COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
IG - 190/CENIPA/2018

OCCURRENCE:	**SERIOUS INCIDENT**
AIRCRAFT:	**PT-MUG**
MODEL:	**777-32WER**
DATE:	**20DEC2018**

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 20DEC2018 serious incident with the 777-32WER aircraft model, registration PT-MUG. The accident was classified as “[SCF-NP] System/Component Failure or Malfunction Powerplant”.

During the leveling, the crew identified the message ELEC BACKUP SYS and, after consulting the Quick Reference Handbook (QRH), the system was restarted, however, the message remained there.

Approximately eleven minutes after the ELEC BACKUP SYS message, both Pilot Flying (PF) and Pilot Monitoring (PM) lost information of the Primary Flight Display (PFD), from the Navigational Display (ND) and the two Engine Indicating and Crew Alerting Systems (EICASs). There was also a simultaneous loss of the primary lighting in the passengers’ cabin and the crew’s cabin.

After a few seconds, the PFD and the ND of the PF were restored, as well as those of the PM. The EICAS screens, approximately thirty seconds later, have been restored.

The crew activated the Auxiliary Power Unit (APU) and consulted the Synoptic screen of the electrical system to verify the aircraft's power configuration. The EICAS screen displayed the left and right Integrated Drive Generators (IDG), the APU generator and the left Backup Generator (BUG) with available power. The right BUG had an amber “X”, indicating that it was unavailable as a power source.

The Synoptic of the electrical system indicated that the buses did not supply power from any available source.

The aircraft presented the message RAT DEPLOYED and the power generation started to be provided by the Standby system.

The crewmembers decided to make an emergency landing, above the maximum certificated landing weight, at the Tancredo Neves Aerodrome (SBCF), Confins – MG. fter the overweight landing, excess heat from the main landing gear brakes caused the tires of the main landing gear to deflate through the thermal fuse.

The aircraft had minor damage.

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

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

AC	Alternating Current
ACC-BS	Area Control Center - Brasilia
AMM	Aircraft Maintenance Manual
ANAC	Brazil's National Civil Aviation Agency
APOC	Airport Operations Center
APP-BH	Approach Control – Belo Horizonte
APU	Auxiliary Power Unit
ATC	Air Traffic Control
BPCU	Bus Power Control Unit
BTB	Bus Tie Breaker
BUC	Backup Converter
BUG	Backup Generator
CA	Airworthiness Certificate
CCB	Converter Circuit Breaker
CENIPA	Aeronautical Accident Investigation and Prevention Center
CIV	Pilot's Flight Logbook
CMA	Aeronautical Medical Certificate
CMM	Component Maintenance Manual
COE	Emergency Operations Center
CSN	Cycles Since New
CTR	Control Zone
CVR	Cockpit Voice Recorder
DC	Direct Current
DP	Differential Protection
EFB	Electronic Flight Bag
EGLL	ICAO Location Designator – Heathrow International Airport, London - England
EICAS	Engine Indicating and Crew Alerting System
ELMS	Electrical Load Management System
FAA	Federal Aviation Administration
FCDC	Flight Control Direct Current
FDR	Flight Data Recorder
FIM	Fault Isolation Manual
GCR	Generator Control Relay
GCS	Generator Control Switch
GCU	Generator Control Unit
IDG	Integrated Drive Generator

IFRA	Instrument Flight Rating - Aircraft
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
KVA	Kilo Volt-Ampere
LGE	Foam Generating Liquid
METAR	Aviation Routine Weather Report
NTSB	National Transportation Safety Board (USA)
OPAS	Overhead Panel ARINC-629 System
PCM	Commercial Pilot License - Airplane
PF	Pilot Flying
PMG	Permanent Magnet Generator
PLA	Airline Pilot License – Airplane
PLEM	Aeronautical Emergency Plan
PM	Pilot Monitoring
PN	Part Number
PPR	Private Pilot License - Airplane
PRAI	Inoperative Aircraft Removal Plan
PSA	Power Supply Assembly
QRH	Quick Reference Handbook
RAT	Ram Air Turbine
ROLS	Remote Oil Level Sensing
RS	Safety Recommendation
SBCF	ICAO Location Designator – Tancredo Neves Aerodrome, Confins - MG
SBGR	ICAO Location Designator – Governador André Franco Montoro Aerodrome, São Paulo - SP
SCI	Fire Fighting Section
SN	Serial Number
TBB	Transfer Bus Breaker
TPR	Aircraft Registration Category of Regular Public Transport
TRU	Transformer Rectifier Unit
TWR-CF	Tancredo Neves Aerodrome Control Tower, Confins - MG
UTC	Universal Time Coordinated
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
VSCF	Variable Speed Constant Frequency

1. FACTUAL INFORMATION.

Aircraft	**Model:** 777-32WER **Registration:** PT-MUG **Manufacturer:** Boeing Company	**Operator:** TAM Airlines S.A.
Occurrence	**Date/time:** 20DEC2018 - 0343 UTC **Location:** Tancredo Neves Aerodrome (SBCF) **Lat.** 19°37'28"S **Long.** 043°58'19"W **Municipality – State:** Confins – MG	**Type(s):** "[SCF-NP] System/Component Failure or Malfunction Powerplant" **Subtype(s):** NIL

1.1 History of the flight.

The aircraft took off from the Governador André Franco Montoro Aerodrome (SBGR), São Paulo - SP, to the Heathrow Aerodrome (EGLL), London - England, at about 0230 (UTC), in order to perform a public air transport flight regular, with two commanders, two co-pilots, twelve flight attendants and 339 passengers on board.

With about seventeen minutes of flight, during leveling, the ELEC BACKUP SYS warning messages appeared. The crewmembers performed the procedures described in the Quick Reference Handbook (QRH) for this fault. Eleven minutes later, there were failures in the electrical system with the compromise of other aircraft systems. The crew decided to proceed to an emergency landing at Tancredo Neves Aerodrome (SBCF), Confins - MG.

The touch was performed with the aircraft above the Overweight Landing. There was an overheating in the braking system by emptying the tires of the main landing gear through the thermal fuse.

The aircraft had minor damage. All crewmembers and passengers left unharmed.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	-	-
Minor	-	-	-
None	16	339	-

1.3 Damage to the aircraft.

The aircraft showed locking and damage to the brake and wheel sleeves. Due to Overweight Landing, there was overheating of the tires and consequent deflation (Figure 1).

Figure 1 - Image of the aircraft and tires.

Damage was also found to the W8821 cabling and to the D7232 connector related to the events of the multiple failures that occurred in flight (Figure 2).

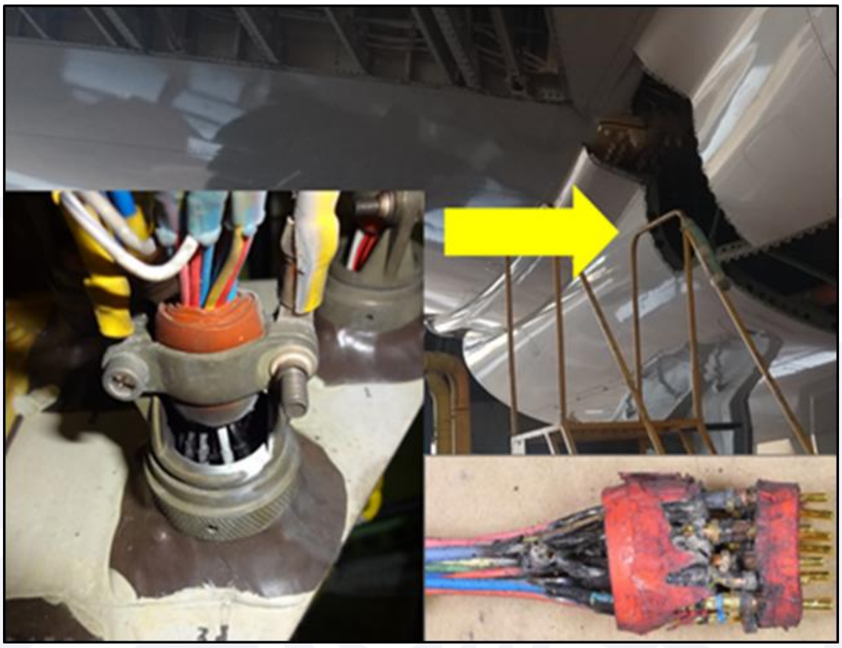

Figure 2 - Location and damage to the D7232 connector.

1.4 Other damage.

None.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Flown Hours		
	Pilot	2nd Copilot
Total	22.200:00	10.000:00
Total in the last 30 days	55:10	67:20
Total in the last 24 hours	02:00	02:00
In this type of aircraft	7.755:00	4.330:25
In this type in the last 30 days	55:10	67:20
In this type in the last 24 hours	02:00	02:00

N.B.: The data related to the flown hours were obtained through the Pilots' Flight Logbook records (CIV). The Commander and the 2nd Copilot were operating the aircraft during the sequence of events described in this report.

Flown Hours		
	Master Commander	1st Copilot
Total	29.000:00	9.159:40
Total in the last 30 days	38:25	28:25
Total in the last 24 hours	02:00	02:00
In this type of aircraft	4.806:30	4.310:40
In this type in the last 30 days	38:25	28:25
In this type in the last 24 hours	02:00	02:00

N.B: The data related to the Master Commander e do 1st Copilot were obtained through the Pilots' Flight Logbook records (CIV).

1.5.2 Personnel training.

The Master Commander took the PPR course at the Bragança Paulista Aeroclub – SP, in 1976.

The pilot took the PPR course at the Brasil's Aeroclub, Rio de Janeiro - RJ, in 1990.

The 1st copilot took the PPR course at the Jundiaí Aeroclub – SP, in 2001.

The 2nd copilot took the PPR course at the Piracicaba Aeroclub – SP, in 2004.

1.5.3 Category of licenses and validity of certificates.

The Master Commander had the PLA License and had valid B777 aircraft type Rating (which included the 777-32WER model) and IFRA Rating.

The pilot had the PLA License and valid B777 e IFRA Ratings.

The 1st copilot had the PCM License and valid B777 e IFRA Ratings.

The 2nd copilot had the PCM License and valid B777 e IFRA Ratings.

1.5.4 Qualification and flight experience.

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

1.5.5 Validity of medical certificate.

The pilots had valid CMAs.

1.6 Aircraft information.

The aircraft, serial number 38888, was manufactured by Boeing Company, in 2012, and it was registered in the TPR category.

The aircraft had valid Airworthiness Certificate (CA).

The technical maintenance records were updated.

The information on the engines installed on the aircraft, on the date of the occurrence, was as follows:

Installed Engines		
Description	Engine n° 1 (LEFT)	Engine n° 2 (RIGHT)
Part Number (PN)	GE90-115BG02	GE90-115BG02
Serial Number (SN)	906543	907201
Date of Installation	27SEPT2018	20NOV2015
Time Since New (TSN)	32.952:55 hours	25.857:30 hours
Time Since Overhaul (TSO)	1.017:25 hours	25.857:30 hours
Cycles Since New (CSN)	3.880	3.041
Cyclos Since Overhaul (CSO)	117	3.041

The information for the Backup Generator (BUG), installed on the right side of the aircraft, and the Backup Converter (BUC), on the date of the occurrence, were as follows:

Electrical System Components		
Description	BUG	BUC
PN	1701768	757183G
SN	21772	AAA4002238
Date of Installation	22NOV2015	18DEC2018
TSN	25.857:30 hours	24.171:05 hours
TSO	25.857:30 hours	16:40 hours
CSN	3.041	2.850
CSO	3.041	3

Electrical System Description

The aircraft's electrical system was responsible for the generation, control and distribution of the electricity supply.

Electricity generation was subdivided into three categories: Main, Backup and Standby.

Within the Main subcategory, the sources of power generation and the supply capacity are shown below:

- Integrated Drive Generator (IDG) Left (120kVA - Kilo Volt-ampere);
- Integrated Drive Generator (IDG) Right (120kVA);
- Auxiliary Power Unit (APU) (120kVA);
- Primary External Source (90kVA); and
- Secondary External Source (90kVA).

The backup power generation source was the BUG, installed one in each engine, with the capacity to supply 20kVA each.

The sources of Standby power generation were the RAT and the main batteries. The RAT had a supply capacity of 7.5kVA and the main batteries 47 Ampere-Hour.

The aircraft loads were prioritized on the main and transfer buses on the left and right, in addition to the Standby bus.

Each bus received power from a source selected from among those that were available. The critical flight control and avionics systems were powered by the Standby bus and had a greater amount of redundancies regarding the available energy sources.

The buses could be powered by different energy sources according to the flight phase and the available energy generation sources.

Other important electrical charges, but not essential for the flight and cabin information, were powered by Transfer Buses and also had increased redundancy in the available energy sources.

Electric loads of lower priority, such as galleys and the entertainment system on board, were operated by the main buses (Main Buses).

Under normal flight conditions, the two main generators or IDG supplied power to all electrical buses on the aircraft.

The electrical system was designed so that, in the event of a failure of both IDGs, the main buses would be de-energized while the transfer and standby buses would be powered by the Backup Generators.

Additional failures of the Backup Generators would de-energize the transfer buses leading to the deployment of the Ram Air Turbine. The RAT used free air flow to turn an electric generator and supply power to the Standby busbars.

The possible power modes were: Ground Power, APU Power, IDG Power, Backup Generator Power and Standby Power.

The APU generator could supply power to the aircraft on the ground or in flight. On the ground, it supplied power through the ground busbars. The APU generator could also power the aircraft alone or share the load with an IDG, Backup Generator or external source.

Powering through the IDGs usually occurred when the engines were running. Each of them supplied power to one side of the electrical system. If an IDG failed, the opposite IDG could power the main buses, while the Backup Converter could use the power of the Backup Generator for the associated transfer bus.

Figure 3 illustrates the distribution of energy through the two IDGs. In the normal flight configuration, the green lines represent the feed by the IDG. The Backup Converter received power from the PMG, components installed inside the Backup Generator.

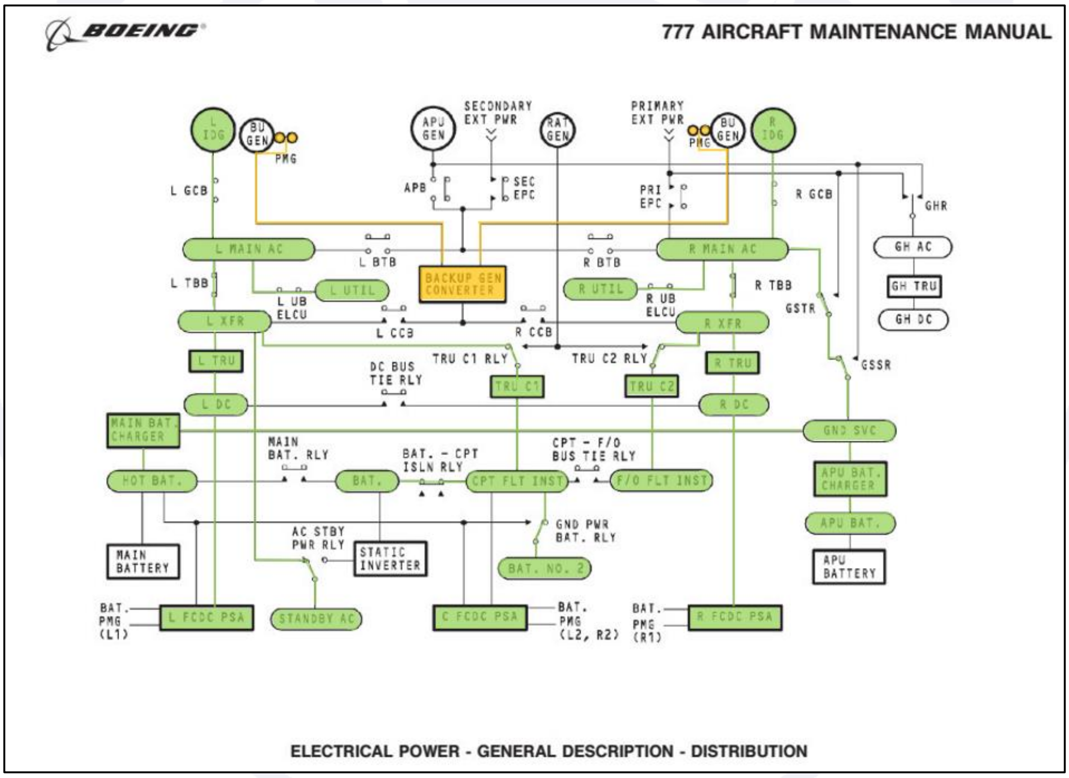

Figure 3 - Distribution of energy through the two IDGs.
Source: Adapted from the Boeing Company's AMM.
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The Backup Generator Power was of a variable speed and frequency type. They worked with the engine speed. The Backup Converter transformed variable frequency input from either Backup Generator and converted it to 3-phase, 115/200 VAC, 400 Hz power to supply the aircraft's electrical system. The Backup Generator supplied power to the left and right transfer buses (L XFR Bus and R XFR Bus) in abnormal conditions and during Autoland operation.

Each Backup Generator included a Permanent Magnet Generator (PMG), which were the primary power source for Flight Control Direct Current - Power Supply Assembly (FCDC - PSA) and Backup Converter.

Figure 4 shows the electricity distribution scheme through the two Backup Generators.

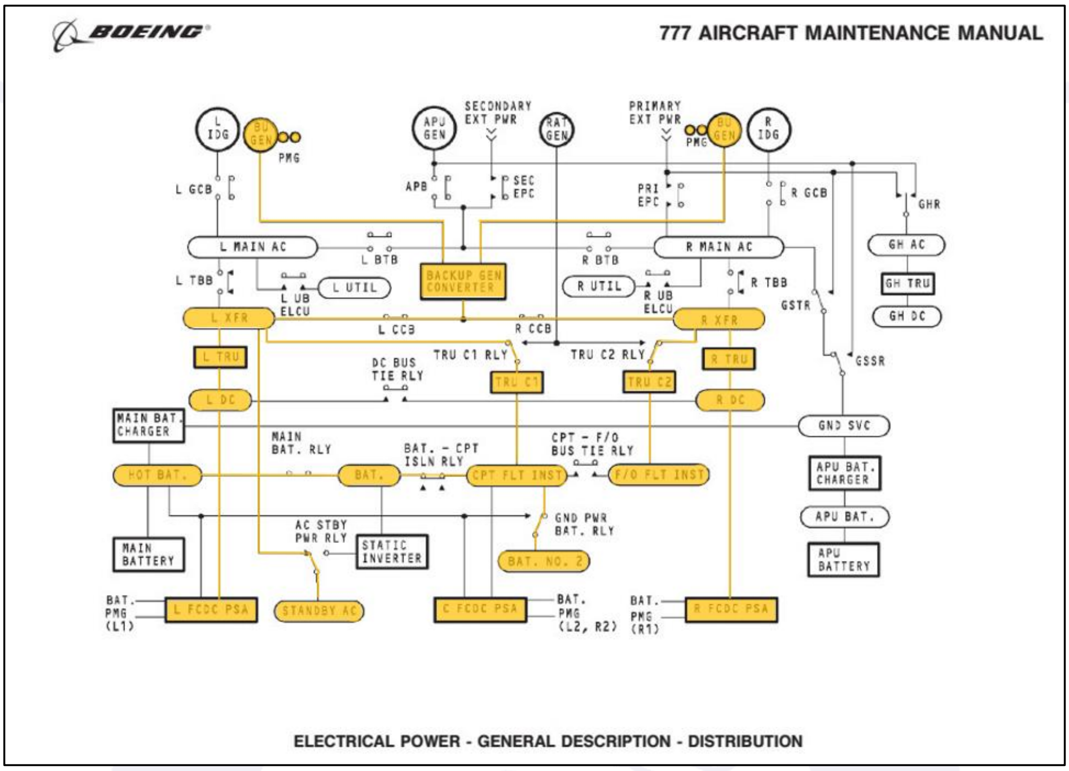

Figure 4 - Distribution of energy through the two Backup Generators.
Source: Adapted from the Boeing Company's AMM.

If all normal sources of energy supply were lost, power would occur through the Standby Power, generator of the RAT, which would supply power to the flight instrument buses. This would be accomplished by the two central TRUs. The flight instrument bus on the left would supply power to the battery and to the Standby AC buses.

Figure 5 illustrates the power distribution in the Standby mode through the RAT generator and the main batteries.

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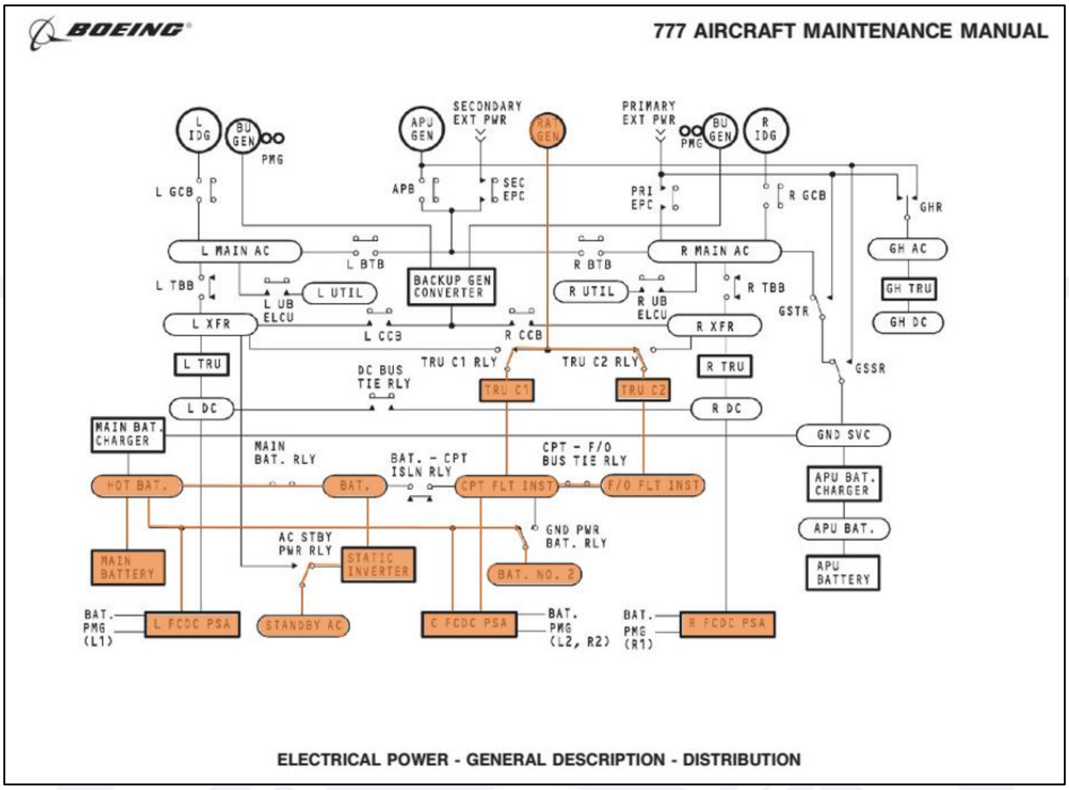

Figure 5 - Power distribution in Standby mode.
Source: Adapted from the Boeing Company's AMM.

If the RAT generator did not start operating, the main batteries would supply power to the battery busbars, the left flight instrument bus and the Standby AC bus.

Description of Power Backup System Components

The main components of the Backup Power Supply System for the B777 aircraft had two Backup Generators (one in each engine) of the VSCF type and the electronic component called Backup Converter.

Each Backup Generator was capable of supplying power at a voltage of 337V to 360V of AC, in a frequency between 957Hz and 1,860 Hz. In addition, each generator had three Permanent Magnet Generators (PMG) that produced power for emergency supply of the Flight control commands and the Backup Converter.

For the two Backup Generators to produce energy, they needed to be demanded by the Backup Converter. This function was called Generator Excitation and was performed using the Backup Converter Voltage Regulator, Exciter Field and Generator Control Relay (GCR).

The Voltage Regulator controlled the supply of the Exciter Fields located in each of the Backup Generators. The Voltage Regulator rectified the AC current of the Backup Converter's power PMG to produce Direct Current (DC) for the Exciter Field, passing through the GCR. The Generator used the Exciter Field current to produce AC current that was sent to the Backup Converter.

The Backup Converter received energy to supply the AC busbars of the Backup Generators, performed the conversion to DC and, subsequently, made the inversion to AC power at a voltage of 115V, three-phase and 400Hz of power, capable of adequately feed the aircraft's systems using the Converter Circuit Breaker (CCB) contactors.

The Backup Converter controller monitored the voltage that fed the CCB, using a function called Voltage Regulator. The controller adjusted the inverter output to maintain the voltage at 115V.

The Backup Converter also had the protection function regarding the electricity generated in reserve mode. Protection was performed by opening the GCR associated with the Backup Generator (left or right) interrupting the excitation for energy generation by that generator. The following are some of the protection functions of the Backup Converter:

- Control Switch Off;
- Converter Fault; and
- Low Oil Pressure.

The Backup Converter could be powered by two PMGs (one from each engine). The PMGs operated from the rotation of the engines, that is, while the engines were running, the PMGs would be supplying energy.

The Backup Converter also automatically controlled the operation of the TBBs and CCBs contactors on both sides, according to the electrical energy available to power the aircraft.

Both TBBs and CCBs in normal operation were not energized. Internal springs in each of the contactors kept the TBBs closed and the CCBs open when not energized. This configuration made it possible to supply power to the aircraft systems by the Main Generators (IDGs).

The Backup Converter energized the TBBs and CCBs to provide the power supply through the transfer buses through the Backup Generators. In that case, the TBBs would open and the CCBs would close when energized.

The Backup Converter interfaced with the Backup Generator for the monitoring and control of its functions through electrical wiring, composed of 14 pins, as shown in Figure 6.

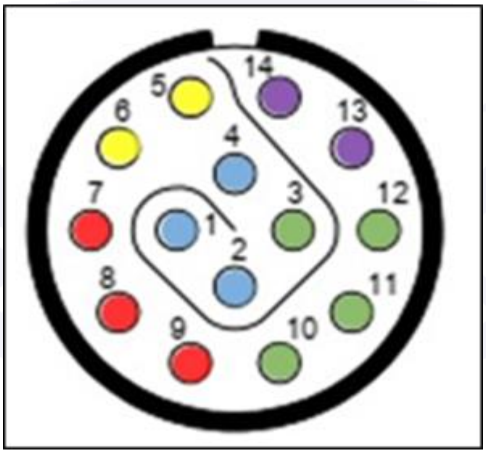

Figure 6 - Connector configuration.

- 1, 2 and 4 - Remote Oil Monitoring;
- 3, 10, 11 and 12 - Differential protection of the generator;
- 5 and 6 - Field Driver;
- 7, 8 and 9 - PMG control; and
- 13 and 14 - Differential Oil Pressure Filter.

Pins 7, 8 and 9, associated with the PMG, were related to higher voltage and current loads.

The Differential Oil Pressure Filter signal was not used by the Backup Converter, so these pins were not used.

The Remote Oil Level Sensing (ROLS) system measured the oil level of the Backup Generators, providing indication to the Backup Converter microprocessors.

Both Backup Generators had a pair of thermistors, located in the BUG, to indicate high and low oil levels. The indication of the oil level was made by measuring the resistance of the pairs of thermistors which was proportional to its temperature, thus determining whether it was submerged or not in the oil.

To measure the resistance of the thermistors, the Backup Converter had two current sources, U1 and U3, one for the left side and one for the right side, respectively. The current generated was ramified in two ways: one for the Backup Generator and another for the AR7 amplifier. The current going to the Generator passed through high frequency noise suppressors FB25 and FB28, one on each side, and was connected to the Backup Generator through pin 4.

In the Backup Generator, there was a Pressure Switch, which, during its normal operation, was open, thus preventing the flow of current to the thermistors and the return of the current to the Backup Converter.

If the oil pressure of the Backup Generator was not within the predicted values, the Pressure Switch would close and the oil level would be monitored, in order to determine if the Backup Generator was in a regular, sub-level or up-level of oil.

In the other part of the way, the amplifier AR7 compared the input signal with a reference signal and, depending on the condition of the oil level: regular, sub-level or up-level, the input voltage in the amplifier was changed and, thus, the Backup Converter was able to determine the oil level of the Backup Generator.

The internal oil level monitoring circuit is shown in Figure 7 (left side) and Figure 8 (right side).

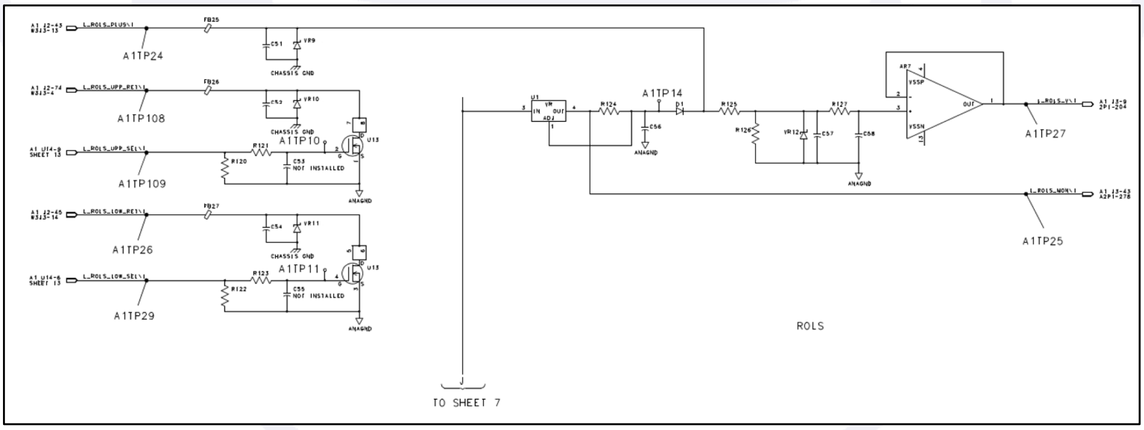

Figure 7 - Left ROLS circuit.
Source: Backup Converter's Component Maintenance Manual (CMM).

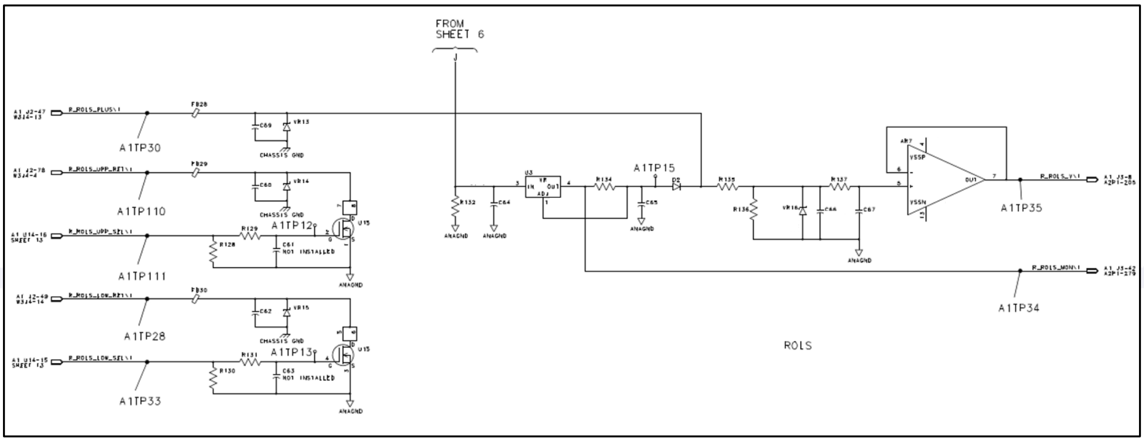

Figure 8 - Right ROLS circuit.
Source: Backup Converter's Component Maintenance Manual (CMM).

If a fault was identified by the Backup Converter oil monitoring system, there would be an interruption of the Backup Generator's excitation (de-excitation), corresponding to the fault side, ceasing to be a usable energy source for the aircraft's power supply.

The Backup Generator Current Transformers monitoring circuit monitored the current produced in each of the three phases of the Backup Generator using the RIGHT_GEN_CT_PHA, RIGHT_GEN_CT_PHB, RIGHT_GEN_CT_PHC signals and the reference signal RIGHT_GEN_CT_COM.

The RIGHT_GEN_CT_COM signal was connected to the internal ground of the Backup Converter, called ANAGND, which in turn was isolated from the ground of the aircraft called Chassis Gnd.

Part of the simplified circuit is shown in Figure 9.

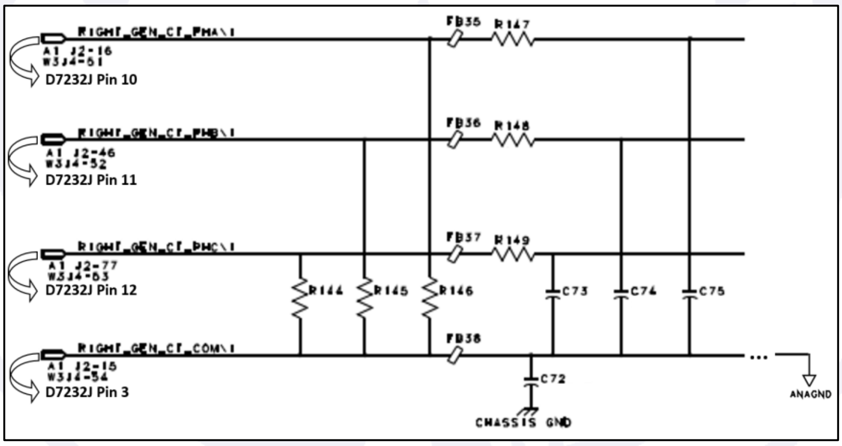

Figure 9 - Extract from the Monitoring Circuit of the Backup Generator Current Transformers, right side.
Source: Backup Converter's CMM.

The Discrete Signal Monitoring Circuit performed the measurement of some test parameters. Among them were the GCS and the TBBs and CCBs contactors.

The Backup Converter provided a voltage of 18V that passed through the contactors and returned to the Backup Converter. Zener diodes turned the voltage to 5V when the contactors were closed and 0V when the contactors were open.

The Discrete Signal Monitoring Circuit for the contactors (CCB and TBB) is shown in Figure 10.

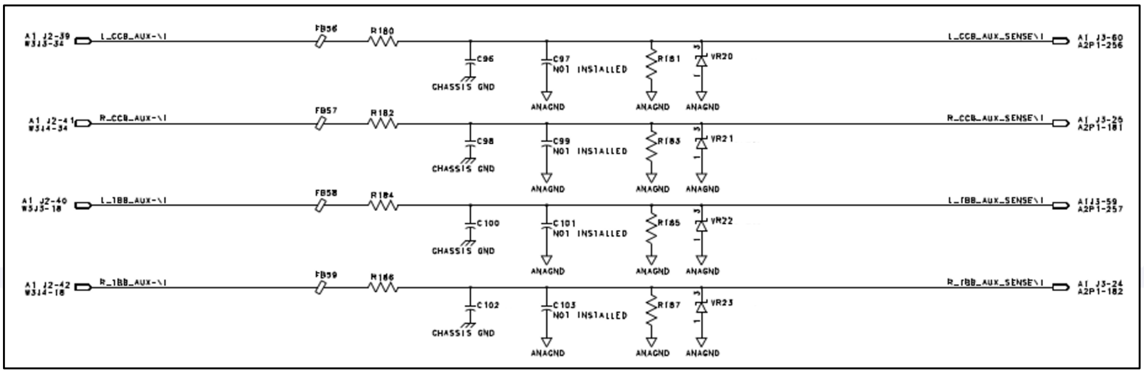

Figure 10 - Part of the contactors' discrete signal monitoring circuit (CCB and TBB).
Source: Backup Converter's CMM.

The fault condition of the contactors (TBB or CCB) occurred when the monitored position of the contactor differed from the commanded position for a period of 50 to 100 milliseconds.

There were two possibilities for failures that could occur in either a TBB or a CCB. For this, it was adopted the definition that the adjacent contactor was the one that differed from the failed contactor on the corresponding side. That is, if the failed contactor was the right TBB, then the adjacent contactor would be the right CCB. Thus, there were the following situations:

1. The failed contactor was commanded open and was monitored in the closed position (Contactor Commanded Open but Sensed Closed): the adjacent contactor was commanded open and the failed contactor was commanded closed.

For example: if the right CCB was commanded open and was monitored closed, the Backup Converter would command the closing of the right CCB and the opening of the right TBB.

2. The failed contactor was commanded closed and was monitored in the open position (Contactor Commanded Closed but Sensed Open): the adjacent contactor was commanded closed and the failed contactor was commanded open.

For example: if the left TBB was commanded closed and was monitored open, the Backup Converter would command the closing of the left CCB and the opening of the left TBB.

After any of the faults occurred, both the failed contactor and the adjacent contactor were locked or "frozen" in the commanded positions after the faults.

Maintenance Information

During the period of occurrence, the operator followed the Operator Maintenance Program, revision 17, of 04NOV2016, approved by the ANAC for the scheduled tasks.

The program divided tasks into sets, called checks. The checks related to systems and zones inspection were called “A” and “C”, with multiple intervals of 750 flight hours. Those related to structure and zones inspection were called “S”, with multiple intervals of 1,125 days.

The tasks scheduled for zones inspection related to the areas of the electrical components mentioned above were, for the most part, 6,000 flight hours or 1,125 days.

The damaged connector area, shown in section 1.3, was inspected by a Maintenance Organization during a check of 2,250 days, between 13MAY2018 and 10JUN2018. In the records of this task, no discrepancy was reported.

On 12JUL2018, the failure message “Backup Gen Remote Oil Level Sense/Low Oil Pres Circuit (R) is failed” was recorded. Research was carried out following the Fault Isolation Manual (FIM) 24-25-00-810-804. In summary, the following steps were planned:

- check whether the message is active, locked or not active at the maintenance terminal. If the fault is non-active, then it is an intermittent fault without the need to perform subsequent tasks;

- measure the resistance between pins 1-4 and 2-4 of the Backup Generator connector referred to oil sensors and oil pressure switch. If the resistance is out of the limits, the Backup Generator is replaced, otherwise the fault search is continued;

- measure the resistance between pins 4-13 and 13-14 of the Backup Converter connector referred to wiring and the components already measured in the previous step. If the resistance is out of the limits, the backup wiring connecting the Backup Converter with the Backup Generator is performed, otherwise the fault search continues; and

- perform the replacement of the Backup Converter.

According to the maintenance records, the Backup Converter was removed, according to the data below:

Electric System Components		
Description	Removed BUC	Installed BUC
PN	757183G	757183G
SN	AAA4002238 (2238)	AAA4002246 (2246)
Date of Removal/Installation	12JUL2018	12JUL2018
TSN	24.154,4 hours	20.932,8 hours
CSN	2.847 cycles	2.441 cycles

The Backup Converter SN 2238 was sent for repair, where damage was found to internal electronic components related to the oil level monitoring circuit. It was reported repaired on 27AUG2018.

On 18DEC2018, another failure message was recorded, Elec Backup Gen R. A failure search was performed, according to FIM 24-25-09-00-810-802.

The first stages of the failure investigation consisted of the initial assessment of the condition through operational testing and downloading of the Backup Converter failure messages.

The next step was to replace the Backup Converter. If the message was not active or was no longer displayed, the fault was considered corrected.

If the fault message was active or locked, the fault search should be continued, which involved several steps such as replacing the Backup Generator, the contactors (CCB and TBB) and the checking of the wiring pins that included the pins of the PMG.

The Backup Converter was replaced (as detailed below), after which the functional tests were performed and the failure was considered complete. The Backup Converters replacement data on 18DEC2018:

Electric System Components		
Description	Removed BUC	Installed BUC
PN	757183G	757183G
SN	2246	2238
Date of Removal/Installation	18DEC2018	18DEC2018
TSN	22.773,2 hours	24.154,4 hours
CSN	2.651 cycles	2.847 cycles

After installing the Backup Converter SN 2238, the aircraft performed two flights between the cities of São Paulo and Miami, totaling approximately 15 hours and 2 cycles.

During the third flight after the Backup Converter replacement, the failures described in section 1.11 occurred - Flight recorders.

1.7 Meteorological information.

The METAR of the SBCF brought the following information:

METAR SBCF 200300Z 09009KT 9999 SCT035 22/17 Q1016=

METAR SBCF 200400Z 14004KT 9999 FEW040 22/17 Q1016=

METAR SBCF 200500Z 13008KT 9999 SCT040 22/17 Q1016=

At 03h16min02s (UTC), the APP-BH reported that the Aerodrome was operating in visual conditions, wind with 050° direction and intensity of 5kt. The temperature was 21°C and the altimeter setting QNH 1016.

At 03h40min34s (UTC), the TWR-CF reported that the wind direction was 200° with 3kt intensity.

1.8 Aids to navigation.

Nil.

1.9 Communications.

According to the transcripts of the communication audios, it was found that the crewmembers maintained radio contact with the control agencies. There was no technical abnormality of communication equipment on the ground that prevented or hindered the transmission and understanding of messages and authorizations throughout the flight.

In order to support the analysis of the sequence of events that preceded the emergency landing, the Investigation Team highlighted some transmissions during the flight that can help in understanding the dynamics of the event.

To record the times described in this field, the Coordinated Universal Time (UTC) was used as a reference.

At 2h47min2s am, the ACC-BS authorized the PT-MUG aircraft to fly straight to the Rubic position: “TAM eight zero eight four, authorized straight Rubic!”

At 02h56min16s, the ACC-BS received the emergency message from the aircraft PT-MUG: “Brasília, MAYDAY, MAYDAY, MAYDAY, TAM eight zero eight four with total failure of the electrical system!”

At 02h56min32s, the ACC-BS received a message of the PT-MUG aircraft crew’s intention: "We are now eighty miles from Confins, request to proceed to Confins!"

The ACC-BS authorized to proceed to Confins and, at 02h56min53s, informed the arrival ISVAD1A RWY16, published on 12NOV2015, for the aircraft PT-MUG: “I state TAM eight zero eight four, prepare arrival Isvad one A runway one six!”

At 02h58min52s, the ACC-BS informed the procedure ILS K RWY16, published on 12NOV2015, in use for landings at the Aerodrome (SBCF): “TAM eight zero eight four, procedure to Confins ILS kilo, threshold one six to Confins!”

At 3h00min34s, the APP-BH authorized the descent of the PT-MUG aircraft to FL090, without restrictions: “TAM eight zero eight four control descent without restrictions to flight level zero nine zero.”

At 03h00min58s, the crewmembers collided the descent and asked the APP-BH to start the fuel jetting: "It will start descending ... it's descending to zero nine zero as instructed and requests to start jettisoning fuel now for reduction during the descent, sir."

At 03h01min12s, the APP-BH authorized the descent of the PT-MUG aircraft to the altitude of 7,000ft and the performance of the procedure: “Roger. It’s already authorized to descend to seven thousand feet the adjustment of the altimeter one zero one six. Also authorized the ILS kilo threshold one six TAM eight zero eight four.”

At 03h06min21s, the crew asked the APP-BH for a position to carry out the wait: “Control, could you please inform us a reference ahead of us so we can select an orbit here?”

At 03h06min27s, the APP-BH informed the Tislo position, in response to the aircraft's request for a position to hold: “Tislo. Tislo position. T I S L O.”

At 03h27min31s, the crewmembers asked the APP-BH to confirm the length of the airfield runway: “Radio check. Confirm len ... runway length three thousand meters?”

At 03h28min09s, the APP-BH reported that the Aerodrome runway had 3,000 meters long, that were approved and another 600 meters paved: “Hmmm ... three thousand meters approved and six hundred more paved, sir. Three thousand six hundred in total”.

At 03h28min15s, the crewmembers informed that the aircraft was overweight to make the landing, that it was not possible to jettison the fuel and that the support of the firefighting team was necessary: “… Please, get the firefighters, ok buddy? The aircraft is very heavy, without any conditions of ... jettisoning … aaaa ... ask for ... your help."

At 03h36min27s, the crewmembers reported that the aircraft had 96,000kg of fuel: “Ninety-six tons of fuel.”

At 03h40min34s, the TWR-CF authorized the landing and reported the wind conditions: "TAM eight zero eight four, I inform free runway allowed landing on the runway one six, wind two zero zero degrees three knots. Ground support has already been requested".

In order to support the analysis of communications and coordination after the aircraft has stopped and passengers disembarked, the Investigation Team highlighted some transmissions that may help in understanding the dynamics of the event. To record the times described in this field, the Cockpit Voice Recorder (CVR) recording time was used as a reference.

At 00h39min19s am, the crew asked: "Are firefighters extinguishing the fire in the tires?"

At 00h39min20s, the TWR-CF passed on the following message: "It was only reported now ... it was in high temperature and it caught fire, on fire."

At 00h39min23s, the crew informed: "We are waiting then ... they are extinguishing the fire" ...

At 00h39min30s, the crew requested contact with the Fire Section team (SCI): "Is it possible that the firemen get in touch to inform how the aircraft's brakes are?"

At 00h39min44s, the TWR-CF transmitted: "Okay ... we will contact them here."

At 00h40min02s, the crewmembers requested to use the emergency frequency for coordination: "Okay ... would there be a possibility for us to maintain coordination on 121.5?"

At 00h40min08s, the TWR-CF transmitted that the coordination would be done at the emergency frequency: “Okay, coordination on 121.5.”

At 00h40min16s, the crew asked if it would be possible to coordinate directly with the SCI team of the Aerodrome through the emergency frequency: "So we talked to the firefighters on 121.5, correct?"

At 00h40min55s, the TWR-CF reported that direct coordination was not possible: “It is not possible.”

At 00h45min22s, the TWR-CF reported that the SCI team had requested the evacuation of the aircraft: "It was requested by the firefighters to carry out the evacuation of the aircraft from the left side, now."

At 00h45min36s, the crewmembers questioned the information received: “Did the firemen request this? Aren’t they managing to put out the fire?”

At 00h45min44s, the TWR-CF confirmed that the request was from the SCI team: "It was the firemen ... they didn't say anything, they just asked for evacuation by the left side."

At 00h46min07s, the crew questioned again about the request received: “Are they unable to fight the fire? Because it's safer to go down the stairs, instead of evacuating.”

At 00h47min32s, the crewmembers were more emphatic in confirming the need for evacuation: "Did you coordinate if we really have to evacuate?"

At 00h47min36s, the TWR-CF reported: “We are coordinating here with the firefighters.”

At 00h47min38s, the crewmembers expressed their preference for not carrying out an evacuation, but a disembarkation: “Okay ... because it is calmer if people go down the stairs, but if there’s no other way, we’ll command it!”

At 00h47min45s, the TWR-CF reported: “Okay, I'll see you here and I'll be back to you.”

At 00h48min35s, the crew asked: "Tower, any new information?"

At 00h48min48s, the TWR-CF reported that the disembarking stairs was being directed to the aircraft: “TAM 8084 has requested the stairs and it’s already on its way.”

At 00h48min56s, the crew asked: “And the firemen said that you can wait for the stairs, right?”

At 00h49min20s, the TWR-CF reported that it was possible to wait for the disembarking: "Yes ... you can wait ... the stairs are on the way."

At 00h49min25s, the crewmembers were still confused with the type of disembarkation: “Please, just to have a better confirmation ... the firefighters had initially requested to evacuate the aircraft from the left side. Now, in a new contact, they say that we don't need to evacuate, right? Is it to wait for the stairs, is that it?”

At 00h49min43s, the TWR-CF reported: “TAM 8084 I affirm ... it’s what was requested and passed on to us.”

At 00h49min49s, the crew questioned: "That’s what was reported by the firefighters, correct?"

At 00h49min51s, the TWR-CF replied: “By the firefighters. Initially they had requested the evacuation by the left side ... then you requested the stairs ... then we got in touch and they said it was to wait for the support of the stairs.”

At 00h50min, the crewmembers transmitted the following information: “No! We requested the stairs if the firefighters confirm with us that there is no need for evacuation.”

At 00h50min14s, the TWR-CF replied: "Roger."

At 00h50min17s, the crewmembers asked if it was possible to have direct contact with the SCI team: "Is there any frequency that we can talk directly with the firefighters?"

At 00h50min21s, the TWR-CF replied that the contact with the team was only possible through a link: "No, negative ... I would have to make a link here with the tower."

At 00h50min27s, the crew asked to confirm if evacuation was necessary: "Then please confirm with him, if there is a need for evacuation by the firemen."

At 00h50min32s, the TWR-CF replied: “Okay, we'll see it.”

At 00h50min34s, the crew asked: "As soon as possible."

At 00h52min12s, 1 minute and 38 seconds after the previous message, the crewmembers asked: “Tower? 8044. Any information?”

At 00h52min16s, the TWR-CF replied: “We are coordinating here.”

At 00h52min50s, the TWR-CF reported: “We got in touch with the team that heads the firefighters ... they don’t have that decision to express the need for evacuation of the aircraft now. As I understand it, you associated the stairs with the need that evacuation is really expressed, is that correct?”

At 00h53min00s, the crewmembers replied: “No, on the contrary ... if evacuation is not necessary, we request the stairs to disembark the passengers ... wheelchairs and everything else ... if the firefighters say they cannot put the stairs near the aircraft and they are not able to extinguish the fire ... then we will evacuate the aircraft.”

At 00h53min30s, the TWR-CF questioned: "Roger ... the evacuation of the aircraft then, in case they are not managing to extinguish the fire ... will be done by the aircraft's own means ... on the left side, correct?"

At 00h53min40s, the crew replied: “Correct, according to the request made by the firefighters ... except that we need a quick information from the firefighters to know if we are going to wait ... if we are going to turn the stairs to make the disembarkation of our passengers or if we are going to evacuate.”

At 00h57min39s, the crewmembers asked: "Confins ... 8084 ... any information?"

At 00h57min45s, the TWR-CF reported: “8084, one more minute.”

At 00h58min02s, the TWR-CF reported: “8084 ... at first, it is controlled.”

At 00h58min10s, the crew requested confirmation: "Okay, the fire is controlled and evacuation is not necessary, correct?"

At 00h58min13s, the TWR-CF reported: “Tam 8084, correct. Then the disembarkation will be done through the stairs ... it will be done on the left side at the rear door. The approach to the stairs at the rear door on the left is already being coordinated.”

At 00h58min22s, the TWR-CF asked: “Do you request any more support? Did you say wheelchair ... anything else like that?”

At 1h00min, the crewmembers replied: “From our position, we can't see the stairs ... you would have to coordinate with us when they put the stairs there.”

At 01h01min06s, the TWR-CF informed: “Roger. We are going to make this request so ... as soon as the stairs is placed, they will tell me and I will tell you ... unfortunately we don't have the firefighters vehicle uh ... they don't have the VHF transmission on 121.5 ...

then this link there, despite not being the best possible thing ... it's the most effective way we have to communicate there.”

1.10 Aerodrome information.

The Aerodrome was public, managed by BH Airport S.A. and operated under Visual Flight Rules (VFR) and Instruments (IFR), during day and night.

The Runway was made of asphalt, with thresholds 16/34, dimensions of 3,000m x 45m, with an elevation of 2,713 feet.

1.11 Flight recorders.

The aircraft was equipped with a digital flight data recorder, FDR Honeywell, model HFR5-D (solid state memory), PN 980-4750-009, SN 01898, with a capacity of 1,024 words (each word has 12 bits), thus performing a reading of 1,024 x 12 every 1 second (words per second).

In addition, it was also equipped with a digital cockpit voice recorder, CVR Honeywell, model HFR5-V (solid state memory), PN 980-6032-001, SN 01826, having 3 channels with 2 hours of audio and 1 channel with 3 hours of voice data, the 4 of them recorded in high quality.

The FDR recorded the flight data up to the moment when the power system was interrupted by the electrical system.

The CVR, on the other hand, recorded the occurrence data up to approximately 10 minutes after the moment when the power supply interruption by the electrical system occurred. The Synchronization of the 4 audio channels was necessary, due to the recording time being different in some of them.

The Backup Converter had Non-Volatile Memory (NVM), capable of recording failure messages during a flight. The following table shows the flight failure messages for the issue:

#	*Time*	*Fault Number*	*Description*
1	02:42:10	533/176	*Right Generator DP Trip -Conv Fail*
2	02:42:11	528/172	*DC Content Trip -Conv Fail*
3	02:42:42	608/097	*Left Low Oil Pressure Trip - Low Oil Pressure*
4	02:42:49	849/079	*GCS-L Disagreement with OPAS or Fire Handle Pulled*
5	02:43:08	850/002	*GCS-R Disagreement with OPAS or Fire Handle Pulled*
6	02:53:56	609/200	*Right Low Oil Pressure Trip - Low Oil Pressure*
7	02:53:57	806/013	*Left TBB Commanded Closed but Sensed Open*
8	02:53:57	816/031	*Left CCB Commanded Open but Sensed Closed*
9	02:53:57	807/016	*Right TBB Commanded Closed but Sensed Open*
10	02:53:57	817/034	*Right CCB Commanded Open but Sensed Closed*
11	02:54:17	703/147	*Right Under speed trip-Speed Sense Fail*
12	03:52:02	303/155	*Right Generator Remote Oil Level Detection Failed*

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 Master Commander had been working in aviation for 45 years, 24 of which at LATAM Airlines.

The 2nd Commander joined LATAM Airlines in 1996 and had been flying the Boeing 777 for 10 years.

The 1st copilot was at LATAM Airlines for 7 and a half years and he was a crewmember of the Boeing 777 for 6 years.

The 2nd copilot was in aviation for 19 years, 11 of them at LATAM Airlines.

The Master Commander and the 2nd copilot had already flown together, including training in a simulator recently. The 1st copilot had already been part of a crew with the other pilots previously.

About the flight of the occurrence, it was the first and only flight of the day for the crew. They reported that until the first 15 minutes of flight everything was normal with the operation. From that moment on, they received the first failure message and performed the procedures prevised in the QRH.

After approximately 10 minutes of the first fault, multiple faults related to the electrical system were triggered. They then decided to stay in orbit to try to resolve the situation. They sought to resolve these failures through the checklist and the aircraft manual. However, they did not obtain the expected result, they were not able to effectively identify the problems presented by the aircraft, due to the overlapping of information on the screen (EICAS).

In an attempt to understand what was happening and based on the events they were experiencing, they deduced that the aircraft could be powered only by the battery, which led them to decide to declare an emergency, jettison fuel and proceed to land at Confins Aerodrome, which was operating in visual conditions.

Although it was not possible to jettison the fuel, they proceeded to the landing, as they considered that this was the most correct decision, considering the aircraft's battery time that they had left.

During the management of failures, they were organized in such a way that the Master Commander assisted the Commander and the 2nd copilot helped the 1st copilot.

The crew reported that they had not experienced anything like this before, not even in a flight simulator. They considered that the workload management, due to the experienced failures, was smooth and adequate.

1.14 Fire.

During landing, the brake set overheated, which started the fire on the wheels of the main right and left landing gears.

The Fire Section carried out the fire fighting, which was controlled in 4 minutes.

From the beginning of the fire extinguishing to cooling the set of brakes, 65,700 liters of water and 780 liters of Foam Generating Liquid (LGE) have been spent.

1.15 Survival aspects.

The first communication made by the aircraft with the intention of landing at the Confins Aerodrome (SBCF) took place 40 minutes before landing.

The ATC agency activated the Rescue and Fire Fighting Service via a direct telephone, hot line, while the aircraft was flying en-route to SBCF.

After the aircraft had come to a complete stop and the engines were shutdown, the crewmembers had the visualization of the landing gear's footage camera in the cockpit restored. With that, they obtained the visualization that the fire condition in the landing gear was controlled during the fire extinguishing by the SCI. Thus, it was considered that there was no immediate need to command emergency evacuation through emergency doors and scape slides.

The overheating and fire on the brakes were quickly put out by the fire team. The coordination between the crew, the control tower, and the firefighters for the abandonment of the aircraft's passengers lasted 13 minutes.

The disembarkation of passengers, under the coordination and monitoring of the fire brigade, started at 04h26min (UTC) and ended at 05h38min (UTC).

The Investigation Team identified that the Aerodrome operator had the SBCF Emergency Plan and Inoperative Aircraft Removal Plan (PLEM / PRAI) with the last revision dated from 09JUL2018, according to the PLN-SAE-001.

The PLEM / PRAI established the actions and procedures to be performed by the Apron Inspector, the ATC agency, the Emergency Operations Center (COE), the Airport Operations Center (APOC), the Rescue and Fire Fighting Service (SESCINC) and the Post Mobile Coordination (PCM).

Communications between the TWR and the vehicles of the fire brigade, team leader and other members of the Aerodrome's emergency operations were congested, due to the occurrence.

There was no direct communication between the aircraft and the emergency teams. The TWR established a communication link between the aircraft and the emergency teams.

According to the interviews, during the investigation, it was identified that the radio remained very congested between the emergency teams and the other members of the Aerodrome's emergency operations.

It was identified that the TWR had to wait for a rare opportunity on the phone to be able to communicate with firefighters. Everyone involved used the same channel, which was centralized in the COE.

The disembarkation was accomplished through conventional stairs, which were positioned in the left rear door of the aircraft.

No occupant of the aircraft or a member of the rescue teams suffered injuries during the abandonment of the aircraft.

1.16 Tests and research.

Initially, on 07JAN2019, functional tests were carried out in order to obtain preliminary information about the operation of the aircraft's electrical system.

It was possible to supply electrical power as planned through the APU and from the left engine. When the right engine was started, the synoptic page of the electrical system showed that its Main Generator (IDG) was also operational for the supply of electricity, however, the Backup Generator was not available.

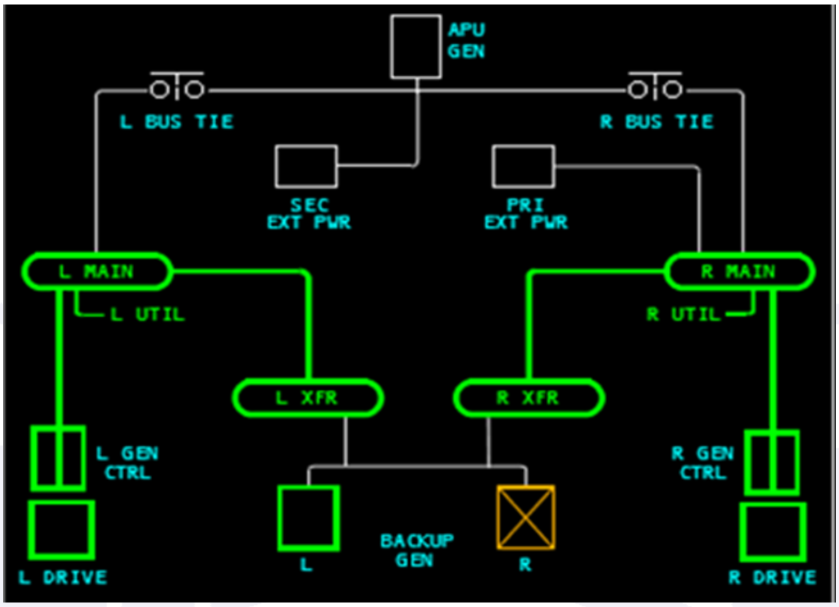

Figure 11 - Representation of the synoptic screen of the aircraft's electrical system during ground tests.

The Backup Generator active fault messages were related to the PMG power and low oil pressure.

Then, continuity measurements were made between the Backup Generator and the Backup Converter. The results showed continuity failures related to the PMG wiring.

Then they proceeded to search for the discontinuity point in the wiring between the Right Backup Generator and the Backup Converter.

It was found damage to the indicated connector, as shown in section 1.3 of this report.

The D7232 connector has been removed from the aircraft along with its attachment structure and adjacent connectors for more detailed inspections.

Figure 12 - Part of the wiring removed from the aircraft.

In addition to wiring, the following components have been separated for analysis:

- Backup Converter / PN 757183G / SN 2238 (installed on the occurrence aircraft);

- Backup Converter / PN 757183G / SN 2246 (removed from the aircraft three days before the event);

- Backup Generator / PN 1701768 / SN 21772 (installed on the aircraft's right engine);

- TBB / PN ELM 831-2 / SN CT-33098 (referring to the right side of the aircraft);

- TBB / PN ELM 831-2 / SN CT-33099 (referring to the left side of the aircraft);

- CCB / PN ELM 832-2 / SN CT-31542 (referring to the right side of the aircraft); and

- CCB / PN ELM 832-2 / SN CT-32631 (referring to the left side of the aircraft).

Test of the Contactors

The four electrical contactors were tested in the laboratory. No significant discrepancies were found that could have contributed to the events observed in this occurrence.

Test of the Backup Generator

The Backup Generator PN 1701768 / SN 21772 was tested in the component repairing Maintenance Organization. The following discrepancies were observed:

- resistance test of the PMG magnets: 0.01 ohm below the minimum in the measurements between pins 7-8 and 8-9; and

- PMG voltage test. Results in the following table, according to the original test protocol. The data in bold represent the values obtained in the test.

Conditions			Limit	
Input Speed ± 100 (rpm)	Oil-In Temperature ± 10°F (± 5°C)	Connector Pins Checked	130.5 - 160.0V Record	% Voltage Unbalance 5% maximum
14,500	200 (93)	7 and 8 (J1)	**105.8**	**40.5**
14,500	200 (93)	7 and 9 (J1)	**113.7**	
14,500	200 (93)	8 and 9 (J1)	**148.7**	

Then, the Backup Generator was disassembled and damage was found to the PMG stator, as shown in Figure 13.

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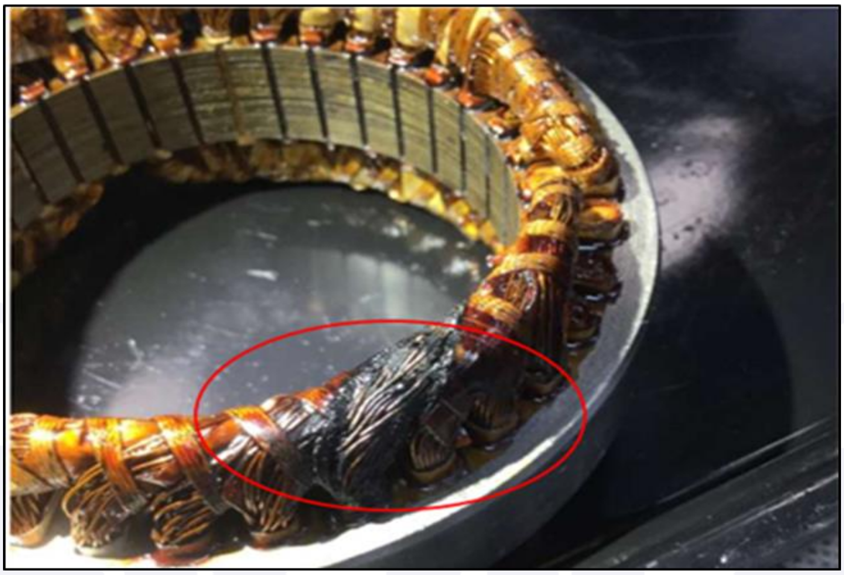

Figure 13 - Damage to the PMG stator.

Test of the Wiring / Connector

The wiring removed from the aircraft was taken for analysis in the laboratory. Figure 14 shows the identification of the wiring parts.

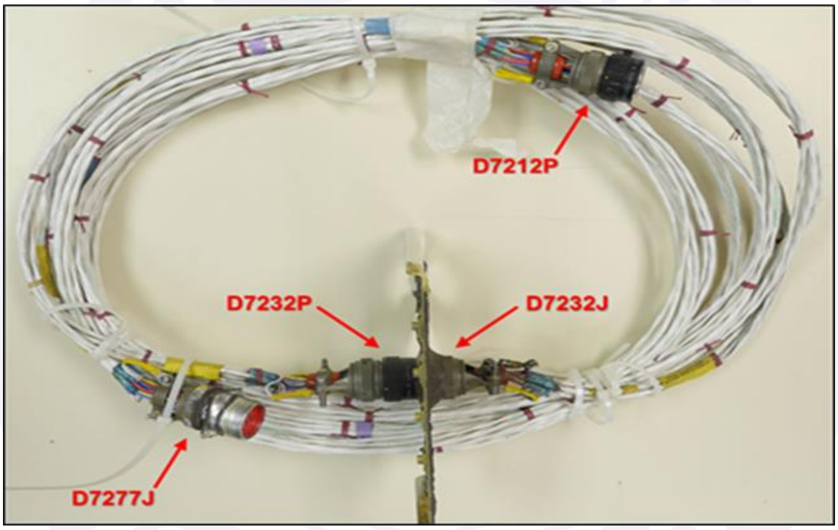

Figure 14 - Identification of the analyzed wiring parts.

The resistance of each thread in the wiring was measured from the adjacent connectors (D7277J and D7212P). The results are shown below and the blank spaces represent threads that did not have continuity (Figure 15).

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		Connector D7232P – Backup Converter													
	Pins	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Connector D7232J – Backup Generator	1	0.35Ω	2.6MΩ				2.8KΩ	20MΩ	24KΩ	0.5MΩ	18KΩ				
	2	2.6MΩ	0.35Ω				1.8MΩ	5.5MΩ	1.4MΩ	1.9MΩ	1.4MΩ				
	3			0.37Ω											
	4				0.38Ω										
	5					0.26Ω									
	6	2.8KΩ	1.8MΩ				0.25Ω		9.6KΩ	0.6MΩ	11KΩ				
	7	20MΩ	5.5MΩ					0.18Ω							
	8	24KΩ	1.4MΩ				9.6KΩ								
	9	0.5MΩ	1.9MΩ				0.6MΩ								
	10	18KΩ	1.4MΩ				11KΩ				0.34Ω				
	11											0.35Ω			
	12												0.35Ω		
	13													0.36Ω	
	14														0.41Ω
	GRD	18KΩ	0.6MΩ								4.5KΩ				

Figure 15 - Resistance of each thread of the wiring.

The resistance in each portion of the connector was also measured. The measurement results on the Backup Converter side are shown in the upper half of the table in blue and the results on the Backup Generator side are shown in the lower half of the table in green (Figure 16).

		Connector D7232P – Backup Converter													
	Pins	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Connector D7232J – Backup Generator	1	1	175KΩ				2.2KΩ		32KΩ		34KΩ				
	2	0.5MΩ	2				160KΩ	200MΩ	180KΩ		155KΩ				
	3			3											
	4				4										
	5					5									
	6	1.9KΩ	0.5MΩ				6		21KΩ		18KΩ				
	7							7							
	8							0.09Ω	8						
	9							0.12Ω	0.12Ω	9					
	10	17KΩ	0.5MΩ				16KΩ				10				
	11											11			
	12												12		
	13													13	
	14														14

Figure 16 - Measurement results.

Then, the area of the connector where the short-circuit occurred was prepared to carry out x-ray and computed tomography scanner inspections. Figures 17, 18 and 19, below, present an overview of the conditions of the connector.

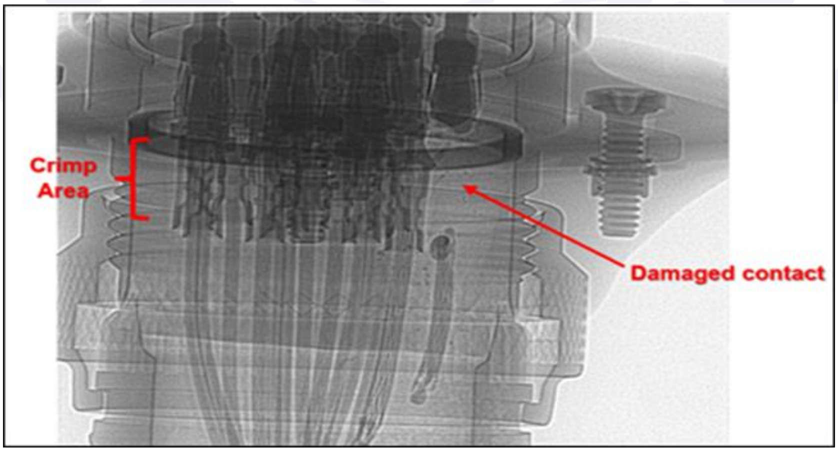

Figure 17 - Overview of damage to the connector on an x-ray inspection.

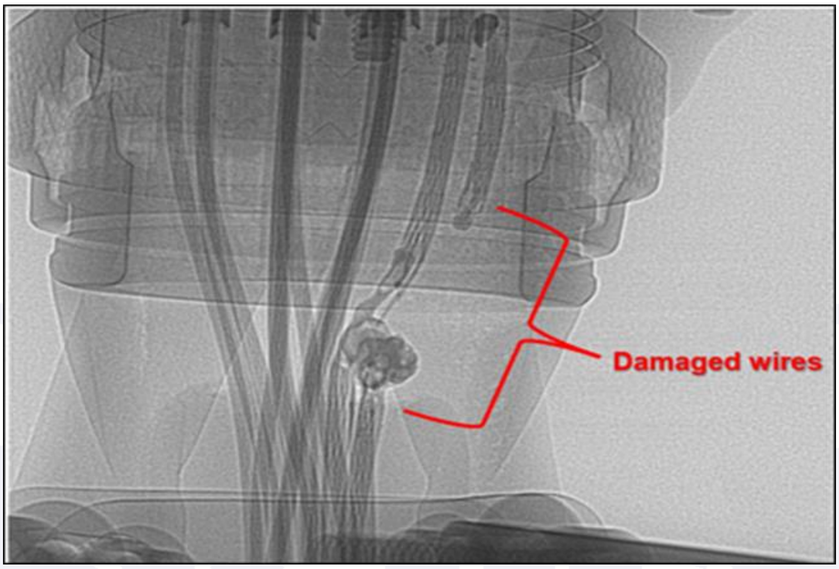

Figure 18 - Overview of damage to the wiring on an x-ray inspection.

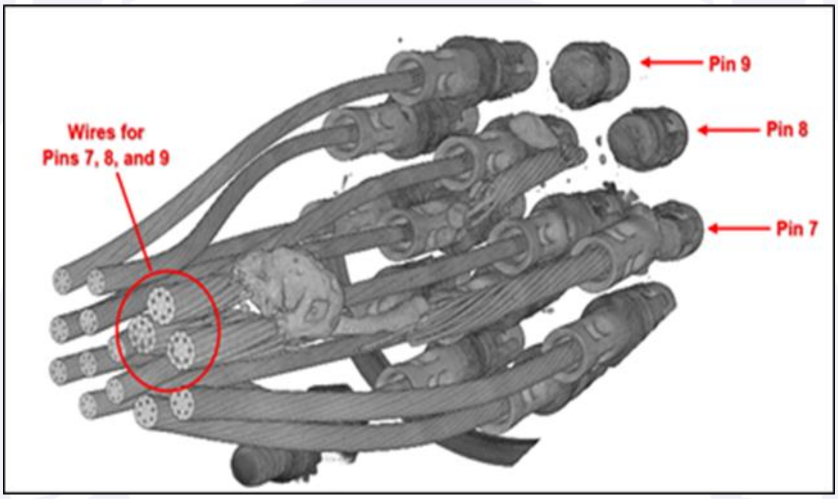

Figure 19 - Overview of damage to the connector.
Computerized tomography scanner.

The points where signs of damage were found are shown in the sequence of Figures 20 to 24, below:

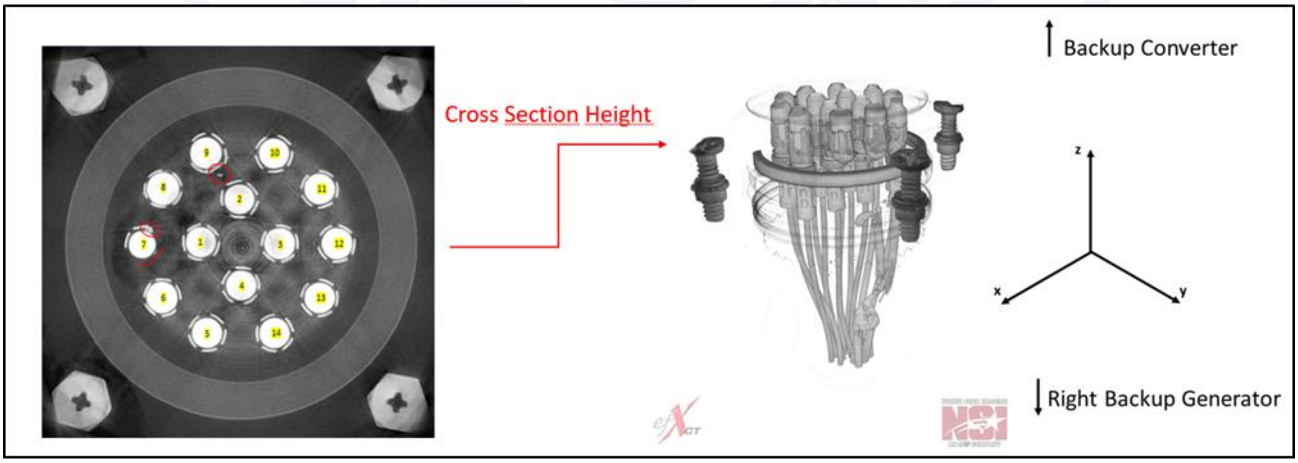

Figure 20 - Connector cross section. Part 1 of 5.

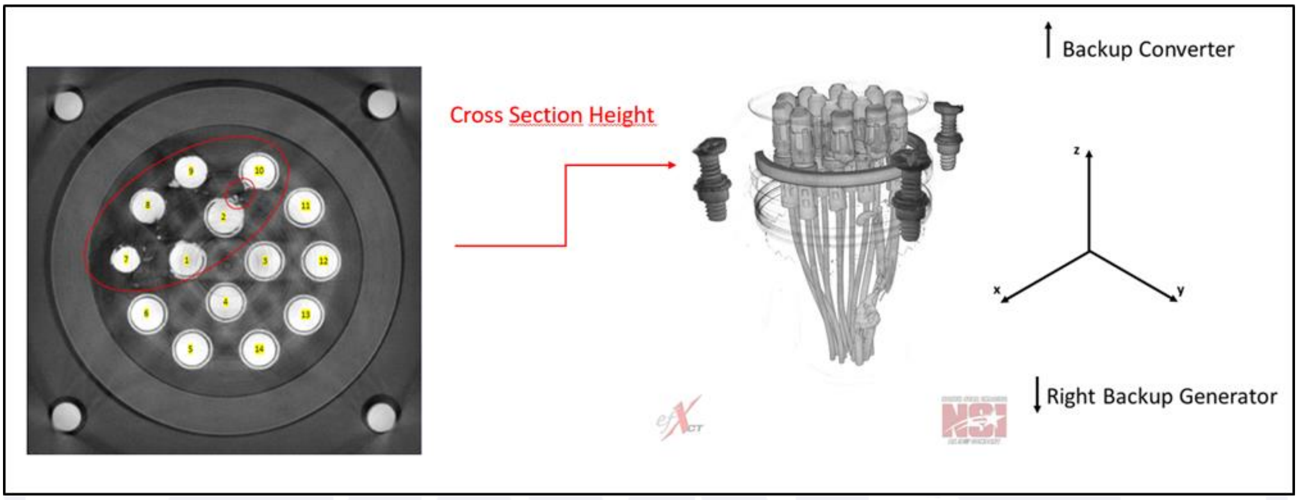

Figure 21 - Connector cross section. Part 2 of 5.

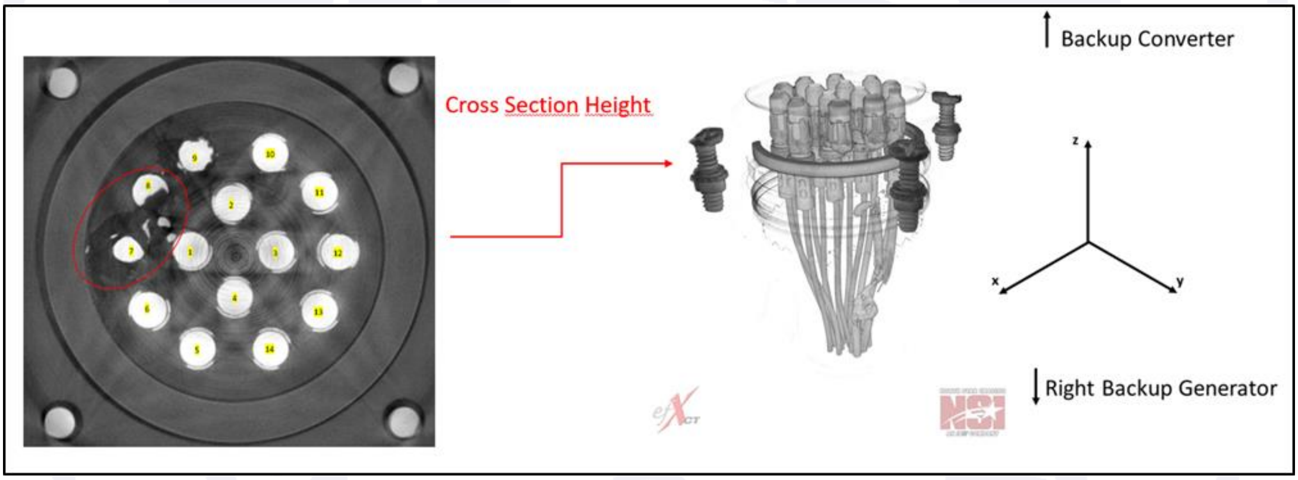

Figure 22 - Connector cross section. Part 3 of 5.

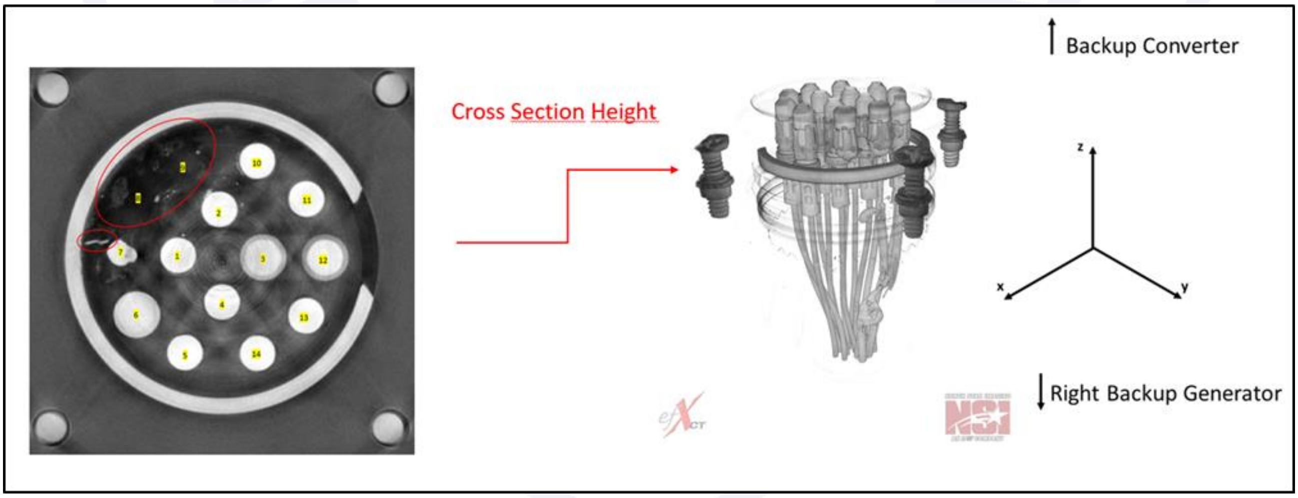

Figure 23 - Connector cross section. Part 4 of 5.

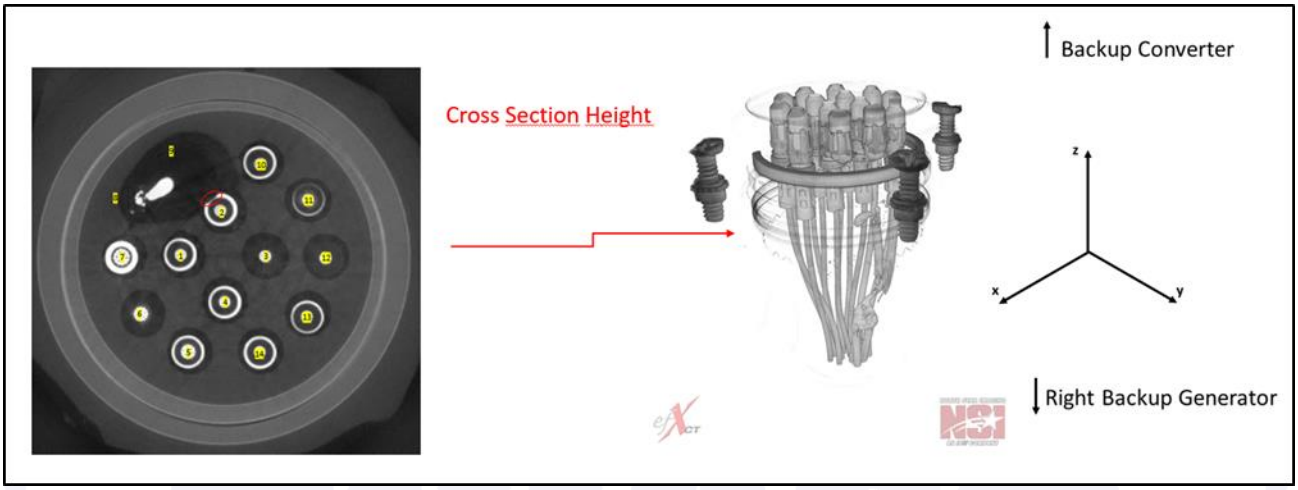

Figure 24 - Connector cross section. Part 5 of 5.

After non-destructive inspections on the connector, they proceeded to its disassemble, in order to check the internal conditions. The disassembly steps are shown in Figures 25 to 29, below:

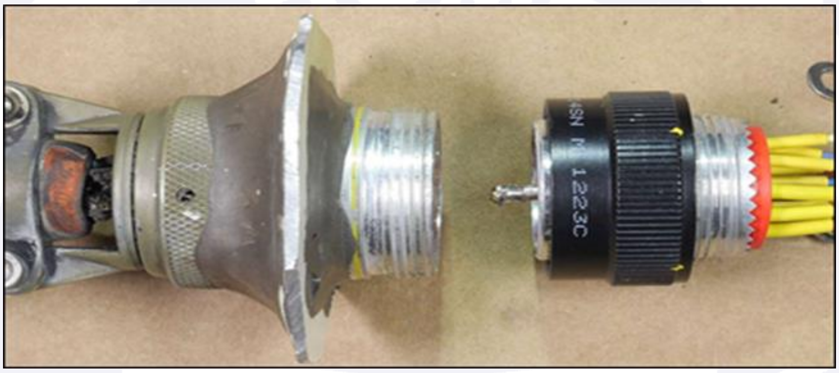

Figure 25 - Separation of the connector D7232P/J.

Figure 26 - On the left the D7232P connector and on the right the D7232J connector.

Figure 27 - D7232P connector after removing the housing.

Figure 28 - D7232P connector disassembled.

Figure 29 - Fragmented material from the disassembly of the D7232P connector.

Analyzes of the connector material were carried out in order to identify the presence of any foreign material. Due to the diversity of the connector material, it was not possible to determine if there was a foreign body inside.

Test of the Backup Converters

The Backup Converter that was installed on the occurrence flight aircraft (SN 2238) and the Backup Converter that had been removed 2 days before (SN 2246) were taken for testing in a component manufacturing and maintenance unit.

Initially, impedance measurement was performed on the two connectors of the two Backup Converters and then the bench test.

The Backup Converter (SN 2246) did not present any significant flaws in any of the tests performed.

The Backup Converter (SN 2238) failed in the impedance measurements and bench tests related to the monitoring circuit of the current transformers of the Backup Generators and the remote oil level monitoring circuit, both on level and sub-level.

In view of the results, they proceeded to dismantle the Backup Converter (SN 2238), in order to check the internal conditions. The following points were found:

- The components (Ferrite Beads) FB29 and FB30 showed visible signs of failure. These components were related to the remote oil level monitoring circuit of up-level and sub-level, respectively, on the right side.

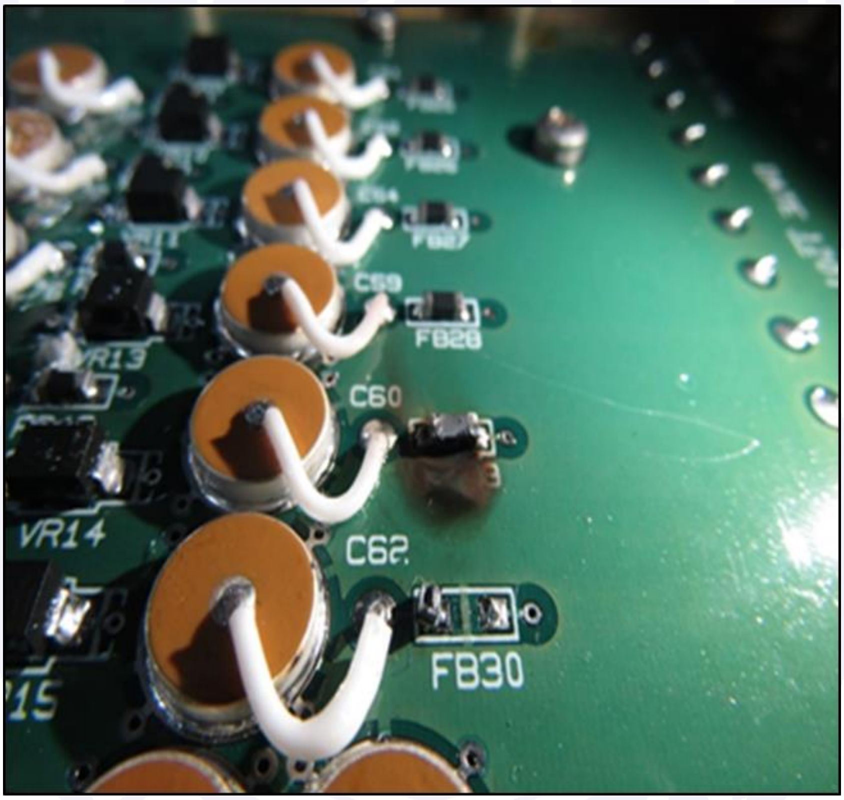

Figure 30 - Damage to components FB29 and FB30.

- The component (Resistor) R146 showed visible signs of failure. This resistor was related to the monitoring circuit of the current transformers of the Backup Generator on the right side.

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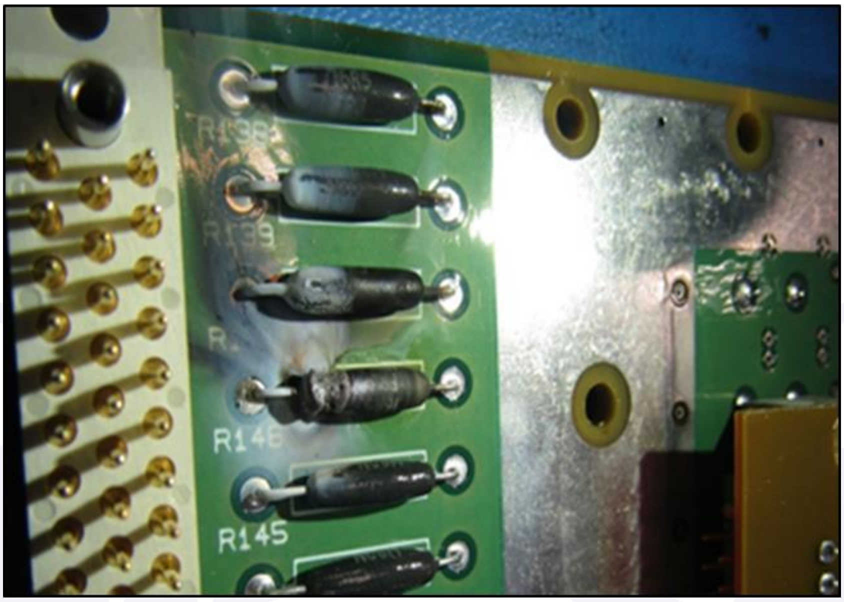


Figure 31 - Damage to resistor R146.

- No damage was found to the FB38 filter and capacitor C72 of the current transformers monitoring circuit.

- The component (Zener Diode) VR14 was tested in short-circuit. This component showed no visible signs of failure. The VR14 was related to the right circuit for remote monitoring of the oil level, over level.

- The component (FET) U15 was tested in short-circuit on pins 3-5. This component showed no visible signs of failure. The U15 was related to the right circuit for remote monitoring of the oil level, up-level.

There were indications that the components (Zener Diode) VR10 and VR11 could be damaged. These components showed no visible signs of failure.

The VR10 and VR11 were related to the left circuit for remote monitoring of the oil level, on level and sub-level, respectively.

1.17 Organizational and management information.

Nil.

1.18 Operational information.

The aircraft was within the weight and balance limits specified by the manufacturer at the time of SBGR takeoff.

The pilots' crew consisted of a Master Commander, a Commander, a 1st copilot and a 2nd copilot. All of them remained in the cabin from the moment of takeoff until the moment of landing at the Confins Aerodrome (SBCF).

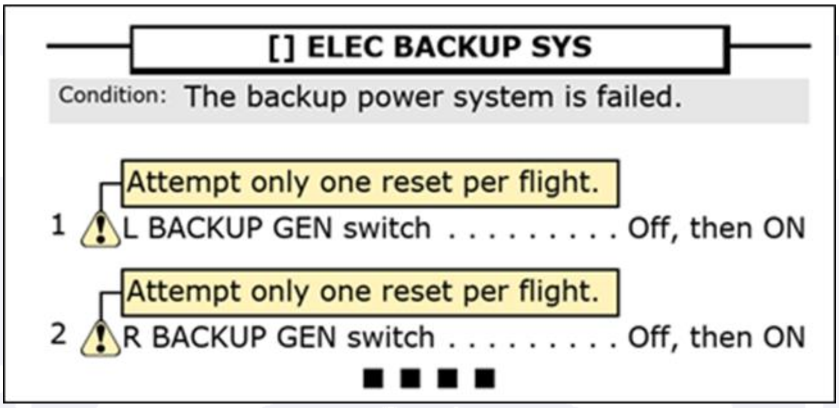
The aircraft was out of the weight limits specified by the manufacturer for landing at Confins.

The SBGR takeoff was carried out by the Master Commander, Pilot Flying (PF), and by the 2nd copilot, Pilot Monitoring (PM), without any type of complication.

Shortly before leveling the aircraft, the Master Commander changed positions with the Commander, who became a PF.

The PF carried out the leveling and the PM, as reported by him, identified the message ELEC BACKUP GEN L, followed by the message ELEC BACKUP GEN R and together they were replaced by the message ELEC BACKUP SYS, which meant that the electrical Backup system had failed.

The PM consulted the QRH and performed the procedure of restarting the system, as foreseen, taking the L BACKUP GEN switch to the OFF position and then to the position ON, later performed the same with the R BACKUP GEN switch. The procedure was unsuccessful and the aircraft continued to fail with the electrical Backup system.



[] ELEC BACKUP SYS

Condition: The backup power system is failed.

Attempt only one reset per flight.

1 L BACKUP GEN switch . . . . Off, then ON

Attempt only one reset per flight.

2 R BACKUP GEN switch . . . . Off, then ON

■ ■ ■ ■

Figure 32 - QRH extract referring to the ELEC BACKUP SYS procedure.
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According to the crew's report, the procedure described in the QRH was only performed once.

The crewmembers made contact with the operator's maintenance sector, through the VHF and, later, through the satellite phone available on the aircraft, to report the failure of the electrical Backup system. Consultations were made to the aircraft's documentation and the initial decision was to continue the flight to the aircraft's destination.

Approximately eleven minutes after the ELEC BACKUP SYS message, both the PF and the PM lost information from the two PFDs, the two NDs, the two EICAS and the two EFBs. Added to this was the simultaneous loss of primary lighting in the passengers’ cabin and the crew’s cabin, as well as an audible warning of disconnection from the autopilot, in addition to the loss of the flight director and the autothrottle.

After a few seconds, the PFD and the ND of the PF were restored, as well as those of the PM. The EICAS screens were restored approximately thirty seconds later.

When the PFD and the ND on the right side returned, the PF started using the left ND for navigation and the PM started to follow the checklist on the ND on the right. Several flaws appeared in the EICAS and were soon replaced by others of higher priority, making it difficult for the procedures described to be fully complied with.

The crewmembers activated the APU and consulted the Electrical System's Synoptic screen to determine the aircraft's power configuration. The EICAS screen displayed the left and right IDGs, the APU generator and the left Backup Generator (BUG) with available power. The right Backup Generator had an amber “X”, indicating that it was unavailable as a power source.

The aircraft presented the RAT DEPLOYED message, however the Electrical System Synoptic showed that the buses were not powered by any available source.

In the aftermath of the RAT DEPLOYED message, the crew came to think of a failure of both aircraft engines, but that possibility was quickly dismissed.

When analyzing the available information, the crew decided to adopt a more conservative posture and interpret that the electrical supply was being done by the battery and, therefore, they had approximately thirty minutes of energy.

The PF was operating the aircraft without the aid of the autopilot, the flight director and the autothrottle. Of the three VHF radios installed, only one was available for communication.

At 02h56min16s (UTC), when the crew declared an emergency, the aircraft was flying in FL290, 82 NM away from Confins and the ideal heading for the Aerodrome was 032º.

Two orbits were performed on the “TISLO” position with curves on the right. In the first, the crew tried to jettison fuel without success. In the second, the aircraft was configured for landing above the limits specified by the manufacturer.

The 1st copilot, who was seated on the right side, behind the PM, used the right EFB to consult the necessary information for the configuration of the aircraft for landing. The speed to perform the approach (Vapp) was approximately 204 kt with flaps at 20º.

The procedure performed was the ILS K RWY16 and the aircraft was in the condition of SINGLE SOURCE ILS. The final approach was intercepted by its own means. The landing was performed with approximately 80,000kg above the landing weight, with a total weight of 330,000kg.

After landing, both pilots activated the braking system and the PF activated the spoilers manually. The aircraft stopped within the runway limits, but the brakes overheated, with the onset of fire.

After the stop, when the engines were cut, the electrical system was fed back through the APU and the cameras that were facing the landing gears started to function, allowing the monitoring of the work of the firefighters.

In the crewmembers' view, the communication with firefighters was indirect and confusing. The TWR passed on incomplete information implying that they should carry out emergency evacuation. However, as they monitor the firefighting through the cameras, the crew evaluated the risk of using slides as an additional risk, not requiring their use.

The crewmembers sometimes questioned whether the fire was controlled or whether they were supposed to start an evacuation. In interviews with the TWR's controllers, it was stated that the difference between the terms was not well understood.

The disembarkation was made through the left rear door, with the coordination of the flight attendants crew.

1.19 Additional information.

The mapped failures of the electrical system and the probability of their occurrence were in the operational safety assessment document of the 777 project (777 Electrical Power Systems Safety Analysis Document).

CENIPA did not have access to this document, due to the export policies of the aircraft’s State of Design. While Boeing was not able to provide a copy of the 777 Electrical Power Systems Safety Analysis document directly to CENIPA, a relevant extract was provided to the NTSB for their review and comment.

According to the information provided by the aircraft manufacturer, the 777 Electrical Power Systems Safety Analysis Document had the prediction of simultaneous failure of the transfer buses (left and right). For the loss of both buses, the potential contributing factors were the failure of the Backup Converter, the loss of the CCBs and the loss of the Backup Generators themselves.

The risk associated with this event, according to the manufacturer's information, was assessed as Class II, Hazardous, based on exposure to the next failure considered critical, which would be the loss of RAT.

Considering the level of risk, the probability of this failure to occur should be less than $1x10^{-7}$ (a failure in 10 million flight hours).

According to the manufacturer, the probability calculated in the 777 Electrical Power Systems Safety Analysis Document was $9.6x10^{-8}$.

1.20 Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

It was a regular flight, between SBGR and EGLL, in order to carry 339 passengers.

The aircraft was climbing to the FL290 with all pilots in the cabin and after approximately 10 minutes of flight, the crew noticed the alert messages ELEC BACKUP LEFT and ELEC BACKUP RIGHT generating the message ELEC BACKUP SYS.

The alert messages that were presented to the crew through the EICAS could be associated with the following faults recorded in the Backup Converter's NVM:

- Right Generator DP Trip - Conv Fail, recorded at 02h42min10s (UTC);
- DC Content Trip - Conv Fail, recorded at 02h42min11s (UTC); and
- Left Low Oil Pressure Trip - Low Oil Pressure, recorded at 02:42min42s (UTC).

The Backup Converter monitored the Backup Generator oil level for a period of 30 to 35 seconds, using a pressure switch. Thus, although there was a difference of just over 30 seconds between the first two messages and the third, it was possible to associate that the three messages originated at the same time.

The messages recorded on the Backup Convertor NVM were consistent with a short-circuit between pins 2, 9 and 10, as shown by the x-ray of the connector's cross section.

In the condition shown in Figure 33, the overcurrent, originating from pin 9, passing through pin 10 and being directed to the energy monitoring circuit generated by the Backup Generator would be consistent with the messages Right Generator DP Trip and DC Content Trip and the damage observed in the Backup Converter.

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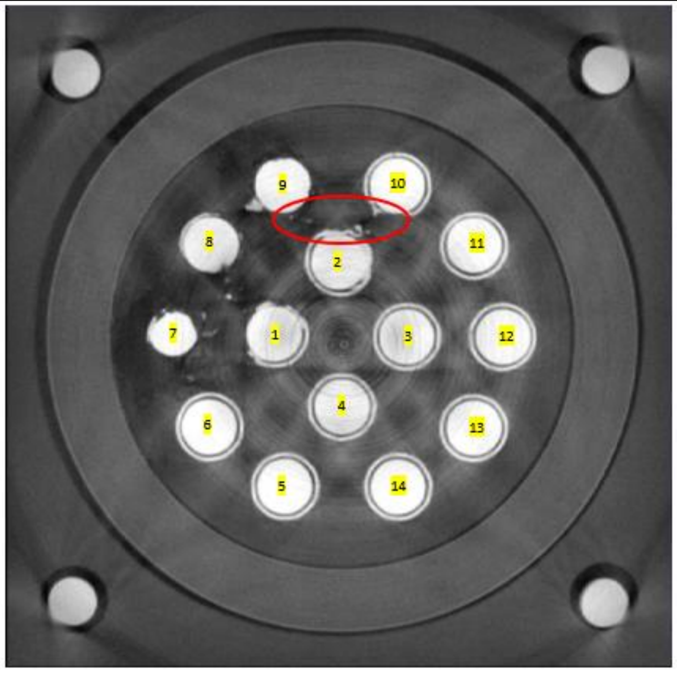

Figure 33 - Wiring condition associated with the first fault messages.

Figure 34 shows a possible path taken by the current from the short-circuit. It would have entered through pin 10, passing through resistor R146 and closing the circuit with the aircraft grounding (Chassis Gnd). This scenario would be consistent with the damage observed only in resistor R146.

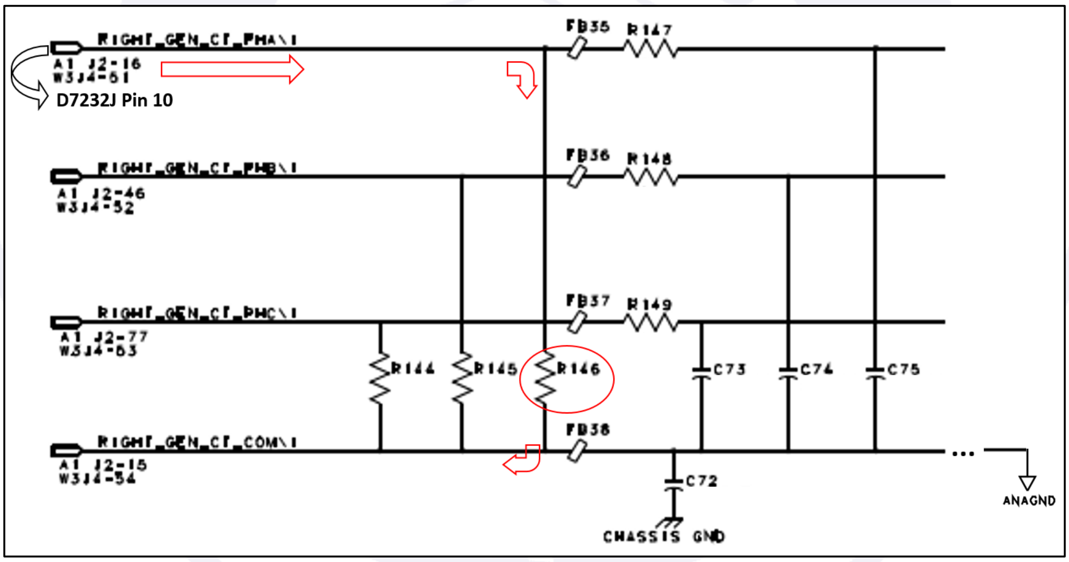

Figure 34 - Current transformers monitoring circuit. The red arrows indicate a possible current path from the short-circuit. Adapted from the Backup Converter's CMM.

Another possibility was that the high current in resistor R146 only occurred because it was associated with a second failure in the connector housing, due to the isolation of the PMG. Without the occurrence of the second fault there would be no way for the current to flow.

The reference signal called RIGHT_GEN_CT_COM, shown at the bottom of Figure 35, was connected to the internal analog ground of the Backup Converter, ANAGND, which was isolated from the Chassis Gnd.

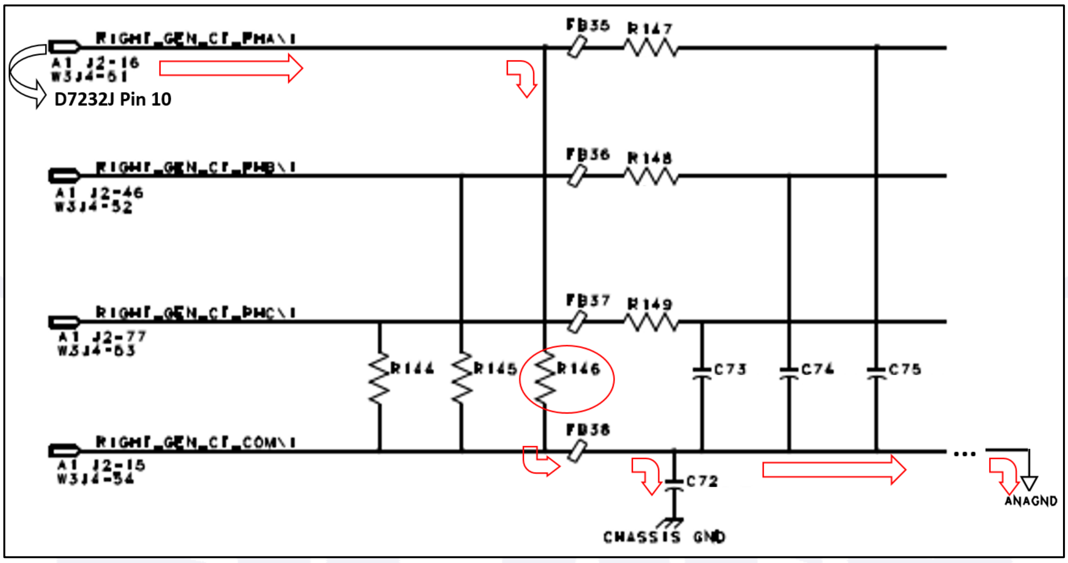

Figure 35 - Current transformers monitoring circuit. The red arrows indicate another possible current path from the short-circuit. Adapted from the Backup Converter's CMM.

Still in this scenario, in addition to the short-circuit between one of the PMG phases and the RIGHT_GEN_CT_COM signal, secondary faults may have occurred between the connector housing and one of the PMG phases, which would make it possible to create the path shown in Figure 35, being consistent with the damage found in the connector region.

However, no damage was found in the other components of the monitoring circuit of the current transformers, such as the FB38 filter and the C72 capacitor, which would be expected by the passage of a larger electrical current, out of the circuit specifications.

Regardless of which of the listed hypotheses was the expression of the event, the messages Right Generator DP Trip and DC Content Trip were translated to the crewmembers, through the EICAS, as ELEC BACKUP RIGHT.

The conditions of the connector led the short-circuit to progress to the area corresponding to pins 1, 7 and 8, responsible for the oil level monitoring circuit of the Backup Generator on the right side, as shown in Figure 36.

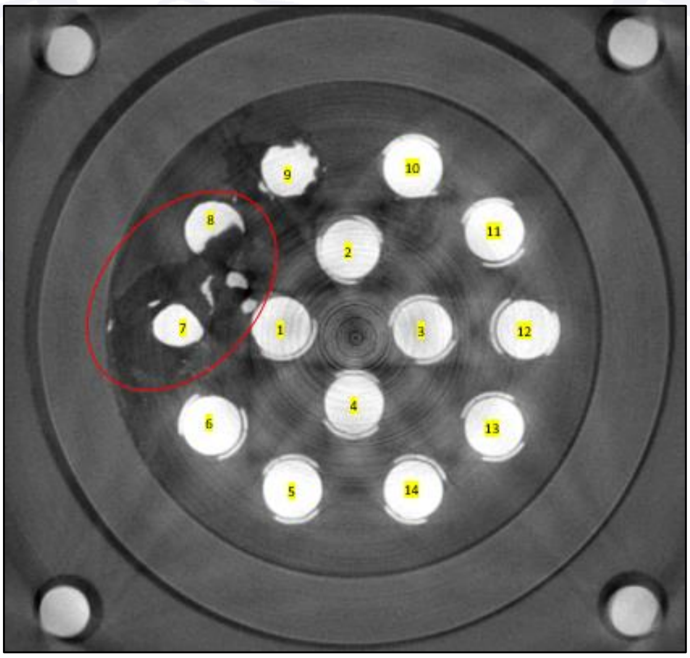

Figure 36 - Damage to pins 1, 7 and 8.

Message number 3 “Left Low Oil Pressure Trip”, related to the oil pressure of the left Backup Generator, could be associated with the damage observed between the PMG pins (7, 8 and 9) and the return pin 1 of the oil level monitoring.

The current originated from the short-circuit between the pins of the PMG and pin 1, possibly, covered the path shown in Figure 37, reaching the analog ground (ANAGND) internal to the Backup Converter. The current path is consistent with the damage found in components FB29 and VR14.

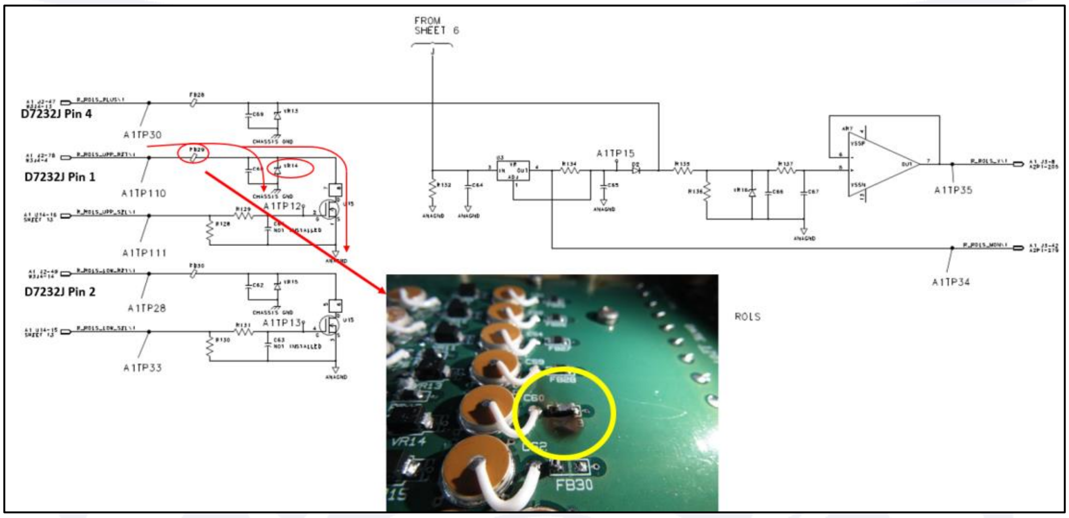

Figure 37 - Possible current path of the PMG in the internal circuits for remote monitoring of the oil level in the Backup Converter. Adapted from the Backup Converter's CMM.

Thus, the capacity of the ANAGND would have been exceeded, allowing a leakage of current in the oil level monitoring circuit on the left side to the Gnd Chassis. This current would have produced a voltage compatible with that of activating the Left Low Oil Pressure Trip message at input 3 of the AR7 amplifier (Figure 38).

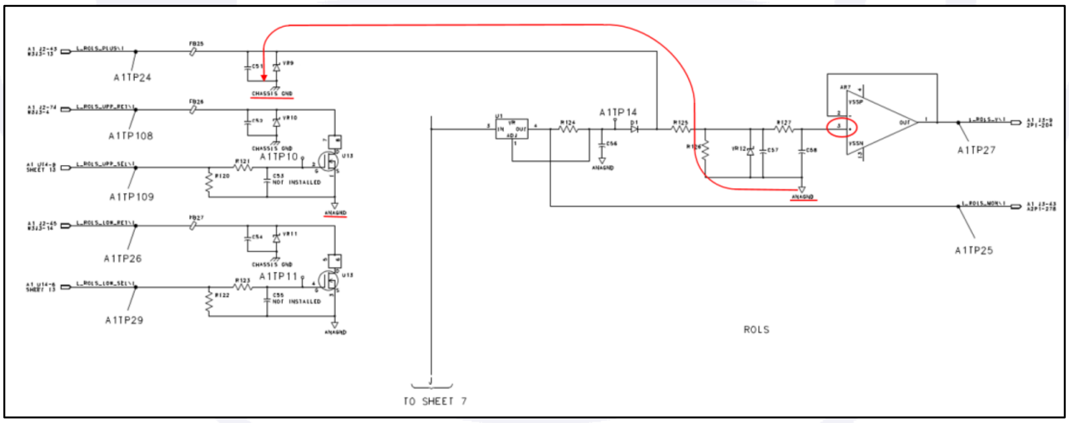

Figure 38 - Possible current path of the short-circuit in the connector related to the Left Low Oil Pressure Trip message. Adapted from the Backup Converter's CMM.

Even though the short-circuit occurred in the connector on the right side, it is possible that only the necessary conditions for the activation of the message regarding the oil level monitoring circuit on the left side (Left Low Oil Pressure Trip) have been reached or been present for the required time interval. At that time, the conditions for activating the message on the right side were not met.

The consultation to the QRH resulted in the action”, on the part of the crew, of trying to reestablish the system by carrying out the procedure of restarting it by moving the ELEC BACKUP GEN L and ELEC BACKUP GEN R switches to the OFF position and then to the

ON position. These actions resulted in messages 5 and 6 recorded by the Backup Converter's NVM transcribed below:

- GCS-L Disagreement with OPAS or Fire Handle Pulled, recorded at 2h42min49s (UTC); and

- GCS-R Disagreement with OPAS or Fire Handle Pulled, recorded at 02h43min08s (UTC).

After the actions taken by the crew, the message ELEC BACKUP SYS remained displayed on the EICAS screen.

After restarting the two Backup Generators, the crewmembers made contact with the operator's ground support team, in order to obtain more information about the failures previously presented.

Between the execution of the actions described in the QRH and the occurrence of new failures, the short-circuit in the connector remained restricted to the PMG pins (7, 8 and 9), not resulting in new failures in the Backup Converter (Figure 39).

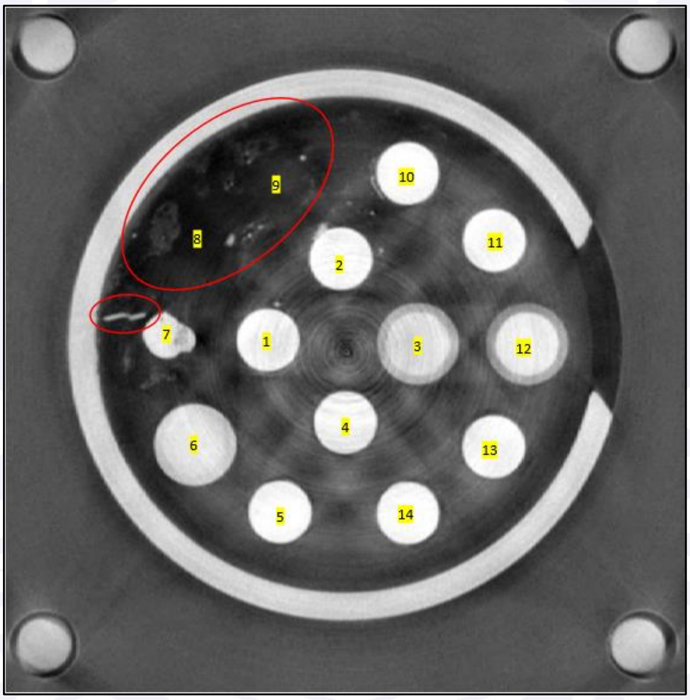

Figure 39 - Damage to pins 7, 8, 9 and in the connector housing.

Eleven minutes and fourteen seconds after the Left Low Oil Pressure Trip fault message, the information from the two PFDs, the two NDs, the two EICAS and the two EFBs was lost. There was also the simultaneous failure of the primary lighting in the passengers' cabin and the crew's cabin, as well as the audible warning of disconnection of the autopilot, the failure of the flight director and the autothrottle.

At the same time that the various systems were erased, the Backup Converter recorded a new set of failures listed below:

- Right Low Oil Pressure Trip, recorded at 02h53min56s (UTC);

- Left TBB Commanded Closed but Sensed Open, recorded at 02h53min57s (UTC);

- Left CCB Commanded Open but Sensed Closed, recorded at 02h53min57s (UTC);

- Right TBB Commanded Closed but Sensed Open, recorded at 02h53min57s (UTC); and

- Right CCB Commanded Open but Sensed Closed, recorded at 02h53min57s (UTC).

At the time of recording this set of messages, a change in the state of the connector was observed, with contact between pins 8 and 9 of the PMG and pin 2 of the oil level monitoring circuit (Figure 40).

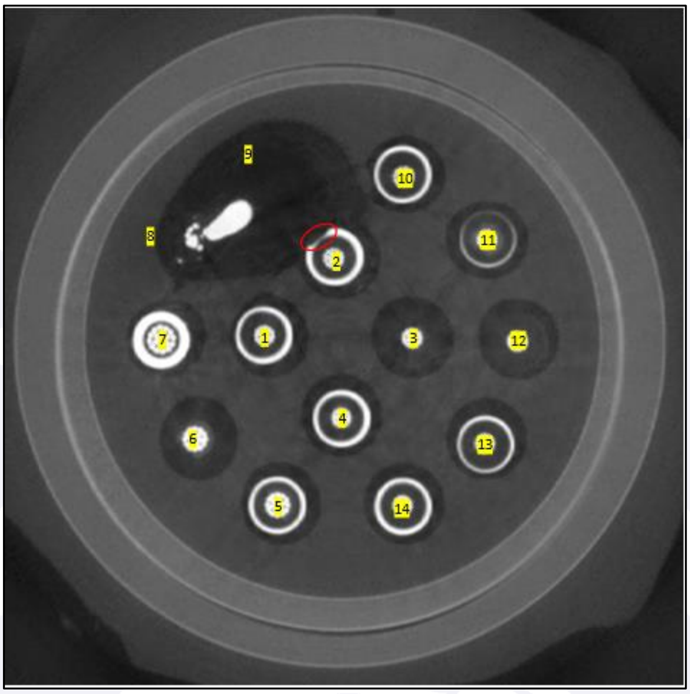

Figure 40 - Evidence of contact between pins 8 and 9 of the PMG and pin 2 of the oil monitoring circuit.

The message Right Low Oil Pressure Trip can be associated with the current originated from the short-circuit between pins 8, 9 and 2. The current path in this second short-circuit was consistent with the damage found in the Backup Converter's FB30 and U15 components (Figure 41).

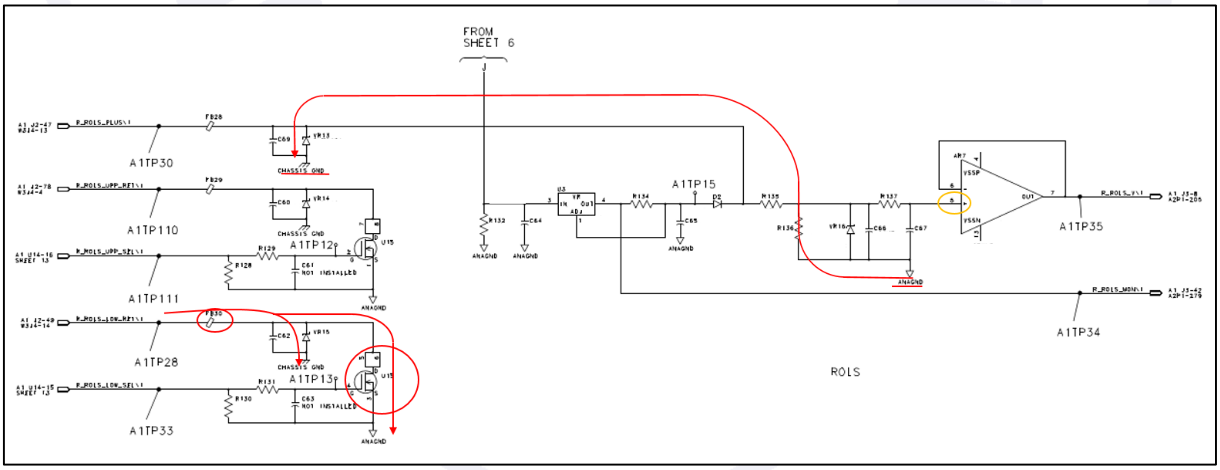

Figure 41 - Possible current path of the short-circuit in the connector related to the message Right Low Oil Pressure. Adapted from Backup Converter's CMM.

Thus, similarly to the first set of messages, the capacity of the ANAGND would have been exceeded allowing a leakage current in the oil level monitoring circuit on the right side and, soon after, in the circuit for detecting the position of the contactors (Figure 42).

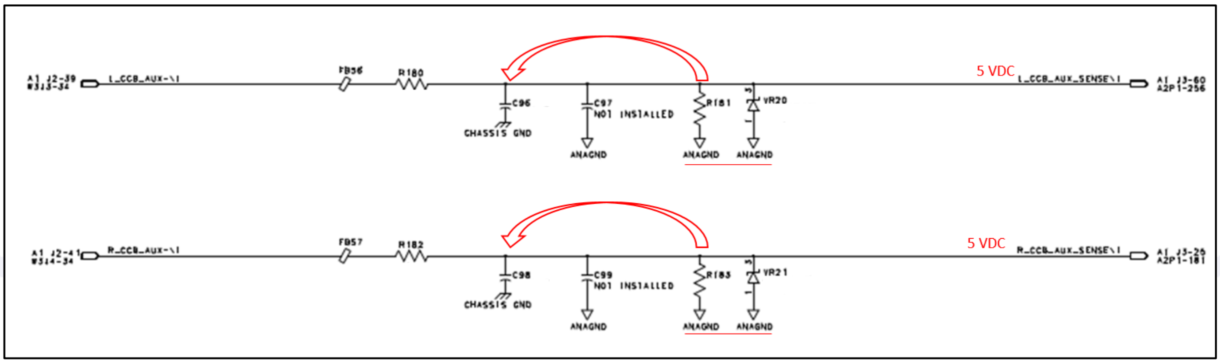

Figure 42 - Possible current path of the short-circuit of the connector affecting the monitoring circuit of the position of the contactors. Adapted from the Backup Converter's CMM.

At the time of the recording Right Low Oil Pressure Trip, the configuration of the contactors for powering the aircraft's electrical system was: TBB closed and CCB open.

The current leakage, through the ANAGND, in the monitoring circuit of the position of the contactors made the Backup Converter identify the positions of the TBB and CCB differently from their effective positions, generating four messages recorded simultaneously at 02h53min57s.

The occurrence of the four failures may have caused a deconfiguration of the aircraft's electrical system. This situation would have been maintained until the engines were shutdown, since the position of the contactors would remain locked after any monitoring failure occurred.

Another possibility would be that, according to the Backup Converter's protection logic, due to the CCB Commanded Open but Sensed Closed message or due to the TBB Commanded Closed but Sensed Open message, the Backup Converter would command the TBBs to the open position and the CCBs to the closed position.

However, even if the CCBs are in the closed position, the Backup Generators would not be available for the electricity supply. The fact that messages related to the Backup system for the generation of electric power have already occurred, generating the ELEC BACKUP SYS fault, made the Backup Generators (right and left) not available for powering the aircraft's electrical system.

Thus, the primary (IDG) and secondary (Backup Generators) energy sources were not available for the aircraft's power supply, due to the successive short-circuits occurring at the connector.

After a few seconds, with no action from the crewmembers, the PFD and the ND of the PF and of the PM were restored. The EICAS screens came back, approximately, thirty seconds later. This can be attributed to the use of the aircraft's battery.

The crewmembers activated the APU in an attempt to have a source providing power for the aircraft systems, however, the action did not change the power condition, since the TBBs were open.

That said, it is possible to conclude that the transfer buses were not being electrically powered and, consequently, the RAT was activated.

Even after the aircraft started to use the Standby system, the volume of fault messages that appeared in the EICAS hindered the total understanding of what was happening, on the part of the crew, as new warnings were constantly appearing and with priority over the previous ones.

This dynamics may have made it difficult for the pilots to identify how the aircraft's electrical power was being distributed, since it was attempted to jettison fuel to avoid overweight landing, even though this was not possible, as the pumps were powered by the main DC bus on their respective side that did not receive power in the Standby power configuration.

Despite the difficulty of correctly identifying how the aircraft was being powered, through the communications and recordings that the Investigation Team had access to, it was clear that all the resources available to the crewmembers were used and that the tasks were divided to not generate work overload for the cabin occupants.

It was also possible to deduce, based on the data collected, that, despite experiencing a situation in flight unprecedented to all, there was no change in the emotional state of the crewmembers to the point of interfering in the operational performance.

The good interaction they maintained favored both the maintenance of spirits in the cabin and the assessment of the situation for making safe and necessary decisions, considering the scenario faced.

The overweight landing caused the brakes to overheat, making the tires to deflate through thermal fuses and a beginning of fire, which was fought by the Aerodrome firefighters.

After the total stop of the aircraft, the crew shut the engines down, thus interrupting the operation of the PMG. At that moment, the power supply to the Backup Converter would have been interrupted. Thus, the contactors returned to their non-energized positions, that is, TBB closed and CCB open.

With this, the aircraft started to be powered by the APU (through TBB) that had been turned on, after the loss of power by the main and backup mode, and kept in this condition during the rest of the flight.

The reconfiguration of the contactors and, consequently, the restoration of the aircraft's electrical power through the APU allowed the crew to monitor, from the cabin, the action of the firefighters and the situation of the landing gear through the cockpit display that showed the landing gear images.

Communications between the crewmembers and the TWR-CF presented difficulty in understanding the difference between the terms evacuation and disembarkation by the TWR controllers at the Aerodrome, which was confirmed in the interviews.

Communications indicated that the two terms were used synonymously, prompting the crewmembers to ask several questions about the need to command the emergency evacuation or wait for a landing using the stairs.

Additionally, the congestion of the phone in the communications of the emergency teams at the airport made it difficult for the TWR-CF to obtain the information requested by the aircraft, particularly in relation to the need of performing an evacuation or disembarkation, since there was no direct communication between the aircraft and the firefighters.

Based on the information available on the aircraft's cameras and because they realized that communications regarding the need for emergency evacuation were not consistent with the images they received, the crewmembers considered it safer and chose not to command the evacuation. They considered that the unnecessary use of slides would pose an additional risk to aircraft occupants.

The actions and procedures provided for in the SBCF Emergency Plan and Inoperative Aircraft Removal Plan (PLEM / PRAI), last revised on 09JUL2018, PLN-SAE-001, were valid and correct, however, in terms of the flow of communications, the need for improvement was identified.

The disembarkation was carried out through conventional stairs, which was positioned on the left rear door of the aircraft, and no occupants suffered injuries during the abandonment.

According to the research carried out, it was possible to rule out that the origin of the short-circuit was due to its manufacturing process, since the time between the occurrence and the manufacture of the aircraft was approximately 26 thousand flight hours. Nor were found any environmental conditions external to the connector that could have contributed to the occurrence of the short-circuit.

In addition, no evidence was found in the Backup Generator that could be associated with the origin of the short-circuit, with the imbalance of the PMG phases and the damage observed in its stator related to the consequences of failures in the connector.

The connector region was checked in a scheduled inspection (2,250 days check) of the aircraft that took place between 13MAY2018 and 10JUN2018. However, the maintenance task performed did not previse the opening or manipulation of the D7232 connector.

On 12JUL2018, approximately one month after the scheduled inspection, a maintenance intervention was performed motivated by the failure message “Backup Gen Remote Oil Level Sense/Low Oil Pres Circuit (R) is failed”.

The maintenance task was performed according to the FIM manual 24-25-00-810-804 and prevised the verification of the Backup Generator oil level sensors, the measurement of the wiring resistance of the pins 1, 2 and 4 that passed connector D7232 and, finally, the replacement of the Backup Converter.

Thus, the replacement of the Backup Converter (BUC SN 2238 removed and BUC SN 2246 installed) indicated that the resistance of pins 1, 2 and 4 was within the expected values and, as the measurement of the other pins was not required, there was an indication of a possible connector failure that could result in the short-circuit.

On 18DEC2018, a new Backup Converter replacement was performed (BUC SN 2246 removed and BUC SN 2238 installed), this time motivated by the Elec Backup Gen R failure; being performed the failure research task related to the FIM 24-25-09-00-810-802.

During the first stage of the failure investigation, after replacing the Backup Converter, the aircraft was considered ready for return to service. That said, it was not required to continue the failure investigation, and several wiring pins were not checked between the Backup Converter and the Backup Generator, including the PMG pins.

After the installation of the Backup Converter SN 2238, the aircraft performed two flights between the cities of São Paulo and Miami, totaling approximately 15 flight hours and 2 cycles, with no record of new failures. The next flight, on 20DEC2018, was the one in which the failures related to this serious incident occurred.

Thus, despite the examinations, tests and research carried out, it was not possible to identify the origin of the short-circuit in the connector, since they were not identified: foreign material inside; environmental factors that could have contributed to the short-circuit; or maintenance procedures that could be associated with incorrect handling of the wiring harness and connector.

3. CONCLUSIONS.

3.1 Facts.

a) the pilots had valid CMAs;

b) the commanders had valid B777 aircraft type Rating (which included the 777-32WER model), PLA and IFRA Ratings;

c) the copilots had valid B777 aircraft type Rating (which included the 777-32WER model), PCM and IFRA Ratings;

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

e) the aircraft had valid CA;

f) the aircraft was within the weight and balance limits to perform the flight until its destiny (EGLL);

g) the technical maintenance records were updated;

h) the operator followed the Operator Maintenance Program, inspection 17 of 04NOV2016, approved by the ANAC;

i) the damaged connector area was inspected during a 2,250-day check between 13MAY2018 and 10JUN2018;

j) the Backup Converter AAA4002238 was removed on 12JUL2018, after registering the failure message Without oil indication of the BUG RH;

k) the Backup Converter AAA4002246 was installed on 12JUL2018, after registering the failure message Without oil indication of the BUG RH;

l) the Backup Converter AAA4002238 was considered repaired on 27AUG2018;

m) the Backup Converter AAA4002246 was removed on 18DEC2018, after the registration of the failure message Elec Backup Gen R;

n) the Backup Converter AAA4002238 was installed on 18DEC2018, after recording the failure message Elec Backup Gen R;

o) the weather conditions were favorable for the flight;

p) at 02h42min10s (UTC), three fault messages related to the Electrical Backup System were recorded. The messages were displayed to the crewmembers as ELEC BACKUP SYS;

q) the crewmembers performed the ELEC BACKUP SYS checklist procedures. Due to these actions, two other failure messages were generated;

r) about eleven minutes after the first messages related to the Electric Backup System, five other failure messages were recorded by the Backup Converter NVM;

s) at approximately 02h53min (UTC), there was a failure of the Main and Backup Electrical System, causing the de-energization of several aircraft functions;

t) the PF and the PM lost information about the two PFDs, the two NDs, the two EICAS and the two EFBs;

u) the automatic pilot was disconnected;

v) the flight director and the autothrottle function were lost;

w) after a few seconds, the PFD and ND were restored;

x) the EICAS screens were restored approximately thirty seconds after the PFD and ND;

y) the crewmembers activated the APU;

z) the Synoptic screen of the electrical system showed the left and right IDGs, the APU generator and the left BUG with available power;

aa) the Synoptic screen of the Electrical System displayed an amber “X” for the right Backup Generator, indicating that it was unavailable as a power source;

bb) the message RAT DEPLOYED occurred;

cc) at 02h56min16s (UTC) the crewmembers declared an emergency;

dd) the aircraft was above the weight limit for landing on SBCF;

ee) the crew kept radio contact with the control agencies;

ff) there was no technical abnormality of the communication equipment that prevented or hindered the transmission and understanding of messages;

gg) the aircraft stopped within the runway limits;

hh) the brakes overheated with the beginning of fire;

ii) the SBCF’s SCI carried out the fire fighting, which was controlled in 4 minutes;

jj) the crewmembers saw that the fire condition on the landing gear was controlled during the performance of the SCI;

kk) the crewmembers considered that there was no need to command evacuation of the aircraft through the emergency doors and slides;

ll) communications between the aircraft and the emergency teams were performed on a communication bridge by the TWR-CF;

mm) the terms evacuation and disembarkation were used interchangeably by the TWR-CF;

nn) the exchanges of messages between the TWR-CF and the emergency teams took place in a single communication channel;

oo) disembarkation was carried out through conventional stairs positioned on the left rear door of the aircraft;

pp) the aircraft had minor damage; and

qq) all occupants left unharmed.

3.2 Contributing factors.

- **Project – undetermined.**

The deconfiguration of the TBB and CBB, regardless of whether it was caused by the failures in the monitoring circuit of the contactors' position or due to a combination of these with previous failures of the oil level monitoring circuit, made the Main and Backup Electrical Systems unable to power the aircraft, even with power generation.

Even though it was not possible to determine how the short-circuit started in the connector or even to indicate the dynamics of the CBB and TBB deconfiguration, it is a fact that the failure generated a series of as-designed system reconfigurations, preventing the supply of the Main Electrical Systems and Backup, despite the generation of energy.

The loss of the Main and Backup System, due to the occurrence of a short-circuit in a connector and its splits, causing a deconfiguration of the TBB and CCB contactors, to the point of having their risk assessed as Class II, Hazardous, based on the exposure to the next critical fault, which would be the loss of RAT, could indicate a weakness in the aircraft's electrical system design.

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 Air Space Control Department (DECEA):

IG-190/CENIPA/2018 - 01 **Issued on 07/08/2021**

Work with the ATC agencies to ensure that their controllers have the correct understanding of the difference between a landing procedure and an aircraft evacuation.

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

IG-190/CENIPA/2018 - 02 **Issued on 07/08/2021**

Assess the need and relevance of regulatory adjustments, which determine the requirement that rescue and fire teams have direct VHF communication with aircraft involved in emergencies at the Aerodrome.

IG-190/CENIPA/2018 - 03 **Issued on 07/08/2021**

Work with the BH Airport S.A. to evaluate the possibility of improving the PLEM / PRAI of the SBCF Aerodrome, regarding the flow of communications in emergencies between all agencies, in order to improve communication in situations of engagement by the SESCINC teams.

IG-190/CENIPA/2018 - 04 **Issued on 07/08/2021**

Work together with the Boeing Company to make sure that, considering the events observed in this serious incident and the level of risk assessed as Class II, the probability of occurrence of this failure has remained less than $1x10^{-7}$ (one failure in 10 million flight hours).

To the Federal Aviation Administration (FAA):

IG-190/CENIPA/2018 - 05 **Issued on 07/08/2021**

Work together with the Boeing Company to make sure that, considering the events observed in this serious incident and the level of risk assessed as Class II, the probability of occurrence of this failure has remained less than $1x10^{-7}$ (one failure in 10 million flight hours).

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

None.

On July 8th, 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, the United States of America forwarded the document 66-CB-H220-ASI-19210, containing comments from the aircraft manufacturer's The Boeing Company.

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 15

Text to be corrected (Chapter 1, Page 37, Lines 38-41)

The Investigation Team did not have access to this document, due to the export policies of the aircraft's State of Design.

Text proposed by the NTSB

CENIPA did not have access to this document, due to the export policies of the aircraft's State of Design. In accordance with ICAO Annex 13 guidelines, the document was instead reviewed by the National Transportation Safety Board of the United States.

CENIPA's Opinion

Partially incorporated.

CENIPA's Argumentation

The text was changed in order to make it clearer.