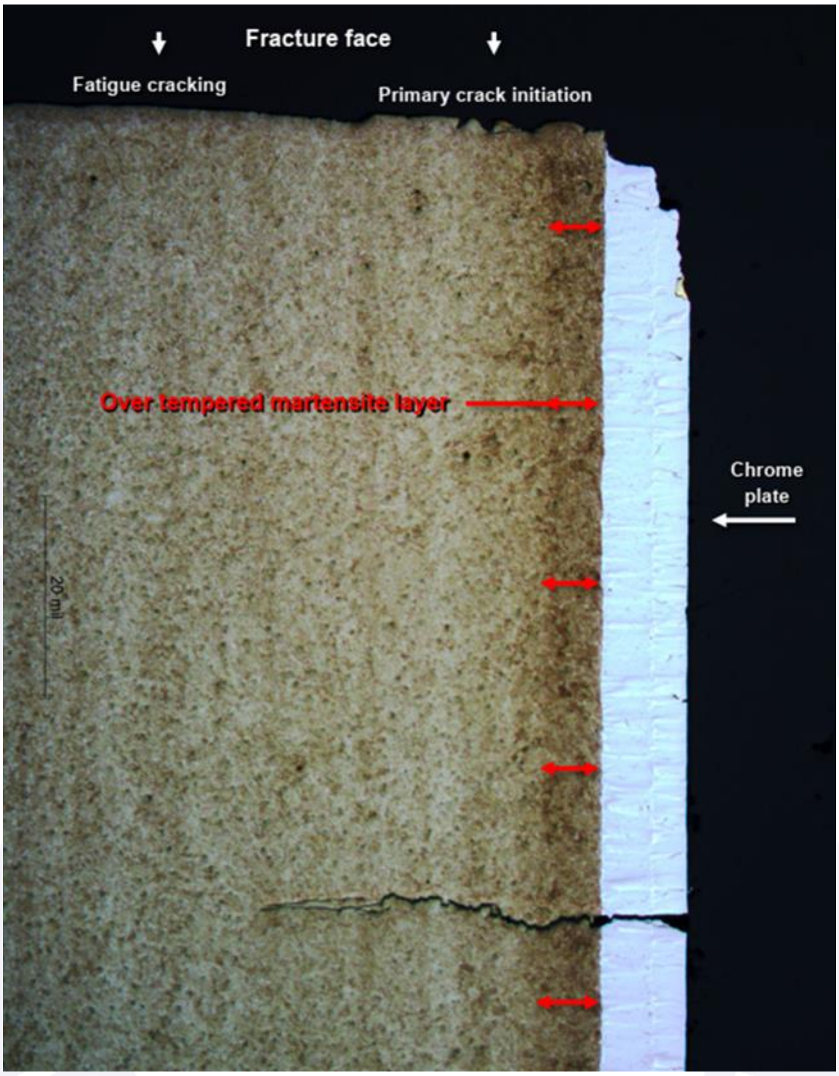

Figure 29 - Sample for metallographic examination at the origin of the failure.

The darkened region, highlighted by the red arrows in Figure 29, indicates a region that has been subjected to an excess temperature of Martensite (form of the crystalline structure of the iron-carbon alloy) or Over Tempered Martensite (OTM). This condition can also be referred to as burning the base metal.

The complementary part of the sample taken for metallographic examinations was taken for the procedure of removing the chromium layer.

The fracture surface was protected with DUCO Cement (a nitro cellulose from the cement family). The chromium layer was removed electrolytically with sodium hydroxide and sodium carbonate solution.

The surface of the part was then inspected for heat damage by the Nital-Etch process, using a solution of nitric acid and alcohol. The result of this inspection showed a region with damage from excessive heat, highlighted by the red circles in Figures 30 and 31.

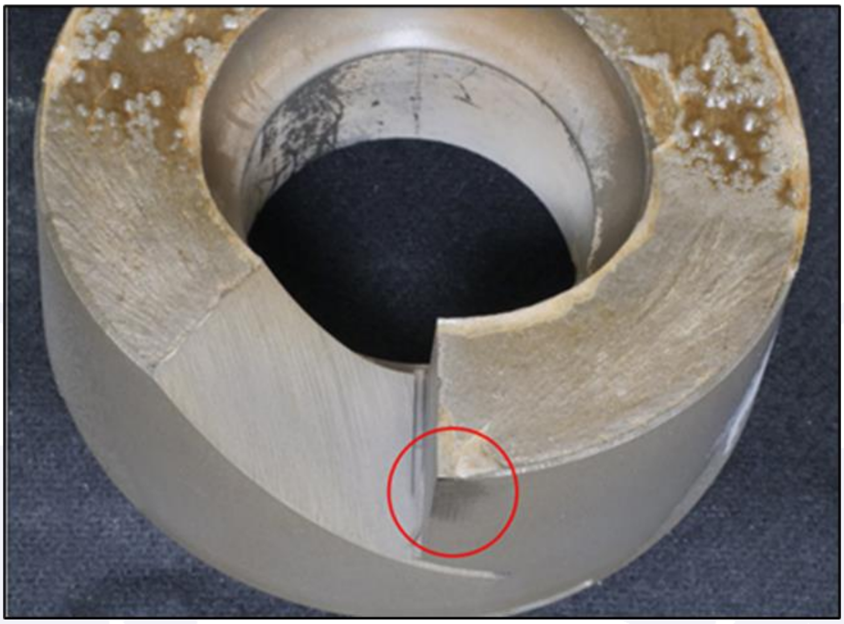

Figure 30 - Result of the inspection with Nital-Etch.

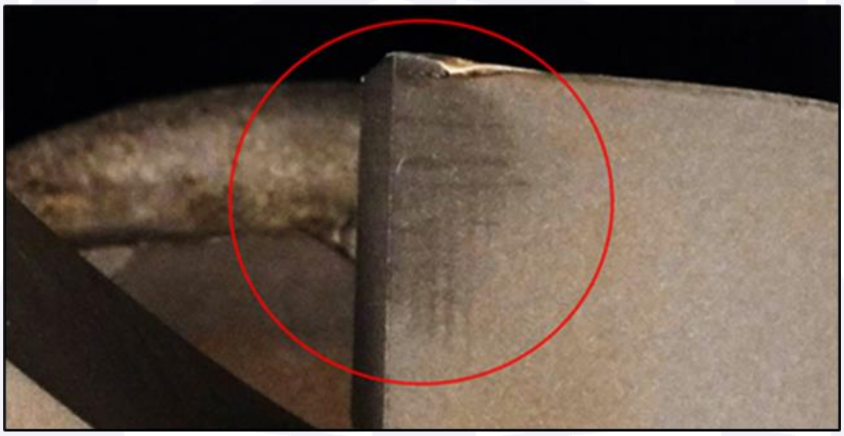

Figure 31 - Detail of the result of the inspection with Nital-Etch.

A new inspection by magnetic particles was performed on the sectioned portion of the base metal revealing cracks, as shown in Figure 32 below:

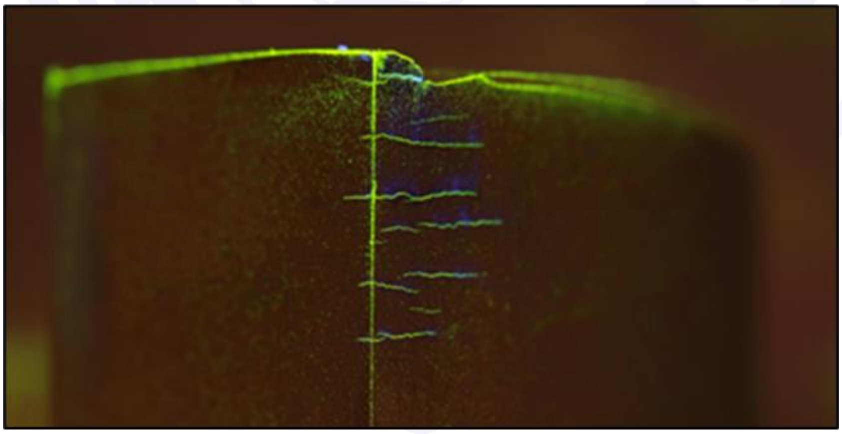

Figure 32 - Cracks revealed in the inspection by magnetic particles.

Metallographic tests of microhardness, residual stress and chemical tests were also performed in the analyzed portion.

The microhardness test resulted in an average value of 50.1 on the Rockwell C scale of hardness, Hardness Rockwell C (HRC) in the dark areas highlighted in the inspection by Nital-Etch (Figure 33).

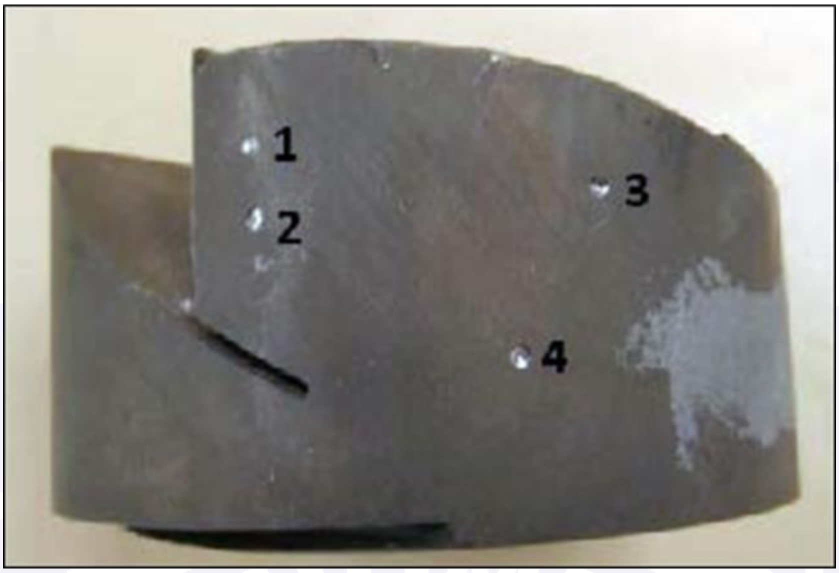

Figure 33 - Residual stress test points.

In areas where the inspection for heat damage did not change, the average hardness value found was 54.6 HRC. The expected value range for the base metal alloy of the aft trunnion pin was between 52 to 56 HRC.

The residual stress test was performed at the locations indicated in Figure 33. Point 1 is within the dark area shown in Figure 31 and points 2, 3 and 4 are located outside this region. Points 2, 3 and 4 showed typical results of the metallic alloy of the aft trunnion pin, after performing the Shot Penning procedure. Point 1, on the other hand, showed variation in the result.

Chemical tests showed that the composition of the aft trunnion pin, SN E4798, was within the expected specifications, with the exception of Manganese (Mn). The expected composition was between 0.90% ± 0.03%, the value found was 0.9693%.

On 17OCT2018, the Investigation Team visited the shop facilities that carried out the general review of the MLG (PN 161A1100-54 / SN MAL05154Y2498), in order to check if there was any difference between the criteria provided by the SOPM 20-10-04 and the procedures performed by the company. There was no evidence that the procedures carried out in May and June 2016, the period of the general review of the MLG, were different from those provided in the manuals.

1.17 Organizational and management information.

The OM was certified by the ANAC to perform landing gear maintenance and provided services to the aircraft operating company for over 10 years, having performed, up to the date of this occurrence, around 250 landing gear maintenance. This was the first time that a service issue was reported.

At the time when the service was performed on the aircraft's aft trunnion pin, the landing gear workgroup team was composed by 16 people, distributed in different functions.

All parts received for maintenance were checked before proceeding to the repair sectors. According to the company's professionals, the work was carried out as provided in the manual.

Every two years, training was offered to employees, both complete and upgrading or recycling.

The Shop Production Control area was responsible for defining the time for each stage of the work process of the parts.

The FSO of the landing gear part in question was filled in incorrectly by the galvanizing professional. Regarding this fact, the company raised the hypothesis that, probably, there was a discrepancy between the period of time in which the part was effectively treated by the chrome bath and the one registered with the FSO.

Regarding the grinding service on aircraft components, there was no specific training for the professional who worked in this area. This employee completed the training of grinding in general and, at the OM, he did a familiarization training with aeronautical services, since there was no specific training requirement by the Brazilian regulatory agency.

The rectifier that acted on the landing gear of the crashed aircraft was 39 years old. He retired in the same year as this occurrence. He was considered the most experienced, committed, careful and patient of the OM in his area.

The grinding machine went through scheduled maintenance. All calibration tools were calibrated and controlled by the tooling sector.

According to the professionals, the manuals used by the OM brought a description considered superficial of the tasks, defining only the flow of what would have to be done. For them, the manuals did not offer enough support for performing the overhaul service.

According to data collected, Boeing's maintenance manuals had different guidelines for the same service, such as the use of penetrating liquids.

The OM was not aware, until the date of this accident, about the occurrence of two events similar to this one, involving aircraft of the same model.

The inspection of the grinding services was performed visually, based on the specification of the item received, that is, the verification of the part was done according to what the owner had reported.

The training for this function was carried out in a practical way, in which a professional, considered to be more experienced, followed the work done by the beginner.

The OM professional who checked the landing gear of the crashed aircraft had been with the company for more than ten years and, for the past three years, served as an inspector.

The working hours at the OM were considered by the interviewees from the different sectors as quiet, with no work overload.

1.18 Operational information.

It was a regular passenger flight, for which the aircraft had been prepared within the weight and balance limits specified by the manufacturer, in order to comply with the SBSP to SBCF section.

The copilot was the PF of that flight, which went on without any abnormality until the moments before the ground touch at the Confins Aerodrome.

The instrument approach procedure used by the crewmembers was the SBCF ILS K RWY 16.

For landing, the aircraft was configured with flaps deflected at 30º and its total weight was approximately 127,600lb (~ 57,850kg).

The Tancredo Neves Aerodrome operated under visual flight conditions.

When the aircraft was in the final approach, the Confins TWR controller reported a 060º wind, with 5kt and 1025hPa of altimeter adjustment.

The flight data recorders registered that, at the moment of touch, the aircraft was at a speed of approximately 139kt, with a descent rate of around 780ft / min.

The vertical acceleration recorded in the FDR, at the moment of touch, was 1.48G, with the right landing gear being the first to touch the ground.

Based on the continuous monitoring of flight data, through the MOQA, the operator had agreed parameters for the adoption of maintenance procedures.

Thus, the operator defined actions to be performed in the case of landings registration with load factors above: 1.65G (Severity Class 1), 1.80G (Severity Class 2) and 2.00G (Severity Class 3).

The Investigation Team had access to all records of exceedances (extrapolation of parameters) of vertical acceleration at the landing of this aircraft, since its last overhaul, verifying that, only in February 2018, there was an overrun of the limit defined by the manufacturer, when recorded a landing with 2.17G load.

At that time, the maintenance procedures provided for the hard landing inspection were carried out and, with no damage identified, the plane was released for normal operation.

Returning to the context of the present accident, it was found that the aircraft had a pitch of 3º (pitch up), 1.5º of bank angle (rolling) to the right and 0.3º of drift angle (yaw) to the left, at the time of touching the ground in SBCF.

From the recordings of the cabin environment, it was possible to identify a strong noise when the aircraft touched the ground. Such a noise was reported by the crew as a metallic sound, which gave the impression of having been produced by a metal-to-metal beat.

According to the information provided, despite the loud noise, the crew did not experience any abnormal impact of the aircraft on the ground during landing.

One of the flight attendants associated the noise heard on landing with a condition of tail strike collision and, therefore, reported her perception to the commander.

Based on the flight attendant's report, as soon as he parked the aircraft, the commander asked the maintenance team to inspect the plane's warp, to see if there were any marks that could confirm the crewmember's suspicion.

During the inspection, the maintenance team found that there was no evidence of a collision of the aircraft's tail. However, a hydraulic leak was identified in the right main landing gear.

Upon being informed about the leakage of hydraulic fluid, the PR-GGD commander recorded the occurrence of hard landing in the logbook, so that a more detailed inspection could be carried out on the aircraft.

From this more detailed visual inspection, the maintenance team identified substantial damage to various components of the landing gear and areas adjacent to it, as described in section 1.3.

In addition to reporting the event in the logbook, the commander immediately reported the occurrence to the company's Operational Safety sector, so that the first steps regarding the investigation of the event could be taken.

1.19 Additional information.

The research carried out by the Investigation Team identified two occurrences, in India, with characteristics similar to those of this event and with Final Reports already published.

The first event took place on 13APR2015, at the Khajuraho Aerodrome, involving the VT-JGA aircraft (B737-800). In this occurrence, about fifteen seconds after the touch, during the post-landing run, the aft trunnion pin of the aircraft's left landing gear broke, causing subsequent damage, highlighted in Figures 34 and 35, obtained from the Final Report issued by the Indian investigative authority, the Directorate General of Civil Aviation (DGCA).

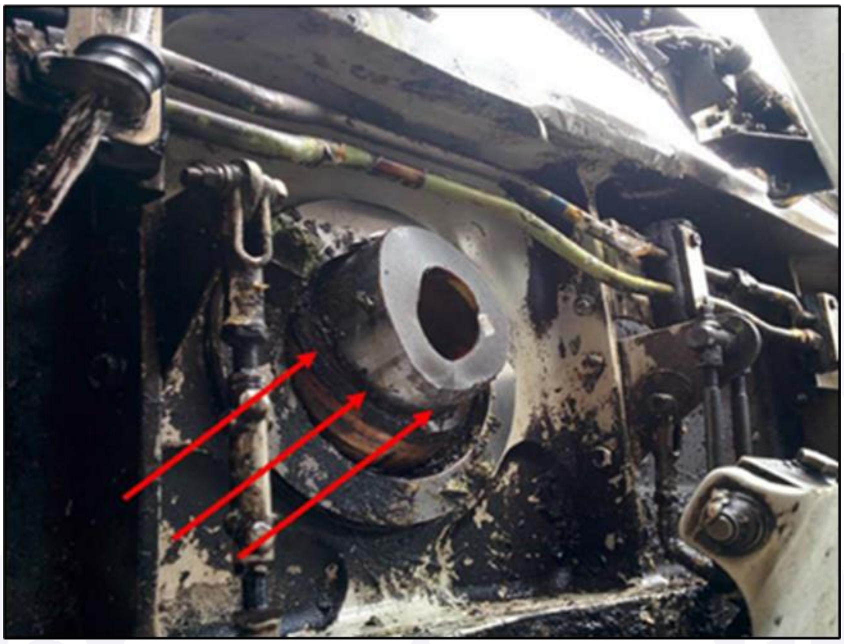

Figure 34 - Detail of the aft trunnion pin on the left landing gear of the VT-JGA aircraft.
Source: Final Investigation Report on Accident to M/s Jet Airways (Pvt.) Ltd. Boeing B 737-800 Aircraft VT-JGA at Khajuraho Airport.

Figure 35 - Damage to the wing of the VT-JGA aircraft after the break of the aft trunnion pin.
Source: Final Investigation Report on Accident to M/s Jet Airways (Pvt.) Ltd. Boeing B 737-800 Aircraft VT-JGA at Khajuraho Airport.

During the investigations, it was found that the greatest vertical acceleration recorded on landing was 1.65G.

Information about the aft trunnion pin SN E2410 installed on the collapsed landing gear of the VT-JGA aircraft:

- Date of installation: 30APR2012;
- TSN: 37,126 flight hours;
- TSI: 8,895 flight hours;
- CSN: 27,429 cycles; and
- CSI: 6,724 cycles.

The Final Report mentioned that the left landing gear aft trunnion pin failed due to overload after fatigue crack propagation. The crack originated in the area affected by the heat, where there was excessive grinding during the general overhaul. The initial crack growth was characterized as intergranular (aided by a hydrogen embrittlement mechanism) until fatigue took over.

The fracture characteristics are shown in Figure 36.

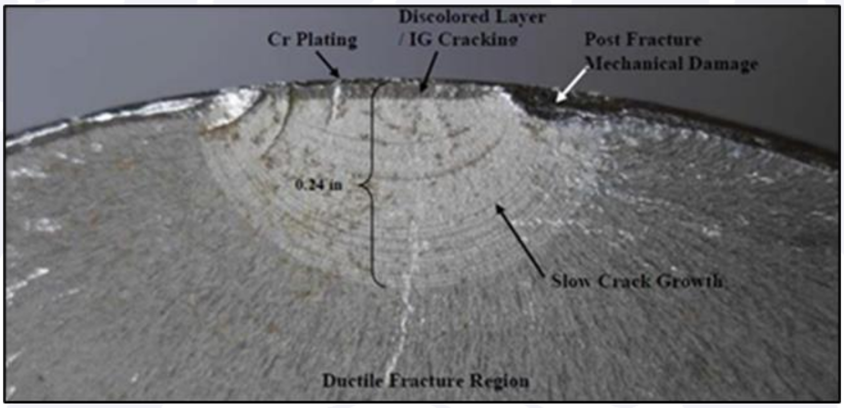

Figure 36 - Fracture characteristic of the aft trunnion pin SN: E2410 that was installed on the VT-JGA aircraft.
Source: Final Investigation Report on Accident to M/s Jet Airways (Pvt.) Ltd. Boeing B 737-800 Aircraft VT-JGA at Khajuraho Airport.

The second event took place, on 03MAR2016, at the Mumbai Aerodrome, involving the aircraft VT-JGD (B737-900).

In this event, when the aircraft was about to clear the runway after landing, the aft trunnion pin SN 2430 (Figure 37), installed on the right landing gear, broke.

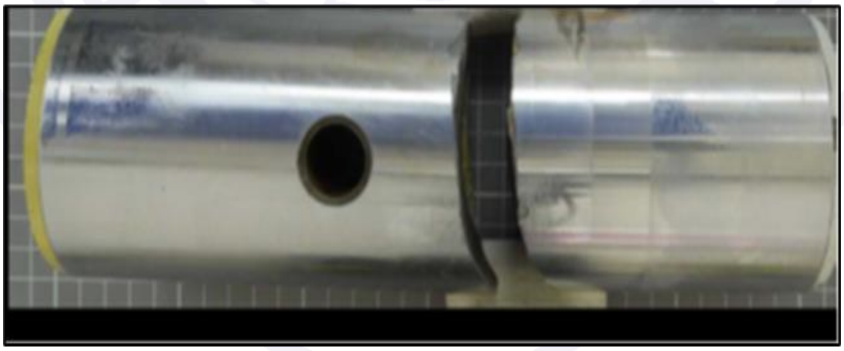

Figure 37 - Detail of the fractured aft trunnion pin SN 2430 that was installed on the right landing gear of the VT-JGD aircraft.
Source: Final Investigation Report on Accident to M/s Jet Airways (India) Ltd. B-737-900 Aircraft VT-JGD at Mumbai Airport.

As a consequence, subsequent damage was caused to the upper surface of the right wing of the VT-JGD aircraft (Figure 38).

Figure 38 - Damage caused to the right wing's upper surface of the VT-JGD aircraft as a result of the break of the aft trunnion pin.
Source: Final Investigation Report on Accident to M/s Jet Airways (India) Ltd. B-737-900 Aircraft VT-JGD at Mumbai Airport.

During the investigations, it was found that the highest vertical acceleration recorded on landing was 1.44G.

Information about the aft trunnion pin SN E2430 that was equipped in the collapsed landing gear of the VT-JGD aircraft:

- Date of installation: 06AUG2013;
- TSN: 36,963 flight hours;
- TSI: 7,747 flight hours;
- CSN: 21,914 cycles; and
- CSI: 4,664 cycles.

The VT-JGA Final Report showed that the right landing gear aft trunnion pin failed due to damage from burning the base metal as a result of excessive grinding of the chromium layer, which probably occurred during the last general overhaul.

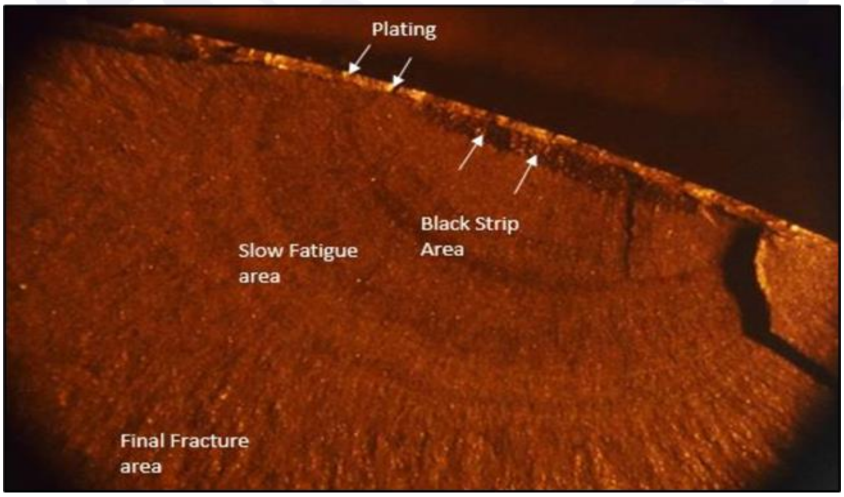

Figure 39 - Fracture characteristic of the aft trunnion pin SN E2430 that was installed on the VT-JGD aircraft.
Source: Final Investigation Report on Accident to M/s Jet Airways (India) Ltd. B-737-900 Aircraft VT-JGD at Mumbai Airport.

1.20 Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

The aircraft took off from the Congonhas Aerodrome (SBSP), to the Tancredo Neves Aerodrome (SBCF). The flight took place without abnormalities until the moment of landing.

During the touch of the landing gear on the ground at SBCF, the crewmembers heard a loud noise described as a metallic sound.

According to the recorded data, it was found that the vertical acceleration at the moment of touch was around 1.48G and the vertical speed close to the moment of touch was approximately 780ft / min, with the right landing gear being the first to have touched the ground.

Due to the suspected occurrence of a tail strike, the commander requested an inspection of the aircraft. In this survey, the maintenance team found that there was no evidence of a collision of the aircraft's tail. However, a hydraulic leak in the right main landing gear was identified and reported.

Thus, the commander registered in the logbook the occurrence of hard landing, so that a more detailed inspection of the aircraft could be carried out.

Subsequently, damage was found in the landing gear area (SN MAL05154Y2498), as described in Section 1.3 of the report. It was found that the aft trunnion pin, SN E4798, installed on the aircraft's right landing gear, was fractured in its entire transversal section.

The examinations performed on the aft trunnion pin, SN E4798, with the presence of representatives from the CENIPA and the NTSB, revealed, among other aspects described in Section 1.16 - Tests and research that:

- the fracture started in an area shown in Figure 17 and, in greater detail, in Figure 18;

- a dark area was observed, characterized by a burning of the base metal or OTM;

- metallographic tests of residual stress, microhardness and chemical tests showed a change in the mechanical properties of the part in the area damaged by the burning of the base metal, which caused a weakening of the mechanical properties of the part;

- the initial crack had an intergranular characteristic; and

- the inspections performed on the chromium layer showed that there was damage in the same area where the OTM was identified. Figure 24 shows the result of the inspection by penetrating liquid and Figure 27 shows the result of the inspection by magnetic particles after cutting the section of interest of the aft trunnion pin SN E4798.

Thus, it was inferred that, during the general revision process of the aft trunnion pin SN E4798, the excess temperature, resulting from excessive grinding of the chromium layer, caused damage to the base metal and cracks in the chromium layer.

The process of replacing the landing gear assembly, including the aft trunnion pin SN E4798, is detailed as follows.

On 27APR2016, the landing gear set MAL05154Y2498 was removed from the PR-GGB aircraft with 20,970 cycles, to perform the general overhaul due to the number of General Overhaul cycles (21,000 cycles).

The overhaul of the landing gear was carried out by the company TAP *Manutenção e Engenharia Brasil* S.A., from 05MAY2016 to 01JUL2016.

The first stage of the General Overhaul consisted of the preliminary inspection. Subsequently, disassembly, cleaning, paint removal and identification of the controlled items that made up the MLG were carried out. In these steps, no significant discrepancies were found.

The removed components were then sent to specific overhaul procedures according to their own characteristics. Among these components, the aft trunnion pin PN 161A1192-4, SN E4798 stood out.

In relation to the maintenance performed in this item, initially, the tasks transcribed in Figure 9 were performed, in summary, stress relief procedure, visual inspection and by magnetic particles and compliance with items related to SB 737-32-1448. The stress relief procedure aimed at reducing residual stresses resulting from the operation of the landing gear when installed on the aircraft.

In the FSO fields, referring to visual and magnetic particle inspections, no damage or discrepancies were recorded in the aft trunnion pin SN E4798.

Regarding the detailed inspection referring to SB 737-32-1448, the following discrepancy was recorded: bubbles in the chrome (Bubbles on Chrome). According to the OM mechanics, this condition was a sign of internal corrosion of the aft trunnion pin, that is, in the base metal of the pin.

It is noteworthy that the visual inspections were performed by different OM professionals and, comparing the procedures performed, it was identified that there was a lack of uniformity between the inspection criteria, since different results were obtained in similar procedures.

These discrepancies possibly occurred due to the absence of clear guidelines in the documents provided by the OM to maintainers regarding the criteria for the visual inspections.

Thus, considering that one of the inspections indicated possible corrosion of the base metal of the aft trunnion pin SN E4798, the OM decided to carry out a procedure to remove the protective chrome layer from the pin.

It was observed, after removing the protective layer, that the Nital-Etch inspection did not identify burning areas, constituting an indication that there was no overtemperature damage to the base metal.

It was also verified that the inspection by magnetic particles showed no cracks, being indicative that the base metal had no flaws, such as, for example, those resulting from corrosion.

Thus, based on the records of the inspections performed, the machining of the base metal on the aft trunnion pin, SN E4798, would not be necessary.

Although the result of the inspections does not indicate damage to the base metal, the OM proceeded to machining the pin, and it is not possible to clarify the reason for carrying out this procedure.

During the machining, approximately six thousandths of an inch of material was removed (as observed by the measurements before and after machining, item 008 of Figure 10 and item 010 of Figure 11), with the part remaining above the minimum dimensions.

After the machining, stress relief procedures, inspection to check for possible damage by overtemperature and inspection by magnetic particles were carried out to check for cracks in the base metal.

According to the FSO records, neither inspection indicated damage to the base metal, revealing that machining did not introduce flaws in the part.

Then, the shot peening procedure was carried out, in order to increase the surface resistance of the piece, as well as the galvanic procedures of chromium and cadmium in order to remake the protective layers of the part.

After each galvanic bath, the part should be taken to the oven for a hydrogen relief procedure. It was possible to perform a single hydrogen release for more than one galvanic bath, as long as certain criteria established in the manuals were respected.

In the FSO records, it is possible to observe an intersection between the period that the part was in the application of cadmium and the period related to the hydrogen relief of the chromium bath (items 016 and 015 of Figure 12, respectively).

In view of the fact that it is not possible to carry out these two processes concurrently, it was considered that the FSO was filled in incorrectly.

The chromium layer applied in this process did not reach the necessary dimensions, and its removal and application of a new galvanic bath was adopted as a solution.

Analyzing the records of the second application of the chromium layer, it was found that the duration of the galvanic bath (two hours) would not be consistent with the chromium thickness obtained. Thus, analyzing the available data, the possibility was raised that there was the application of overlapping chrome layers.

However, it was not possible to confirm this hypothesis. The OM that performed the service claimed an error in filling in the respective field of the FSO.

The measurement of the part showed that the expected thickness on the second galvanic bath was reached. Thus, the review procedures continued and the aft trunnion pin, SN E4798, was taken to grind the chrome layer, in order to standardize the external diameter of the part.

The examinations, performed after the occurrence, for penetrating liquid and magnetic particles, indicated the presence of an area of the chromium layer with excessive wear. The damage could be associated with excessive wear during the chrome layer grinding process. The heat produced in this process may have been conducted to the base metal, causing damage by overtemperature, weakening the aft trunnion pin.

In a subsequent visit to the OM, it was found that the machines and equipment used were in accordance with those provided in the reference manuals.

Therefore, with the exception of registration errors in the FSO fields, the failure identified in the excessive rectification of the aft trunnion pin, SN E4798, presented itself as an isolated fact in the process. Systemic non-conformities were not observed in the review of the aft trunnion pin by the OM.

In addition, it was not possible to obtain more accurate information about a specific failure, since the person responsible for rectification had retired.

After the chromium grinding procedure, quality inspections were prevised, in order to avoid the release of the part with excessive wear resulting from this task.

As the component was covered with the protective chromium layer, it was no longer possible to carry out the inspection by Nital-Etch, since the solution should be applied directly to the base metal.

Thus, the Boeing Company's SOPM 20-10-04 provided the following guidelines regarding quality control after the chrome layer was rectified:

- visual inspection;

- examination using the Barkhausen method (optional);

- inspection by magnetic particles;

- penetrating liquid inspection (if specified by other instructions); and

- examination using an inspection instrument to detect cracks (in addition to other inspections).

In this sense, the OM performed only visual and magnetic particle inspection, considering that the examination by the Barkhausen method was optional.

There was no specification for conducting inspection by penetrating liquid in the aft trunnion pin in the landing gear review manuals and the examination with inspection instrument for detection of cracks had an additional character.

In the FSO field, the result of the inspection by magnetic particles was recorded as **"No Cracks"**. However, it was found that this inspection was less effective for the detection of cracks after rectification of the chromium layer, since the examination for magnetic particles in the fractured aft trunnion pin, performed after the occurrence, did not present significant indications of presence of cracks in the chrome layer.

The penetrating liquid examination showed better results in the visualization of cracks in the fractured part, thus revealing greater efficiency in detecting this type of failure arising from an excessive grinding of the chromium layer in the aft trunnion pin.

Thus, it can be inferred that the inspection by dye penetrant presents better results regarding the detection of cracks after an excessive grinding of this type of component, which would be an indication of possible burning of the base metal.

Therefore, it is considered that the quality control methods after the grinding of the chrome plated of the aft trunnion pin, in particular related to the mandatory inspection provided by the manuals, could be improved.

In addition, the manual used as a support by maintenance professionals delegated to the shops the adoption of the procedures that were most appropriate to them.

The non-standardization of the chain of procedures to be followed, containing the necessary examinations for certain situations and, since these procedures are technically based, may have given scope for carrying out examinations in which the maintenance team felt safer to perform, not being fully according to the needs of the demand of this aircraft.

In this context, it was found that there were failures to monitor throughout the process of maintenance services performed, given the inconsistencies found in various records of the steps performed.

The PR-GGD aircraft flew 6,834 hours with the SN MAL05154Y2498 landing gear installed after overhaul, performing 3,969 landing and take-off cycles until the aft trunnion pin SN E4798 failed.

During this period of operation, there were 32 class-1 landings, that is, with a load factor greater than 1.65 G, which were not considered critical for the structural point of view of the aircraft.

On 22DEC2016, there was a landing with a load factor of 1.92 G receiving a grade 2 severity level, that is, with a load factor greater than 1.80 G.

On 27FEB2018, the PR-GGD aircraft landed at the Congonhas Aerodrome (SBSP) with a load factor of 2.17 G, receiving a class-3 severity level, that is, a load factor above 2.0 G.

The tasks prevised after class-3 landing were carried out and all items inspected were within the limits specified by the manufacturer.

However, the fragility of the part, due to the burning of the base metal, may have allowed a landing with a higher load factor to cause a crack with an intergranular characteristic, initiating the fracture process of the piece.

Crack propagation occurred through the fatigue mechanism, as a result of the cyclic loads of successive landings performed after the appearance of the initial crack.

The fatigue crack of the aft trunnion pin, SN E4798, reduced the effective area to withstand landing loads by up to 40% of the pin thickness, resulting in overload failure with a load less than the material's resistance capacity.

There were two prior occurrences related to fractures of the aft trunnion pin.

However, despite the similarity of the occurrences, it was not possible to establish a correlation between the number of cycles and the number of hard landings with the possible flaws in the burning of the base metal of the aft trunnion pin.

3. CONCLUSIONS.

3.1 Facts.

a) the pilots had valid CMAs;

b) the pilots had valid B739 aircraft type 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) during landing in SBCF, a loud noise was heard at the moment of the aircraft touched the ground;

i) a leakage of hydraulic fluid was identified in the post-landing inspection;

j) the commander recorded the occurrence of hard landing in the logbook;

k) there was a break in the aft trunnion pin of the right main landing gear;

l) a part of the fractured aft trunnion pin was located on the SBCF runway;

m) the highest vertical acceleration recorded in the FDR, at the time of landing, was 1.48 G;

n) the landing gear, PN 161A1100-54, SN MAL05154Y2498, had been overhauled by the company TAP *Manutenção e Engenharia Brasil* S.A.;

o) the aft trunnion pin, PN 161A1192-4, SN E4798, was part of the landing gear PN 161A1100-54, SN MAL05154Y2498;

p) heat damage was found on the base metal at the fracture site of the aft trunnion pin PN 161A1192-4, SN MAL05154Y2498;

q) the aircraft had substantial damage; and

r) all occupants left unharmed.

3.2 Contributing factors.

- **Aircraft maintenance – undetermined.**

It is possible that, during the process of grinding the chrome layer of the aft trunnion pin SN E4798, excessive wear occurred, which generated heat, burning and weakening of the base metal of the part.

- **Design – undetermined.**

It is possible that the mandatory inspections provided by the Standard Overhaul Pratices Manual, Grinding of Chrome Plated Parts 10-20-04, item 4, Quality Control, after grinding the chrome layer, did not have the necessary effectiveness to detect a burn in the base metal occurred during an overhaul caused by an excessive grinding on this layer of the Aft Trunnion Pin.

- **Support systems – undetermined.**

It is possible that the material provided to maintainers to perform the visual inspection tasks did not contains clear procedures and criteria regarding the need to repair the pin.

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):

A-119/CENIPA/2018 - 01 **Issued on 11/16/2021**

Work with the Boeing Company, manufacturer of the aircraft, in order to verify the effectiveness of the mandatory quality control inspections to be applied to the aft trunnion pin and similar parts, after the chrome plated grinding process, mainly with regard to the provisions of the Standard Overhaul Practices Manual, Grinding of Chrome Plated Parts 20-10-04, item 4, Quality Control.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

The aircraft operator preventively replaced all aft trunnion pins in its fleet that had already been subjected, at any point in their useful lives, to overhaul procedures at TAP-ME.

On November 16th, 2021.

ANNEX A – COMMENTS BY THE STATES PARTICIPATING IN THE INVESTIGATION

In compliance with the provisions of the Chapter 6, item 6.3, of the Annex 13 to the Convention on International Civil Aviation, the States participating in this investigation had the opportunity to make their comments concerning the content of this final report.

Through the National Transportation Safety Board (NTSB), the United States of America forwarded the comments of the Boeing Company about the content of this Final Report.

All comments deemed pertinent have been included in the body of this report. The following are comments that have not been incorporated or have been partially incorporated.

COMMENT 3

Text to be corrected: (Chapter 1, Page 29, Lines 18-20)

According to the professionals, the manuals used by the OM brought a description considered superficial of the tasks, defining only the flow of what would have to be done. For them, the manuals did not offer enough support for performing the overhaul service.

Proposed text / NTSB opinion:

In addition to the requirements specified in Boeing's CMM and SOPM, manufacturers rely on overhaul shops to use industry standards, shop best practices, and shop experience to perform overhauls.

Propose omitting lines 18-20

CENIPA's Opinion:

Not incorporated

CENIPA's Argumentation:

The portion of the text shows an opinion from the OM maintainers.

COMMENT 6

Text to be corrected: (Chapter 2, Page 35, Lines 23-25)

These discrepancies, possibly, occurred due to the absence of clear guidelines regarding the inspection criteria, both those resulting from the SB and those arising from the usual procedures for general review of the item.

Proposed text / NTSB opinion:

The SB performs a visual inspection. If discrepancies are noted, a detailed inspection is performed to determine if the overhaul or replacement of parts is required. Per the SB, an aft trunnion pin overhaul is performed per Boeing CMM 32-11-09, Repair 3-1. This is the same CMM used in a typical aft trunnion pin overhaul, thus there should be no confusion between SB and overhaul guidelines.

Propose omitting the premise of the absence of clear guidance.

CENIPA's Opinion:

Original text modified alternatively.

CENIPA's Argumentation:

The SB inspection criteria were compared with the flowchart of CMM 32-00-05, section 601. The SB contains a detailed inspection definition which demands an intensive examination of the part, besides of to suggest the use of aids, such as mirrors and magnification lens. Such guidelines are not included in CMM 32-00-05.

However, reviewing the original text of the report, it was considered that the guidelines contained in the Maintenance Tasks (FSO) for the item would be more decisive for obtaining different judgments when two equivalent visual inspection procedures were performed.

Therefore, the excerpt was modified as follows:

These discrepancies possibly occurred due to the absence of clear guidelines in the documents provided by the OM to maintainers regarding the criteria for the visual inspections.

COMMENT 7

Text to be corrected: (Chapter 2, Page 37, Lines 18-23)

Therefore, it can be considered that the inspection by magnetic particles in the aft trunnion pin, SN E4798, performed by the pin's repairing OM, would not have detected cracks in the chromium layer in the case of an excessive grinding procedure.

Thus, it is considered the hypothesis that the examination by penetrating liquid may present better results in the detection of cracks after an excessive grinding of this type of component, which would be an indication of possible burning of the base metal.

Proposed text / NTSB opinion:

Correct, the dye penetrant inspection method will detect cracks in the chrome outer surface. However, it will not detect overheat / burn condition of the base metal.

CENIPA's Opinion:

Original text modified alternatively.

CENIPA's Argumentation:

The original text was changed to emphasize aspects relating to quality control after grinding the chrome plated.

These inspections aim to verify the occurrence of cracks in the chromium layer that can be considered as an indication of a possible burning of the base metal.

Therefore, the excerpt was modified as follows:

Thus, it can be inferred that the inspection by dye penetrant presents better results regarding the detection of cracks after an excessive grinding of this type of component, which would be an indication of possible burning of the base metal.

Therefore, it is considered that the quality control methods after the grinding of the chrome plated of the aft trunnion pin, in particular related to the mandatory inspection provided by the manuals, could be improved.

COMMENT 10

Text to be corrected: (Chapter 3, Page 39, Lines 7-10)

It is possible to infer that the inspection by magnetic particles performed by the SN E4798 aft trunnion pin's repairing OM, during the general overhaul, would not have detected the presence of cracks resulting from an excessive grinding procedure in the chromium layer.

Proposed text / NTSB opinion:

Magnetic particle inspection is for detecting cracks in the base metal. It will detect cracks if they are present when performed after the grinding. It will not detect heat damage, or cracks that later result from heat damage or embrittlement.

CENIPA's Opinion:

Original text modified alternatively.

CENIPA's Argumentation:

The original text was modified to emphasize aspects relating to quality control after grinding the chrome plated.

It is possible that the mandatory inspections provided by the Standard Overhaul Pratices Manual, Grinding of Chrome Plated Parts 10-20-04, item 4, Quality Control, after grinding the chrome layer, did not have the necessary effectiveness to detect a burn in the base metal occurred during an overhaul caused by an excessive grinding on this layer of the Aft Trunnion Pin.