COMANDO DA AERONÁUTICA
CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
A-116/CENIPA/2024

OCCURRENCE:	**ACCIDENT**
AIRCRAFT:	**PS-VPB**
MODEL:	**ATR-72-212A (500)**
DATE:	**09AUG2024**

NOTICE

According to the Law n° 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 considering 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 distinct 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 Final Report has been made available to the ANAC and the DECEA so that the technical-scientific analyses of this investigation can be used as a source of data and information, aiming at identifying hazards and assessing risks, as set forth in the Brazilian Program for Civil Aviation Operational Safety (PSO-BR).

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 n° 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 lead 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. Considering 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 Final Report pertains to the 09AUG2024 accident with the model ATR-72-212A (500) aircraft of registration marks PS-VPB. The occurrence was typified as [ICE] Icing, [SCF-NP] System/component failure or malfunction (non-powerplant) and [LOC-I] Loss of control in flight.

The aircraft was dispatched with the Airframe De-Icing system inoperative and during the cruise phase, the aircraft encountered adverse meteorological conditions associated with severe icing. This condition led to excessive ice accretion on critical aircraft surfaces, increased aerodynamic drag, a significant reduction in airspeed, and the activation of multiple warning and caution alerts.

As a consequence, the aircraft entered a stall condition, initiating a descending trajectory in an abnormal attitude, subsequently evolving into a flat spin, which resulted in impact with the ground in a residential area of the municipality of *Vinhedo*, State of *São Paulo*.

The aircraft was destroyed.

The 4 crew members and the 58 passengers sustained fatal injuries.

Canada, as the State of manufacture of the aircraft engines, designated an accredited representative from the TSB (Transportation Safety Board) to take part in the investigation of this accident.

France, as the State of design and manufacture of the aircraft, designated an accredited representative from the BEA (*Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile*) for participation in the investigation of the accident.

Due to the presence of Venezuelan nationals among the casualties, the Venezuelan Accident Investigation Authority (JIAAC) designated a specialist to participate in the investigation.

Due to the presence of Portuguese nationals among the casualties, the Portuguese Accident Investigation Authority (GPIAAF) designated a specialist to take part in the investigation.

TABLE OF CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

ABN	Abnormal Procedure
AC	Altocumulus cloud
AC	Alternating Current
ACMS	Aircraft Condition Monitoring System
ACR	Deferred Corrective Action
AD	Airworthiness Directive
ADF	Automatic Direction Finder
AFCS	Automatic Flight Control System
AFM	Aircraft Flight Manual
AGL	Above Ground Level
AGS	Application Generation Software
ALT	Altitude Mode
AMM	Aircraft Maintenance Manual
ANAC	Brazil’s National Civil Aviation Agency (*Agência Nacional de Aviação Civil*)
AOA	Angle of Attack
AOM	All Operators Message
AP	Autopilot
APM	Aircraft Performance Monitoring
APP	Approach Control
APP-SP	*São Paulo* Approach Control
APRS	Approval for Return to Service
AS	Altostratus cloud
ATA	Air Transport Association
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATPCS	Automatic Takeoff Power Control System
ATR	GIE Avions de Transport Régional
AUTO TRIM	Automatic Pitch Trim
BC	Back Course
BCAST	Brazilian Commercial Aviation Safety Team
BEA	*Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile*
BITE	Built-In Test Equipment
CADE	Administrative Council for Economic Defense

CAM	Cockpit Area Microphone
CAP	Crew Alerting Panel
CB	Cumulonimbus cloud
CBMSP	*São Paulo* State Military Fire Brigade
CCAS	Centralized Crew Alerting System
CCO	Operations Control Center
CENIPA	Center for Investigation and Prevention of Aeronautical Accidents
CFR	Code of Federal Regulations
CG	Center of Gravity
CIMAER	Integrated Aeronautical Meteorology Center
CIV	Digital Individual Flight Logbook
CL	Condition Lever
CMA	Aeronautical Medical Certificate
CMC	Central Maintenance Computer
CMS	Flight Attendant License
COA	Air Operator Certificate
COM	Maintenance Organization Certificate
CRM	Crew Resource Management
CRZ	Cruise
CSN	Cycles Since New
CUSC	Cumulus-Stratocumulus cloud
CVA	Certificate of Airworthiness
CVR	Cockpit Voice Recorder
CX	Drag Coefficient
DAR	Digital ACMS Recorder
DC	Direct Current
DDV	Dual Distributor Valves
DECEA	Department of Airspace Control
DOV	Flight Dispatcher
EAD	Distance Learning
EASA	European Union Aviation Safety Agency
ECS	Environmental Control System
ECTM	Engine Condition and Trend Monitoring
EEPROM	Electrically Erasable Programmable Read-Only Memory
EFIS	Electronic Flight Instrument System
EMA	Upper-Air Meteorological Station/
EOBT	Estimated Off-Block Time
ETOPS	Extended-range Twin-engine Operational Performance Standards
F/O	First Officer

FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FCST	Forecast
FDA	Flight Data Analysis
FDAU	Flight Data Acquisition Unit
FDM	Flight Data Monitoring
FDR	Flight Data Recorder
FF	Fuel Flow
FFS	Full Flight Simulator
FGTS	Severance Indemnity Fund
FIN	Fairing Identification Number
FIR	Flight Information Region
FL	Flight Level
FMS	Flight Management System
FOD	Foreign Object Damage
FOIM	Flight Operations Information Message
FOQA	Flight Operations Quality Assurance
FSTD	Flight Simulation Training Devices
GAMET	General Aviation Meteorological Forecast
GOES	Geostationary Operational Environmental Satellite
GPIAAF	Portugal's *Gabinete de Prevenção e Investigação de Acidentes com Aeronaves e de Acidentes Ferroviários*
GRSO	Gerenciamento dos Riscos à Segurança Operacional
HDG	Heading
HP	High Pressure
HQ	High Quality
HQC	High Quality Combined
HSI	Hot Section Inspection
IAS	Indicated Airspeed
ICAO	International Civil Aviation Organization
ICE	Ice formation
IEP	Ice Evidence Probe
IFR	Instrument Flight Rules
IFRA	Instrument Flight rating – Airplane
ILS	Instrument Landing System
IPC	Illustrated Parts Catalogue

IS	Supplementary Instruction
ITT	Interstage Turbine Temperature
JAR	Joint Aviation Requirements
JIAAC	*Junta Investigadora de Accidentes e Incidentes de Aviación Civil*
LABDATA	Flight Recorders Readout and Analysis Laboratory
LH	Left-hand
LNAV	Lateral Navigation
LOC-I	Loss of Control in Flight
LP	Low Pressure
LPC	Low Pressure Compressor
M	Maintenance Procedures
MCC	Maintenance Control Center
MCT	Maximum Continuous Thrust
MEL	Minimum Equipment List
METAR	Routine Meteorological Aerodrome-Report
MFC	Multi-Functional Computer
MGO	General Operations Manual
MGSO	Safety Management Manual
MOP	MEL Operational Part
MPC	Multi-Purpose Computer
MPD	Maintenance Planning Document
MSIS	Minimum Severe Icing Speed
MTOW	Maximum Takeoff Weight
NAV	Navigation
NH	High Pressure Spool Speed
NI	Number Installed
NL	Low Pressure Spool Speed
NM	Nautical Miles
NO GO	Condition that prevents an aircraft from being dispatched for flight
NP	Propeller RPM
NR	Number Required
NSCA	Brazilian Air Force Systemic Standard
NTSB	National Transportation Safety Board
O	Operational Procedures
OACI	ICAO – International Civil Aviation Organization
OM	Maintenance Organization

OVRD	Override
P&WC	Pratt & Whitney Canada
PAADV	Flight Data Monitoring and Analysis Program
PCM	Commercial Pilot License – Airplane
PIC	Pilot in Command
PL	Power Lever
PLA	Power Lever Angle
PLA	Arline Transport Pilot – Airplane
PMAC	Approved Maintenance Program
PCMCIA	Personal Computer Memory Card International Association
PN	Part Number
PPR	Private Pilot License – Airplane
PROM	Flash Programmable Read-Only Memory
PSAC	Civil Aviaiton Service Providers
PSO-BR	Brazilian Program for Civiol Aviation Safety
PSOE	Specific Civil Aviation Safety Program
PTO	Operations Training Progbram
PWR MGT	Power Management
QAR	Quick Access Recorder
QRH	Quick Reference Handbook
RA	Precipitation of Rain
RALT	Radio Altimeter
RBAC	Brazilian Civil Aviation Regulation
RGB	Reduction Gearbox
RH	Right-hand
RI	Rectification Interval
SASC	Continuous Analysis and Oversight System
SAT	Static Air Temperature
SB	Service Bulletin
SBBS	*Brasília* Flight Information Region Designator
SBCA	ICAO location designator – *Coronel Adalberto Mendes da Silva* Aerodrome, *Cascavel*, State of *Paraná*
SBCW	*Curitiba* Flight Information Region Designator
SBGR	ICAO location designator – *Guarulhos – Governador André Franco Montoro* – International Airport, *Guarulhos*, State of *São Paulo*

SBIP	ICAO location designator – *Usiminas* Aerodrome, *Santana do Paraíso*, State of *Minas Gerais* (MG)
SBJA	ICAO location designator – *Regional Sul* Aerodrome, *Jaguaruna*, State of *Santa Catarina* (SC)
SBKP	ICAO location designator – *Viracopos* Airport, *Campinas*, State of *São Paulo* (SP)
SBMK	ICAO location designator – *Mário Ribeiro* Aerodrome, *Montes Claros*, State of *Minas Gerais* (MG)
SBMT	ICAO location designator – *Campo de Marte* Aerodrome, *São Paulo*, SP
SBRF	ICAO location designator – Gilberto Freyre Airport, *Recife*, *Pernambuco*
SBRP	ICAO location designator – *Leite Lopes* Aerodrome, *Ribeirão Preto*, SP
SBSV	ICAO location designator – *Deputado Luís Eduardo Magalhães* Airport *Salvador*, State of Bahia (BA)
SEV ICE	Severe Icing
SIC	Second in Command
SIGMET	Significant Meteorological Information
SIGWX	Significant Weather
SIPAER	Aeronautical Accidents Investigation and Prevention System
SLD	Supercooled Large Droplets
SMS	Safety Management System
SN	Serial Number
SOP	Standard Operating Procedures
SPECI	Aviation Selected Special Weather Report
SPS	Stall Protection System
SQ	Standard Quality
ST	Stratus cloud
STAR	Standard Termianl Arrival Route
TAF	Terminal Aerodrome Forecast
TAT	Total Air Temperature
TCAS	Traffic Collision Avoidance System
TCU	Towering Cumulus cloud
TLB	Technical Logbook
TPR	Scheduled Public Air Transport
TSB	Transportation Safety Board of Canada
TSN	Time Since New
TSO	Time Since Overhaul

UPRT	Upset Recovery Training
UTC	Universal Time Coordinated
V_{APP}	Approach speed
VmLB0icing	Minimum Maneuvering Speed in Low Bank, Flaps 0°, in Icing Conditions
VHF	Very High Frequency
V_{REF}	Reference Landing Speed
VS	Vertical Speed
YD	Yaw Damper

1. FACTUAL INFORMATION.

Aircraft	**Model:** ATR-72-212A (500) **Registration:** PS-VPB **Manufacturer:** ATR – *GIE Avions de Transport Régional.*	**Operator:** *Passaredo Transportes Aéreos S.A.*
Occurrence	**Date/time**: 09AUG2024 – 16:22 (UTC) **Location:** Residential Area. **Lat.** 23°02’59”S **Long.** 047°01’12”W **Municipality – State:** *Vinhedo – São Paulo.*	**Type(s):** [ICE] Icing [LOC-I] Loss of control - inflight [SCF-NP] System/component failure or malfunction (non-powerplant)

1.1. History of the flight

At 14:58 UTC, the aircraft departed from SBCA (*Coronel Adalberto Mendes da Silva* Aerodrome, *Cascavel*, State of *Paraná*), bound for SBGR (*Guarulhos – Governador André Franco Montoro* – Airport, *Guarulhos*, State of *São Paulo*) in order to conduct a scheduled public air transport flight, with 4 crew members and 58 passengers on board.

During the en-route phase of the flight at FL170, after encountering severe icing conditions, the aircraft entered a stall condition, initiating a descending trajectory in an abnormal attitude, subsequently evolving into a flat spin, which resulted in impact with the ground in a residential area within the municipality of *Vinhedo*, State of *São Paulo*.

1.2. Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	4	58	-
Serious	-	-	-
Minor	-	-	-
None	-	-	-

1.3. Damage to the aircraft

The aircraft was destroyed. In general, there were deformations and fractures throughout the fuselage due to the high-energy impact with the ground.

The aircraft had part of the right wing torn off, the tail cone was severed, both engines sustained substantial damage along their entire length, and the propellers were fractured as a result of the ground impact.

Following the collision, a post-impact fire occurred, which increased the extent of the aircraft’s destruction, especially in the mid-fuselage section, from the wing area to the aft portion, where the fire was more intense.

The forward fuselage section remained relatively preserved when compared to the rest of the aircraft, as it was not affected by the fire.

Figure 1 – General view of the aircraft after ground impact and post-impact fire.

1.4. Other damage

The impact of the aircraft with the ground resulted in the projection of debris in multiple directions. The affected residences sustained damage to walls, partitions, columns, beams, and roofs, caused both by the violent impact of aircraft fragments and by the resulting fire.

Additionally, two vehicles that were parked near the impact site, in the garage of the residence that contained most of the wreckage, were completely destroyed by the fire resulting from the accident (Figure 2).

Figure 2 – Vehicles destroyed in the vicinity of the wreckage.

1.5. Personnel information

1.5.1. Crew's flight experience

Hours Flown		
	PIC	SIC
Total	5,248:50	5,143:55
Total in the last 30 days	59:18	02:36
Total in the last 24 hours	02:36	02:36
In this type of aircraft	665:54	3,543:55
In this type in the last 30 days	59:18	02:36
In this type in the last 24 hours	02:36	02:36

Note: Flight-hours data obtained through the pilots' individual digital flight-logbooks (CIV).

1.5.2 Personnel training

The Pilot in Command (PIC) completed his PPR course (Private Pilot – Airplane) in 2009, at *Aeroclube de Jundiaí*, State of *São Paulo*. In 2012, he earned his PCM license (Commercial Pilot – Airplane) and, in 2015, his PLA license (Airline Transport Pilot – Airplane).

The Second in Command (SIC) completed the PPR course in 1981, at *Aeroclube de São Paulo*, State of *São Paulo*, and earned his PCM license in 1984.

The Lead Flight Attendant completed the Flight Attendant Course (CMS) at *Aerosul Escola de Aviação Civil Ltda.* and obtained her CMS license in 2018.

The other Flight Attendant completed the CMS course at Sky Angels *Escola de Aviação Civil* and obtained her CMS license in 2023.

1.5.3. Category of licenses and validity of certificates and ratings

The PIC held a PLA license and had valid type ratings for AT47 type aircraft (which included the ATR-72-212A [500] aircraft model) as well as for IFRA (IFR Flight – Airplane).

The SIC held a PCM license and had valid ratings for AT47 type aircraft and IFRA.

Both flight attendants held CMS licenses and valid AT47 type aircraft ratings.

1.5.4 Qualification and experience for the type of flight

Most of the PIC's professional experience was as a co-pilot, particularly on jet aircraft. He began his career in commercial aviation at another Brazilian company. After that company ceased operations, he had a brief period in executive aviation.

Subsequently, the PIC taught in flight attendant training courses and later worked as an airline transport pilot in Kazakhstan. He worked a few months in that country and, for personal reasons, returned to Brazil, where he was hired in November 2022 by the operator for whom he worked until the date of the accident.

He also had previous experience in general aviation, with approximately 1,205 flight hours, in addition to about 3,332 hours on jet aircraft, particularly on the Airbus A320 and A330 models.

At the time of his most recent hiring, he had no prior experience regarding the aircraft type in question. During his tenure with the company, he accumulated 155 flight hours as a co-pilot and was subsequently promoted to captain, totaling 665 hours on the aircraft type.

The SIC began his aviation career at an air taxi company in the northern region of the country. Seeking professional advancement, he was hired by a scheduled air transport company, which was later acquired by another Brazilian airline. Despite this acquisition, the acquiring company decided to retain some personnel, including the SIC. At the end of his employment with that company, he was hired in August 2019 by the operator for whom he worked until the date of this accident.

The SIC accumulated a total of 5,143 flight hours, including approximately 1,600 hours in general aviation, 1,800 hours in scheduled air transport operations, and 1,700 hours with the operator. He had prior experience on the ATR model, totaling 3,543 hours on that aircraft type.

Supplementary Instruction (IS) No. 121-021, Revision A, related to Section 121.423 of the Brazilian Civil Aviation Regulation No. 121 – Operating Requirements: Domestic Air Transport, International Air Transport, and Supplemental Operations, issued by the National Civil Aviation Agency (ANAC), which addressed Upset Recovery Training (UPRT), established the minimum acceptable methods for flight crews operating under this RBAC.

This training was applicable to airplanes equipped with a Flight Simulation Training Device (FSTD) specific to the aircraft type.

The lesson plan approved by the company's Training Management included, within its syllabus, a phase dedicated to recovery from unusual attitude. This stage of the training was essential to ensure that pilots were prepared to recognize and respond appropriately to flight situations that deviated from the normal operating envelope.

The syllabus for this phase focused on the review of the following essential topics:

- aerodynamic principles applied to unusual attitude recovery;
- energy management during critical maneuvers;
- proper use of flight controls; and
- effective recovery techniques under stall conditions and abnormal attitudes.

The company's Operations Training Program (PTO), established in manual M-PTO-001-09, version V.11, in effect at the time of the accident, included the conduct of Upset Recovery Training (UPRT) (Figure 3), as well as training for operations in adverse meteorological conditions (Figure 4), both integrated into Full Flight Simulator (FFS) sessions.

B.1.3.2.4.4.4. Upset recovery (UPRT)

Este treinamento tem como objetivo apresentar aos pilotos a avaliação de situações onde a velocidade está próxima à velocidade de estol, bem como demonstrar atitudes anormais e as manobras para a correta recuperação da atitude normal de voo nas aeronaves.

CONTEÚDO PROGRAMÁTICO	MODALIDADE ☒EAD ☒WBT ☐PRESENCIAL	CARGA HORÁRIA
1. Prevenção de Atitudes Anormais (*Upset*)		00:30
2. Fatores que levam a uma situação de perda de controle		
3. Identificação de situações em Atitudes Anormais		
4. Técnicas de recuperação		
5. Fatores aerodinâmicos presentes em uma situação de *Upset*		
Total		**00:30**

Figure 3 – Excerpt from the operator's PTO.
Source: M-PTO-001-09, Version V.11.

B.1.5.2.4.4.2. Condições meteorológicas adversas

Este treinamento tem como objetivo apresentar aos pilotos e ajudar a compreender as condições meteorológicas adversas, tal como, a execução dos procedimentos operacionais adequados.

CONTEÚDO PROGRAMÁTICO	MODALIDADE ☒EAD ☒WBT ☐PRESENCIAL	CARGA HORÁRIA
1. Tesoura de Vento*		01:00
2. Pista molhada e contaminada*		
3. Formação de Gelo*		
4. Utilização de fluidos *de-icing* e *anti-icing* (noções básicas)*		
5. Operação em clima quente*		
Total		**01:00**

*: O currículo de voo de condições meteorológicas adversas será ministrado conjuntamente ao(s) módulo(s de voo aplicáveis.

Figure 4 – Excerpt from the PTO for training in adverse meteorological conditions.
Source: M-PTO-001-09 PTO V.11.

Within the scope of the recurrent training conducted in FFS, it was verified that the PIC participated in training sessions from 09 to 12JAN2024, and the SIC from 24 to 27OCT2023.

These training sessions included exercises related to flight in icing conditions and ice accretion during climb and cruise, as well as severe icing scenarios at FL180, with a focus on the procedures to be performed under such conditions (Severe Icing at FL180 – Severe Icing Procedures – Leave Icing Conditions). Both pilots received satisfactory evaluations in these items.

In addition, both pilots performed the exercise corresponding to Upset Prevention and Recovery, which, according to the training records, also included the discussion of methods to prevent loss of control in flight situations and the execution of the corresponding recovery maneuvers. Both pilots received satisfactory evaluations in this item, as well as in the entire simulator session.

Figures 5 and 6 present the training records, highlighting the items related to icing conditions and UPRT.

Código	F-PTO-001-09-11
Tipo	Formulário
Título	Treinamento Periódico em Simulador
Versão	V.05.01
Validade	04/10/2025
Página	Página 1 de 6

VOEPASS

Tripulante: [redacted] Anac: [redacted] ☒ CMT ☐ COP

Período: 09/01/24 a 12/01/24 ☒ PERIÓDICO ☐ REQUALIFICAÇÃO ☐ ELEVAÇÃO

FFS 01 (04 HORAS)

OBJECTIVE				
Review normal, abnormal & emergency procedures.				
TAKE OFF DATA				
Local flight at SBGL / SBRJ			ATR 42-500 ☐	ATR 72-500/600 ☐
RWY: 33	WIND: 060º/15KT	DEP: BKN002	TOW: 18.600 KG	TOW: 22.500 KG
DEP: OMNI	TEMP: 15ºC	VIS. See below	CG: 26.0%	CG: 26.0%
FL180	QNH: 1006 HPa	(when required)	STAB: 1.2 UP	STAB: 1.2 UP

TRAINEE 1 & 2	CM1	CM2
1. Performance computation (Emphasize normal climb gradient / Best climb rate / Best climb angle)	5	
2. Initial cockpit preparation – Cockpit preparation – Final cockpit preparation – GPU	5	
3. Start ENG2 on GPU (propeller brake ON) – Abnormal parameters during start	5	
4. Propeller brake unlocked	5	
5. Before propeller rotation – Normal push-back – Before taxi – Single engine taxi out	5	
6. Start ENG1 with abnormal start (reset after failure treatment) – Before take-off	5	
TRAINEE 1	**PF**	**PM**
7. Normal take-off RWY33 (under IMC 100ft ceiling)	5	
8. EGPWS/TAWS warning during climb – Avoidance maneuver	5	
9. Pilot incapacitation (only applicable for pilots under command upgrade)	5	
10. Short vectors for ILS RWY15 under IMC – Normal landing (Delayed braking technique)	5	
11. Reposition for a new take-off at RWY33 – Normal take off – WINDSHEAR – Avoidance maneuver	5	
12. Normal climb – TCAS TA – TCAS RA – Avoidance maneuver	5	
13. Icing conditions and ice accretion during climb and cruise	5	
14. Severe icing at FL180 – Severe icing procedures – Leave icing conditions	5	
15. Upset prevention and upset recovery	5	
• Discuss methods to prevent an inflight upset and the recovery maneuver	5	
16. [illegible]	5	
17. VFR approach RWY20L	5	
• Discuss the usage of visual approach aids (PAPI & VASIS)	5	
18. ENGINE FIRE at short final (no extinguishing) – Landing (No delayed braking technique)	5	
19. ENGINE FIRE procedures – EMERGENCY EVACUATION	5	

Figure 5 – Recurrent Simulator Training Evaluation Form of the PIC.

Código	F-PTO-001-09-11
Tipo	Formulário
Título	Treinamento Periódico em Simulador
Versão	V.05.01
Validade	04/10/2025
Página	Página 1 de 6

VOEPASS

Tripulante: [redacted] Anac: [redacted] ☐ CMT ☒ COP

Período: 24/10/23 a 27/10/23 ☒ PERIÓDICO ☐ REQUALIFICAÇÃO ☐ ELEVAÇÃO

FFS 01 (04 HORAS)

OBJECTIVE				
Review normal, abnormal & emergency procedures.				
TAKE OFF DATA				
Local flight at SBGL / SBRJ			ATR 42-500 ☒	ATR 72-500/600 ☐
RWY: 33	WIND: 060º/15KT	DEP: BKN002	TOW: 18.600 KG	TOW: 22.500 KG
DEP: OMNI	TEMP: 15ºC	VIS. See below	CG: 26.0%	CG: 26.0%
FL180	QNH: 1006 HPa	(when required)	STAB: 1.2 UP	STAB: 1.2 UP

TRAINEE 1 & 2	CM1	CM2
1. Performance computation (Emphasize normal climb gradient / Best climb rate / Best climb angle)		5
2. Initial cockpit preparation – Cockpit preparation – Final cockpit preparation – GPU		5
3. Start ENG2 on GPU (propeller brake ON) – Abnormal parameters during start		5
4. Propeller brake unlocked		5
5. Before propeller rotation – Normal push-back – Before taxi – Single engine taxi out		5
6. Start ENG1 with abnormal start (reset after failure treatment) – Before take-off		5
TRAINEE 1	**PF**	**PM**
7. Normal take-off RWY33 (under IMC 100ft ceiling)		5
8. EGPWS/TAWS warning during climb – Avoidance maneuver		5
9. Pilot incapacitation (only applicable for pilots under command upgrade)		5
10. Short vectors for ILS RWY15 under IMC – Normal landing (Delayed braking technique)		5
11. Reposition for a new take-off at RWY33 – Normal take off – WINDSHEAR – Avoidance maneuver		5
12. [illegible]		5
13. Icing conditions and ice accretion during climb and cruise		5
14. Severe icing at FL180 – Severe icing procedures – Leave icing conditions		5
15. Upset prevention and upset recovery		5
• Discuss methods to prevent an inflight upset and the recovery maneuver		5
16. Vectors for RNAV RWY20L SBRJ – [illegible]		5
17. VFR approach RWY20L		5
• Discuss the usage of visual approach aids (PAPI & VASIS)		5
18. ENGINE FIRE at short final (no extinguishing) – Landing (No delayed braking technique)		5
19. ENGINE FIRE procedures – EMERGENCY EVACUATION		5

Figure 6 – Recurrent simulator training evaluation form of the SIC.

Also, composing the crew of the aircraft involved in the accident were two flight attendants. The Lead Flight Attendant accumulated 625 flight hours, while the other Flight Attendant had accumulated 412 flight hours. Both of them had satisfactorily completed the company's flight attendant training.

After reviewing the available evidence, the SIPAER Investigation Commission concluded that all crew members met the applicable requirements and were therefore qualified to conduct the flight.

1.5.5. Validity of medical certificate

The crew members held valid CMAs (Aeronautical Medical Certificates).

1.6. Aircraft information

The ATR-72-212A (500) aircraft, SN 908, was manufactured by ATR – *GIE Avions de Transport Régional* in 2010, and was registered in the category of Scheduled Public Air Transport (TPR).

The aircraft was incorporated into the operator's fleet on 29SEP2022.

The aircraft's CVA (Certificate of Airworthiness) was valid.

The aircraft's last 2YE inspection was initiated on 01JAN2023 and completed on 24JUN2023, date of its approval for return to service. The referred inspection was performed by the operator's maintenance organization under COM (Maintenance Organization Certificate) No. 0701-04\ANAC, in *Ribeirão Preto*, State of *São Paulo*. At that time, the aircraft had accumulated a TSN (Time since New) of 15,289 hours and 10 minutes of flight, and a CSN (Cycles since New) of 9,593.

The aircraft's last routine inspection, a Daily Check, was performed on 09AUG2024 by the same maintenance organization in *Ribeirão Preto*, SP. At that time, the aircraft had accumulated a TSN of 17.359 hours and 40 minutes of flight, and a CSN of 11,198.

The aircraft was equipped with two PW100 series engines, model PW127M, designed and manufactured by Pratt & Whitney Canada (P&WC), each coupled to a six-blade composite propeller designed and manufactured by Hamilton Standard Aerospace Systems, model 568F-1, PN 815470-2.

The SN PCE-ED0945 engine installed on the left side of the aircraft (engine No. 1) accumulated a TSN of 11,082 hours of flight and a CSN of 11,281. The component had not yet undergone an overhaul; however, it had been subjected to a Hot Section Inspection (HSI), completed on 03JAN2023. At the time of the accident, the component had accumulated 3,202 flight hours after that inspection.

During the Daily Check on 09AUG2024, in addition to the tasks prescribed for this inspection, the following actions were also performed:

- replacement of ignitor B, which had been inoperative since 07AUG2024, with dispatch carried out under the MEL (Minimum Equipment List).
- a scheduled borescope inspection, consisting of a detailed visual inspection of internal engine components; and
- an automatic propeller feathering (auto-feather) test, also prescribed in the Maintenance Program.

The SN 2012060097 propeller installed on this same engine, had a TSN of 30,763 flight hours. Its last overhaul was completed on 24NOV2019 and had accumulated a TSO of 9,808 flight hours.

The SN PCE-ED0507 engine installed on the right side of the aircraft (engine No.2) was manufactured on 28MAR2012 and accumulated a TSN of 23,479 flight hours and a

CSN of 30,565. This engine had undergone an overhaul completed on 05MAY2023. At the time of the accident, the component had accumulated a TSO of 2,748 flight hours.

The SN 2012030158 propeller installed on the right engine, had a TSN of 22,365 flight hours. Its last overhaul was completed on 13JAN2024, and it accumulated a TSO of 1,423 hours of flight.

Therefore, the engines and propellers were approved for operation, with their maintenance records up to date and in compliance with the operator's Maintenance Program.

1.6.1. Cockpit Indicator light Ilumination Logic

The ATR-72-212A (500) aircraft models were designed and certified following a cockpit indication lighting philosophy known as Dark Cockpit Philosophy. With a few exceptions, under normal operating conditions, all indicator lights required for monitoring the aircraft systems remained extinguished. Thus, the lights would illuminate to indicate a failure or abnormal condition, drawing the pilots' attention to the necessary management actions.

In summary, six types of light colors could be present in the cockpit, indicating different conditions to support the flight crew's situational awareness:

- black (light off): normal operation;
- white: basic operation differing from normal;
- red: WARNING indication;
- blue: system temporarily required during normal operation;
- amber: CAUTION indication; and
- green: standby or alternate system selected.

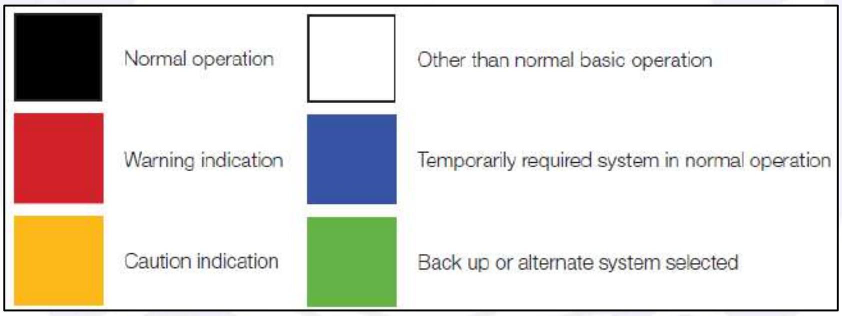


Figure 7 – Cockpit Philosophy Lights of the ATR-72-212A aircraft.
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

Amber and red lights, indicating CAUTION and WARNING, respectively, were associated with abnormal and/or emergency situations, requiring the flight crew to carry out the actions prescribed in the Quick Reference Handbook (QRH).

1.6.2. Centralized Crew Alerting System (CCAS)

The CCAS was responsible for the continuous monitoring of all aircraft systems and for performing the following functions:

- alerting the flight crew to the existence of a system failure or a hazardous aircraft configuration, with a clear indication of the urgency of the situation;
- identifying the failure or condition unambiguously; and
- directing the appropriate corrective action.

System failure and malfunction alerts were processed by the Multi-Function Computers (MFC), which were an integral part of the CCAS.

To fulfill its functions, the CCAS provided alerts in both visual and aural forms.

With regard to visual alerts, the CCAS had three sets of visual devices (lights).

MASTER WARNING and MASTER CAUTION lights

Initially, when illuminated, these lights would flash in order to attract the pilots' attention. Together with aural signals, they enabled the flight crew to detect a failure and identify the level of urgency. They could be extinguished by pressing the light button. This crew acknowledgement procedure, by pressing the light cancel button, also silenced the associated aural signal.

Crew Alerting Panel (CAP) lights

These lights were grouped on a panel located to the left of the cockpit center panel. They provided condensed information regarding the source of failures associated with a given system or, alternatively, about an abnormal aircraft configuration.

Local alert lights

These lights were generally integrated into the panels of each system. They provided detailed information about the failure and guided the corrective action, being, whenever possible, combined with or located adjacent to the control for the corrective action. A limited number of aural alerts drew the flight crew's attention through the loudspeakers located in the cockpit.

Therefore, for the detection of and response to a given system failure, a basic sequential procedure was required, generally divided into three phases associated with the three sets of lights mentioned above:

- alert information: the crew received the indication of a failure or malfunction through a MASTER CAUTION or MASTER WARNING light, associated with the respective aural alert;
- identification: the crew identified, through the message displayed on the CAP, which system was related to the failure or malfunction;
- isolation: based on the message displayed on the CAP, the crew checked the specific system panel to determine which failure had occurred (local alert).

PHASE	FUNCTION	MEANS OF DETECTION
1	ALERT	AURAL + MW/MC light
2	IDENTIFICATION	CAP
3	ISOLATION	LOCAL ALERT

Figure 8 – Basic sequential procedure for response to alerts.
Source: FCOM.

Visual alerts were classified into four levels, according to their importance and the urgency of the action required from the pilots. The aircraft FCOM established the following:

- LEVEL 3 – WARNING: corresponded to an emergency requiring immediate corrective action by the crew. These alerts were identified by a flashing red MASTER WARNING light, associated with a continuous repetitive aural signal (continuous repetitive chime) and a red light on the CAP or another specific aural warning;
- LEVEL 2 – CAUTION: corresponded to an abnormal aircraft condition requiring timely corrective action by the crew. This timing for taking action was left to the crew's discretion. This level mainly encompassed system failures with no immediate impact on safety. The alerts were identified by a flashing amber

MASTER CAUTION light, associated with a single aural tone (single chime) and an amber light on the CAP;

- LEVEL 1 – ADVISORY: corresponded to a condition requiring crew monitoring. This level mainly encompassed failures leading to loss of redundancy or system degradation. These advisories were identified by an amber light without an associated aural signal; and
- LEVEL 0 – INFORMATION: corresponded to information provided by blue, green, or white lights on the control panels.

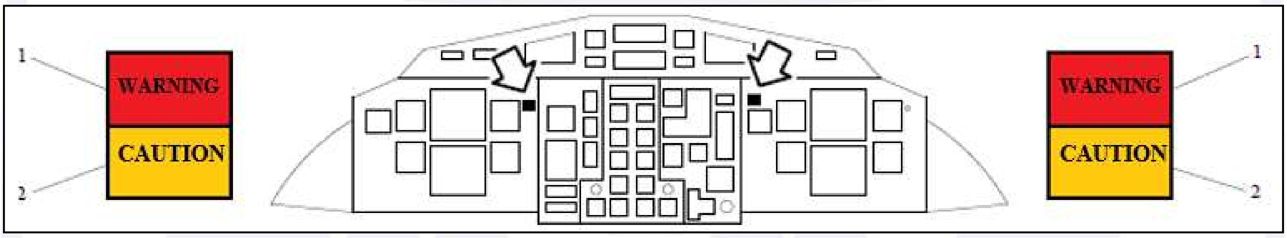


Figure 9 – Representative aircraft panel showing the location of the Master Warning and MASTER CAUTION lights.
Source: FCOM.

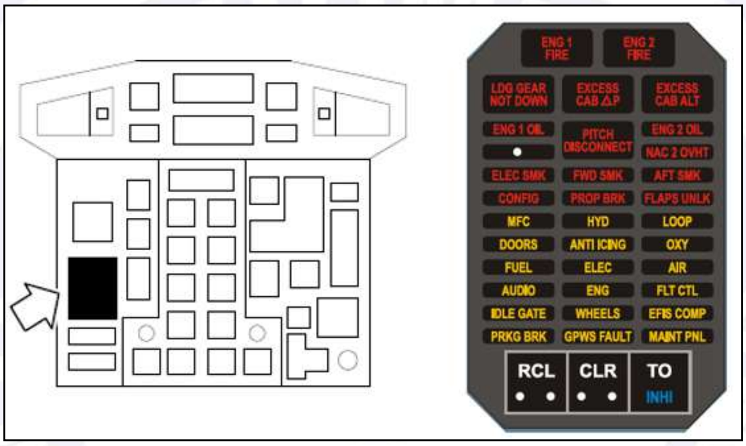


Figure 10 – On the left, CAP location on the cockpit center panel. On the right, the CAP showing all of its indications.
Source: Adapted from FCOM.

Aural alerts generated by the CCAS were subdivided into three types:

- a continuous repetitive tone: used for all WARNING alerts, directly identified by a specific light on the CAP;
- a single aural tone (single chime): used for all CAUTION alerts, directly identified by a light on the CAP; and
- a specific aural alert: for alerts not directly identified by a specific CAP light and that had particular operational significance.

According to the FCOM, the definitions of the CAUTION and WARNING alerts were as follows:

- CAUTION: corresponded to an abnormal aircraft condition requiring timely corrective action by the flight crew. The timing for taking action was left to the discretion of the flight crew. This level primarily encompassed system failures with no immediate impact on safety.
- WARNING: corresponded to an emergency condition requiring immediate corrective action by the flight crew. The following alerts belonged to this category:

a) aircraft in a hazardous configuration or operating under flight conditions close to operational limits; and

b) severe system failures (such as, for example, engine fire).

1.6.3. Pneumatic System

The aircraft was equipped with a pneumatic system capable of supplying other systems that required pressurized air for their operation, such as the Environmental Control System (ECS), the electronic equipment ventilation system, and the De-Icing system.

The pressurized air used by these systems was extracted (bleed air) from the compressors of both engines at two distinct points: one at low pressure (LP) and the other at high pressure (HP).

Cabin and cockpit pressurization and air conditioning were provided by two sets of equipment forming units known as pack 1 and pack 2.

Pack #1 was supplied by bleed air from the left engine and pack #2 by bleed air from the right engine.

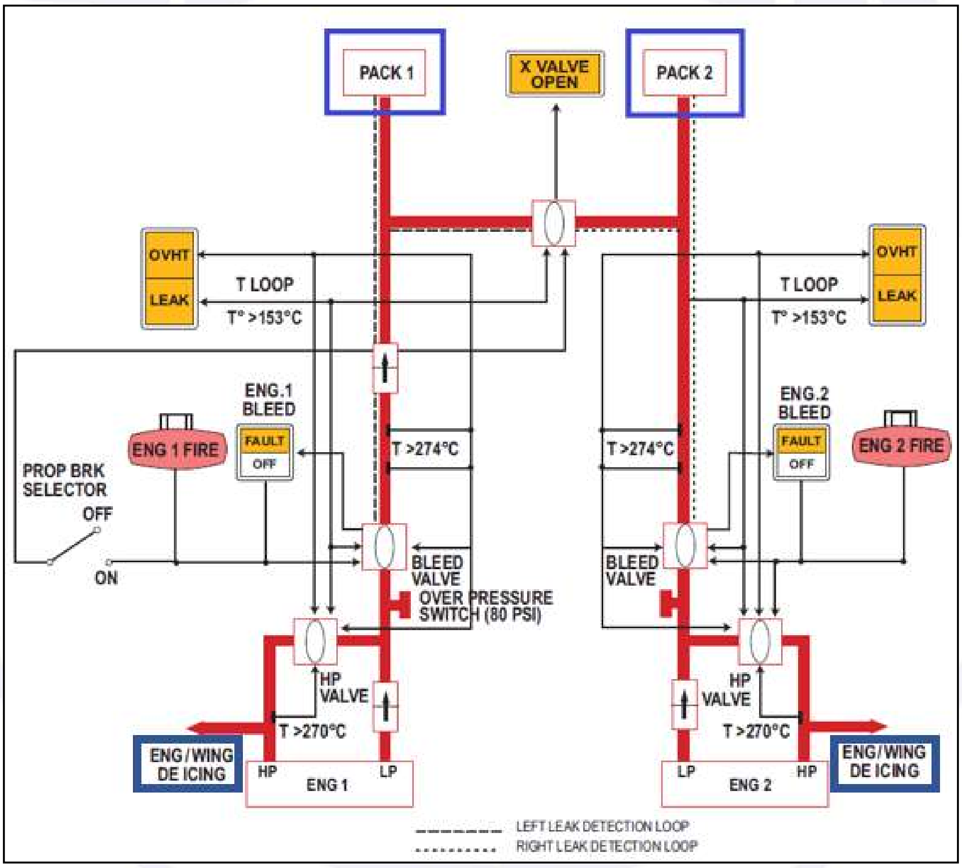


Figure 11 – Aircraft pneumatic system
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

1.6.4. Anti-Ice Systems

According to the Airplane Flight Manual (AFM), the aircraft was certified for operation in icing conditions, provided that the required equipment and instruments were installed and operational (Figure 12), as well as that the prescribed procedures were followed.

2 Kinds of Operation

_39c36470-bd17-4491-9888-80a05bc67d9a | 25 SEP 2015 APPROVED

The aircraft is certified in the transport category for day and night operations, in the following conditions when the appropriate equipment and instruments required by the airworthiness and operating regulations are approved, installed and in an operable condition:

- VFR and IFR
- Flight in icing conditions
- Reverse thrust taxi (single or twin engine).

Figure 12 – Excerpt from the AFM showing the aircraft certification for types of operation.

The systems providing protection against ice formation and accumulation on the aircraft (ice accretion) were subdivided as follows:

- Ice Detection System
- Anti-Icing System;
- De-Icing System; and
- Aircraft Performance Monitoring (APM).

1.6.4.1 Ice-Detection System

The ice detection system used two main components:

- an Ice Evidence Probe (IEP); and
- an Electronic Ice Detector.

The IEP was installed on the left forward fuselage of the aircraft and was intended to provide a visual indication of ice accretion to the pilots (Figures 13 and 14).

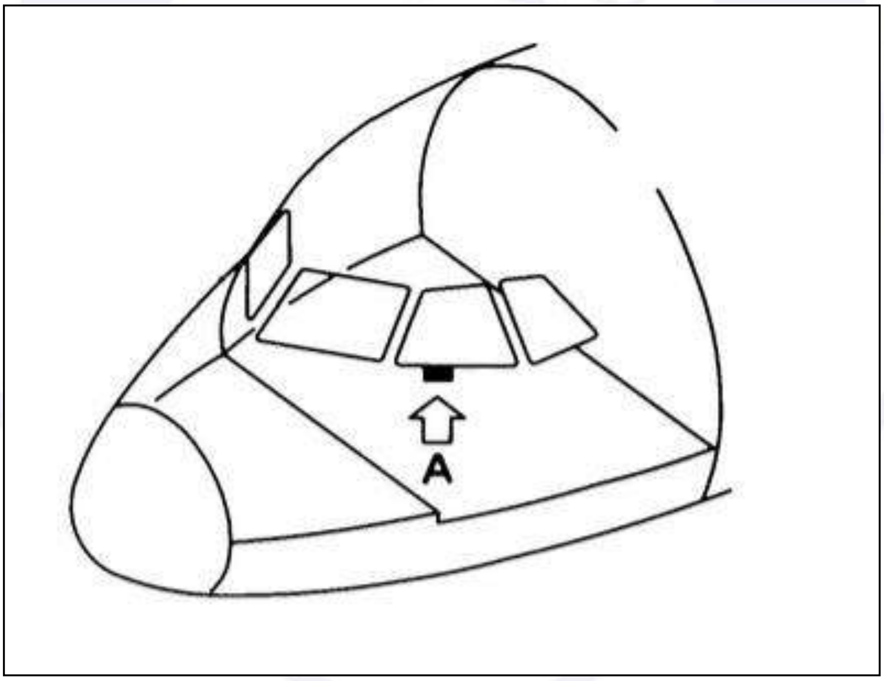


Figure 13 – (A) Indication of the IEP location.
Source: ATR Line Maintenance Manual, ATA 30.

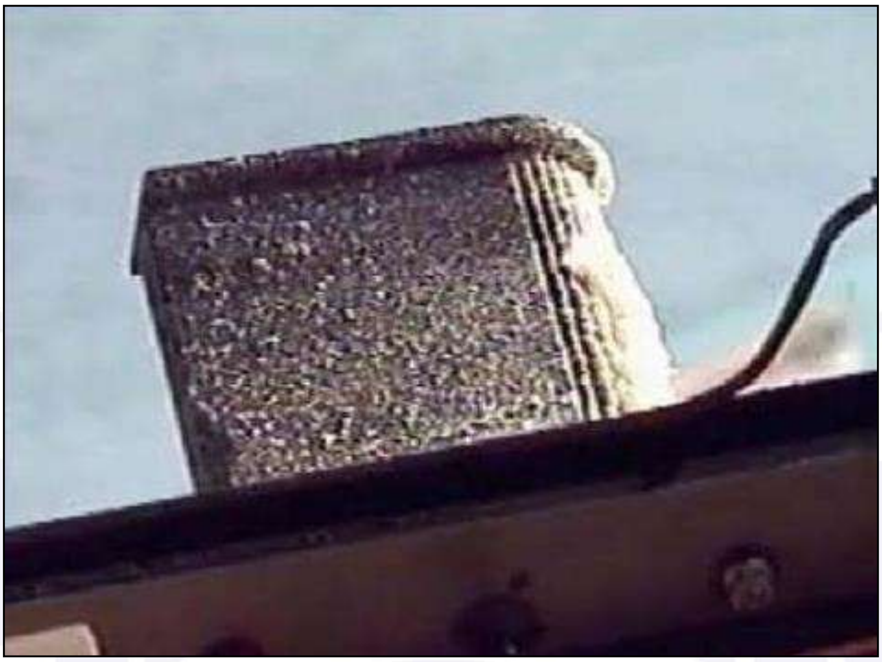


Figure 14 – View of the IEP from the left pilot position.
Source: Ice & Rain, ATR Training Centre.

The IEP was designed to be the first aircraft surface to accumulate ice, as well as the last to become free of it. Thus, the IEP system provided pilots with a visual indication of:

- the onset of ice accretion on the aircraft; and
- the fact that the aircraft was free from icing.

The AFM stated that the aircraft could only be considered free from ice accretion when the IEP was free of ice.

Note

The aircraft is considered clear of ice when IEP is free of ice.

Figure 15 – Note extracted from the Preparing for Icing Conditions procedure of the ATR-72-212A (500) aircraft AFM.

The Electronic Ice Detector installed on the lower surface of the left wing consisted of a system capable of detecting ice accretion and providing alerts to the pilots (Figure 16).

It consisted of a sensor that, when subjected to ice accretion, changed its natural vibration frequency. Whenever the vibration was altered due to the presence of ice, the amber ICING light illuminated on the ICE DETECT panel, located on the central cockpit panel and on the CCAS (Centralized Crew Alerting System), accompanied by the illumination of the amber MASTER CAUTION light and a single chime alert tone.

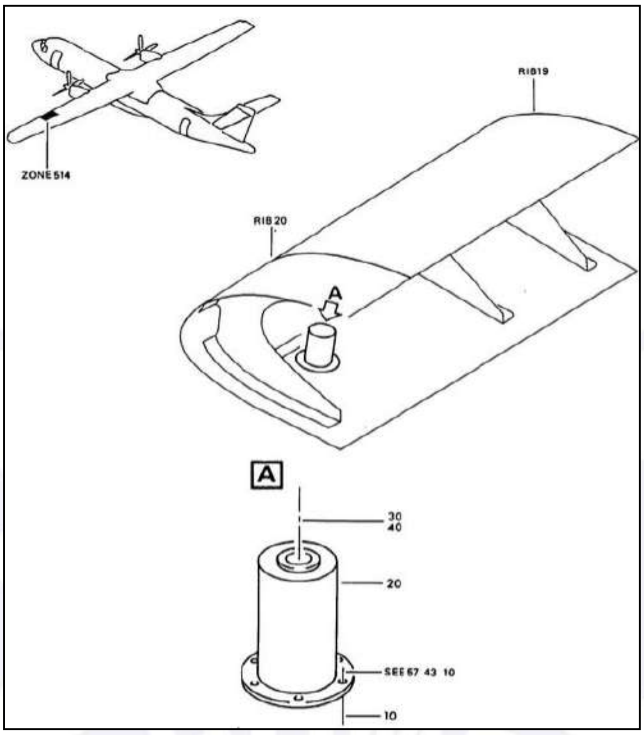


Figure 16 – (A) Indication of the *Electronic Ice Detector* location.
Source: ATR Line Maintenance Manual, ATA 30.

Figure 17 – Electronic Ice Detector.
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

After an ice detection event, the sensor was heated for 7 seconds to sublimate the accumulated ice, and a new 60-second detection cycle was then initiated. If ice accretion occurred during this new detection cycle, the ICING alert remained illuminated. If no ice was detected during a new 60-second cycle, the ICING alert was extinguished.

Thus, if the ice accretion occurred slowly, the process of freezing and sublimation caused by sensor heating could inhibit the alert; however, other unheated parts of the aircraft would continue to accumulate ice gradually, even without detection by the Electronic Ice Detector.

Given this operating characteristic of the Electronic Ice Detector, the aircraft FCOM presented, in Section 1.2 of Chapter 30.2 - ICE AND RAIN PROTECTION ANTI ICING ADVISORY SYSTEM, a CAUTION note alerting operators to this potential inefficiency of the Electronic Ice Detector.

1.6.4.2 Anti-Icing and De-Icing Systems

The manufacturer's design philosophy was based on three levels of anti-ice protection: two Anti-Icing systems using electrical heating, and one De-Icing system using inflatable boots supplied with engine bleed air.

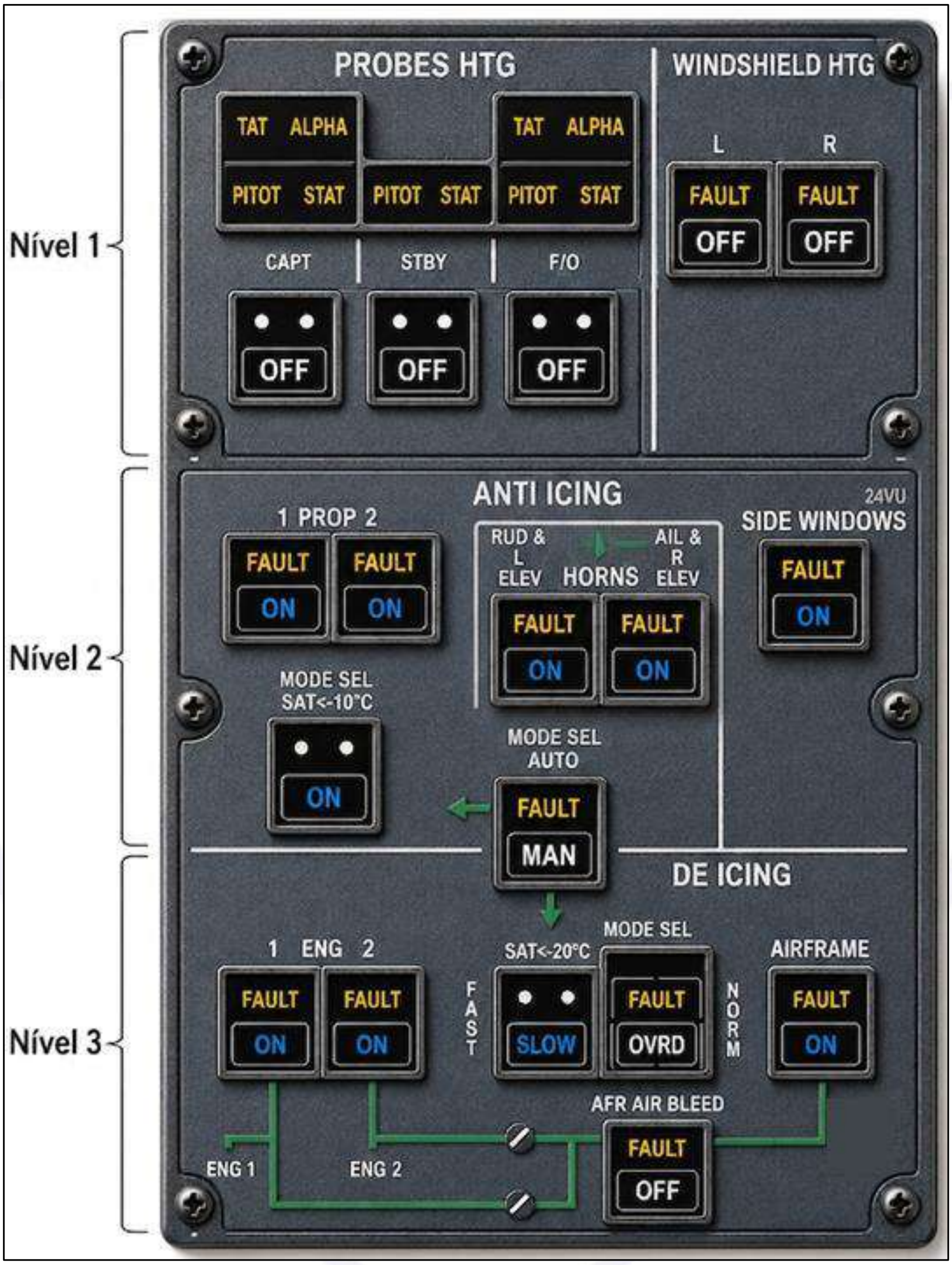


Figure 18 – Anti-Icing and De-Icing panels, located on the Overhead Panel.
Source: ATR Training Centre.

The level 1 permanent Anti-Icing system was activated prior to takeoff and deactivated after landing, and provided electrical heating for the following components:

- 3 pitot tubes;
- 6 static ports;
- 2 TAT (Total Air Temperature) sensors;

- 2 AOA (Angle of Attack) probes; and
- Pilots' windshields.

The level 2 Anti-Icing system, intended for use in icing conditions, provided electrical heating for the following components:

- leading edges of the propeller blades;
- horns of the ailerons, rudder, and elevators; and
- forward side cockpit windows.

The level 3 De-Icing system provided pneumatic pressure, using engine bleed air, to the following components:

- left engine air intake boot;
- right engine air intake boot;
- gas path ducts;
- wing leading edge boots; and
- horizontal tailplane leading edge boots.

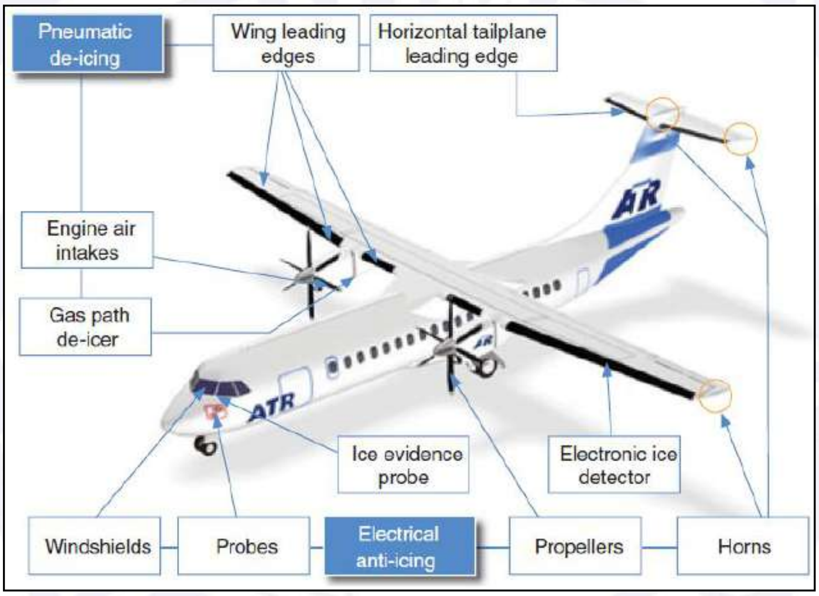


Figure 19 – Identification of the components of the Anti-Ice system.
Source: Cold Weather Operations, ATR Training Centre.

The De-Icing system did not depend on the operation of the packs, since the bleed air used for its activation was supplied from the high-pressure (HP) line, at a point upstream of the high-pressure control valve (HP Valve), which supplied the packs. Thus, even with one or both packs inoperative, the De-Icing system would remain available for use, if required.

A set of boots installed on the wings, the engine air intake plus gas path and on the horizontal tailplane composed the aircraft’s De-Icing system. These boots were of the spanwise type, made of elastomeric material, and featured two pressure lines, designated chambers A and B, which were alternately inflated and deflated using high-pressure engine bleed air.

When in operation, the boots acted to break the ice accumulated on the leading edges of the surfaces on which they were installed, removing it through mechanical action in three stages:

- breaking the ice layer into fragments;
- applying a shear force greater than the adhesive force binding the ice to the boot surface; and
- removing the ice fragments by the airflow.

When deflated, the boots were held flush against the leading-edge structure of their respective surfaces by suction using engine bleed air.

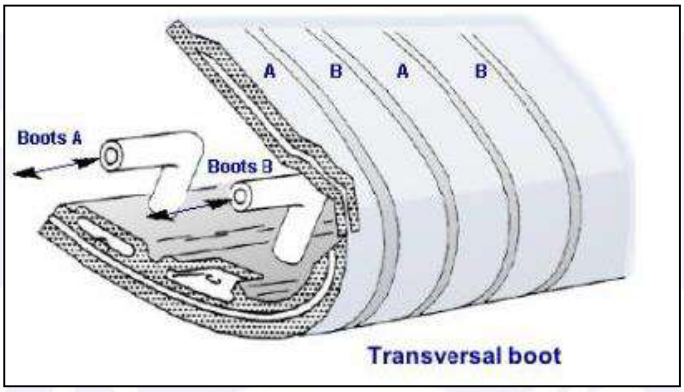


Figure 20 – Schematic illustration of chambers A and B of the wing and horizontal tailplane transversal De-Icing boots.

The pneumatic De-Icing system had seven Dual Distributor Valves (DDVs), which operated the boots in a synchronized manner and at the appropriate intervals in the following positions:

- one at the right engine air intake;
- one at the left engine air intake;
- two on the left wing;
- two on the right wing; and;
- one on the horizontal tailplane.

The manufacturer's Illustrated Parts Catalogue (IPC) showed the position of each DDV based on a Fairing Identification Number (FIN). If a failure was detected by the MFC, which monitored and controlled the pneumatic De-Icing system, an associated fault code would be generated along with the corresponding FIN designation, in order to facilitate the identification and location of the affected valve by maintenance personnel.

Table 1 presents a summary of the technical data from the aircraft's parts catalogue, including the FIN identification designations for each of the seven DDVs of the De-Icing system. An additional column was also included, referencing the numbering of the DDVs shown in Figure 21.

Reference in Figure 21	Part Number (PN)	FIN	Reference on the aircraft
1	B03AA1060	3DN	Left engine boots
2	B03AA1060	4DN	Right engine boots
3	B03AA1040	9DM	Left wing outboard boots
4	B03AA1040	83DM	Left wing inboard and mid-span boots
5	B03AA1040	10DM	Right wing outboard boots
6	B03AA1040	84DM	Right wing inboard and mid-span boots
7	B03AA1040	11DM	Horizontal stabilizer boots

Table 1 – DDV technical data.
Source: IPC.

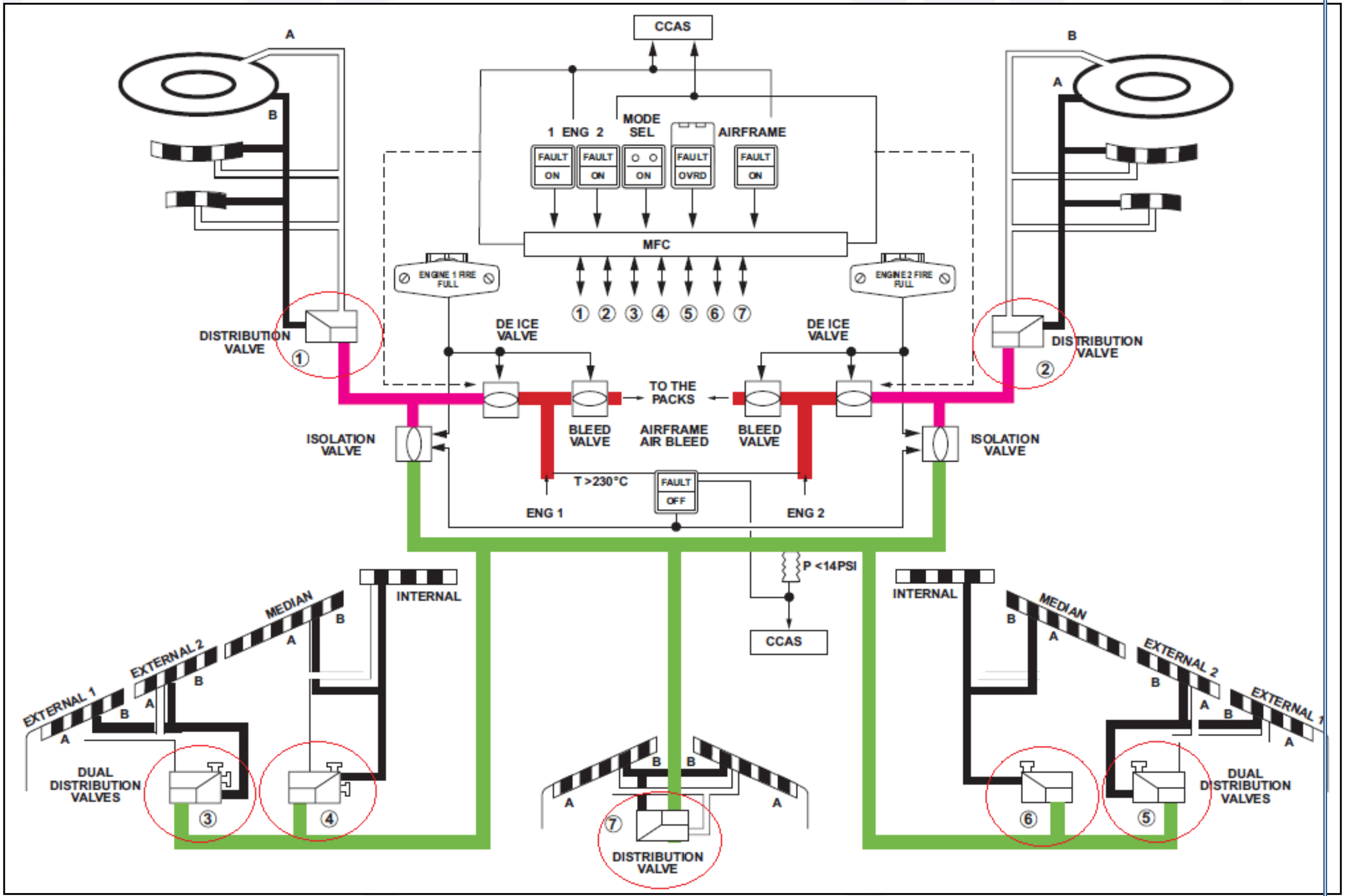


Figure 21 – Indication of DDVs in the pneumatic De-Icing system.
Source: Systems ATR 42-500 / 72-212A Training and Flight Operations Services.

On the central cockpit panel, indications related to the operation and failures of the Anti-Icing and De-Icing systems would be presented to the pilots by means of 3 lights:

- ICING light (amber), located on the ICE DETECT panel.

As soon as the Electronic Ice Detector detected an ice accretion condition, the ICING light (amber) would illuminate, accompanied by the MASTER CAUTION alert and a single chime. This light would continue flashing while the ice accretion condition persisted and the flight crew had not activated the level 2 Anti-Icing horn heating and the level 3 Airframe De-Icing system.

According to the manufacturer's design philosophy, the light would flash to draw the attention of the flight crew, indicating that the Anti-Icing or De-Icing system was not activated. When the Anti-Icing horn heating and the airframe De-Icing systems were selected ON, the light would remain steadily illuminated as long as ice accretion continued to be detected by the Electronic Ice Detector.

- ICING AOA light (green), located on the ICE DETECT panel.

The ICING AOA light illuminated as soon as one of the Anti-Icing Horn buttons was selected to ON. This light served to remind the flight crew that, from that moment on, the maximum AOA the aircraft could reach without activation of the SPS (Stall Protection System) was reduced due to entry into icing conditions.

This light would extinguish upon pilot action (by pressing the push button) after visual confirmation on the IEP that the aircraft was free of ice. This action would restore the stall protection system thresholds to the values corresponding to normal operating conditions.

Figure 22 – Indications of the ICE DETECT panel.
Source: ATR Training Centre.

- DE-ICING light (blue), located on the MEMO Panel.

The blue DE ICING light would illuminate steadily when the level 3 Airframe De-Icing boot system was activated. This light would flash when the Airframe De-Icing system remained ON for more than 5 minutes after the last detection of ice accretion by the Electronic Ice Detector, in order to remind the pilots that icing conditions were no longer present and that the Airframe De-Icing system was still activated, prompting them to switch the system OFF.

In addition to the lights on the central panel, the DE-ICING panel, located on the overhead panel, included the FAULT and ON lights associated with the AIRFRAME pushbutton. The ON light, blue, indicated that the system was activated, while the FAULT light, amber—accompanied by the MASTER CAUTION alert and a single chime—indicated that the system was in a fault condition.

The aircraft manufacturer stated in its manuals that the primary indication of ice accretion on the aircraft should be derived from the pilots' perception through the IEP. Accordingly, the Airframe De-Icing system should be kept ON until the aircraft was no longer in icing conditions.

1.6.4.3. Aircraft Performance Monitoring (APM)

The APM used aircraft and engine parameters to monitor aerodynamic drag under ice accretion conditions, in order to alert the flight crew to the risk of performance degradation during flight in icing conditions. The objective of aircraft performance monitoring was to enhance the crew's situational awareness regarding the risk of performance loss, especially in severe icing conditions. It is important to note, however, that the APM alerts did not provide any means to assess the severity of the icing environment encountered. For this purpose, other aircraft systems were available to provide the flight crew with the relevant information.

In order for the APM to calculate the aircraft's theoretical drag and compare it with its in-flight performance, the calculated takeoff weight had to be entered by the pilots immediately after engine start. According to the aircraft checklist, this input was made using a rotary selector, the Weight Rotator Position, located on the APM panel.

From the moment the engines were started, the APM calculated the fuel consumed and continuously updated the reference speeds based on the corresponding reduction in aircraft weight throughout the flight.

Human–machine interaction with the APM system was accomplished through three panels: the APM panel, located at the right pilot station, and two APM alert panels positioned in front of the pilots, at the left and right pilot stations (Figure 23).

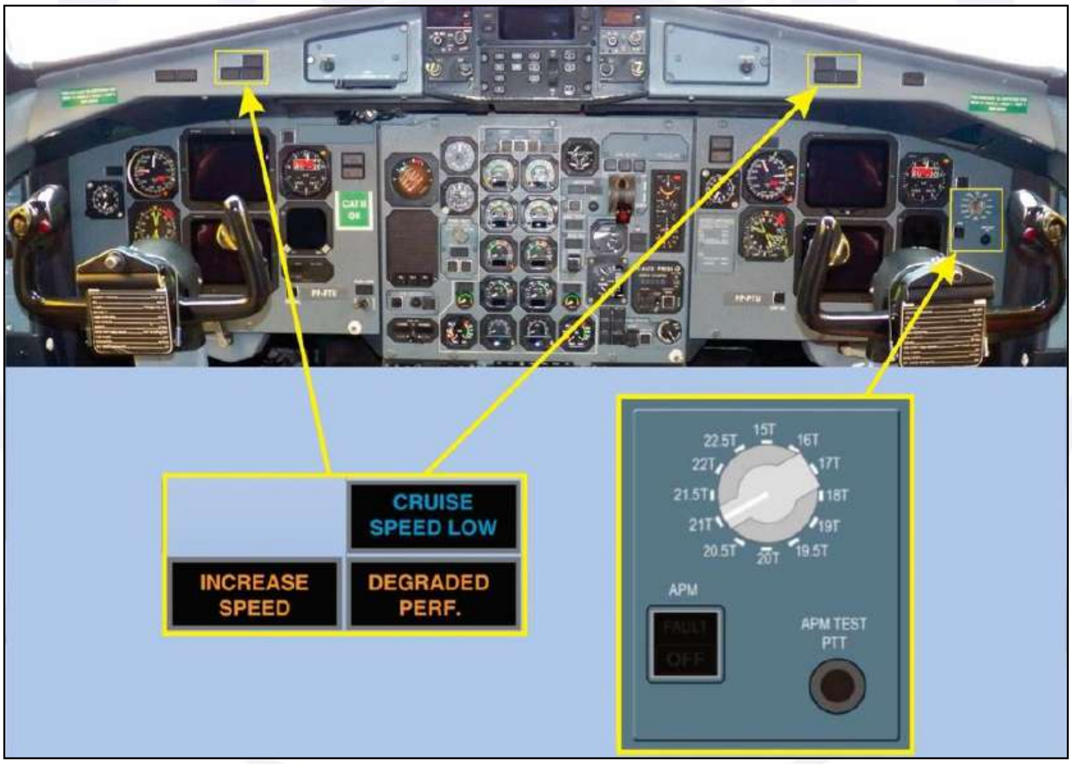


Figure 23 – Location of the human–machine interface components for the APM.

The APM was required to be checked daily by the flight crews, and, in the event of a failure, an amber FAULT indication would illuminate on the panel.

If the aircraft drag increased due to ice accretion and performance was degraded, an advisory message (1st level) and two master caution messages (2nd and 3rd levels) would be displayed to the pilots on the APM alert panels.

<u>1st Level – CRUISE SPEED LOW</u>

The blue CRUISE SPEED LOW message, applicable to 500-series aircraft, indicates a performance degradation (in the order of 10% of drag increase compared to theoretical drag in the same conditions) with a speed decay of at least 10 kt below the expected cruise speed. This advisory could only be presented during the cruise phase.

2nd Level – DEGRADED PERFORMANCE

DEGRADED PERF alert indicates a significant performance degradation (in the order of 22 % or 28 % of drag increase). In climb, the alert is triggered by an increase of drag that generates a drastic reduction of Vertical speed. In cruise, the alert is triggered by an increase of drag that generates an IAS drop (15 kt to 20 kt below the expected cruise speed). In descent, the alert is triggered by a drag rise. The amber message was accompanied by a single chime and a MASTER CAUTION alert.

3rd Level – INCREASE SPEED

The INCREASE SPEED amber alert would flash by a severe performance degradation generating an IAS drop below ICING BUG +10 kt. The alert indicates that the conditions for DEGRADED PERF are met and that the speed is lower than ICING BUG +10 kt, defined as the Minimum Severe Icing Speed (MSIS). The INCREASE SPEED alert could be presented during climb, cruise, or descent.

Figure 24 schematically presents the logic of APM alert activation for the cruise and climb and/or descent phases. On the left, the figure shows the alert activation conditions during cruise. On the right, the conditions during climb and descent.

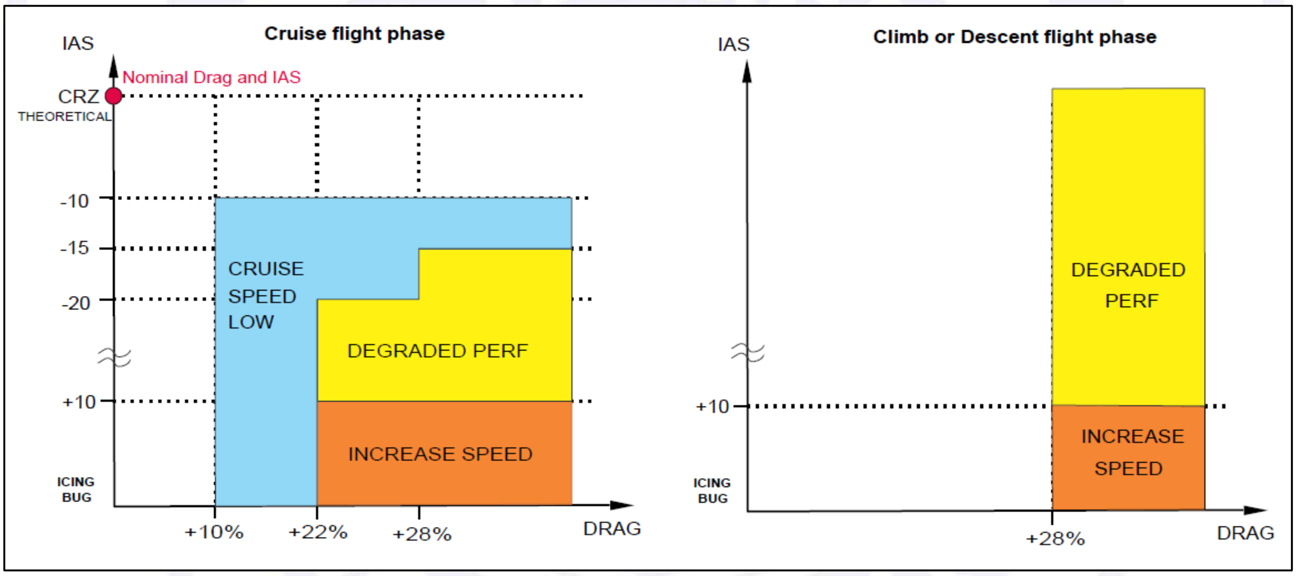


Figure 24 – Logic of APM alert activation as a function of aerodynamic drag and the indicated airspeed computed by the APM.

APM alerts could be triggered if at least one of the following conditions occurred:

- ICING AOA protection activated;
- Airframe De-Icing selected ON;
- Ice accretion detected by the ICE DETECTOR at least once during the flight; or
- Outside static air temperature < 10°C.

In addition to the speed alerts issued by the APM, the airspeed indicators at the left and right pilot stations were equipped with reference bugs, which could be manually set by the pilots.

The red bug represented the reference for the Minimum Maneuvering Speed in Low Bank, Flaps 0°, in Icing Conditions (VmLB0icing), referred to in the manuals as the ICING BUG or RED BUG.

According to the Before Propeller Rotation Checklist, the ICING BUG was to be set by the pilots for each flight, based on the aircraft weight, in order to display the VmLB0icing directly on both cockpit airspeed indicators.

Figure 25 – Airspeed Indicator of the ATR-72-212A, highlighting the ICING BUG.

If the aircraft entered icing conditions during the en-route phase, the pilots were required to consult the manuals to determine the maximum applicable flight level, considering the aircraft weight at that moment.

According to the manufacturer, this maximum level ensured that the cruise speed calculated by the APM remained at least 40 kt above the VmLB0icing. This margin was necessary to provide sufficient time, in the event of a performance degradation caused by ice accretion, for the detection of severe icing conditions and the execution of the prescribed procedures.

If the flight crew identified icing conditions, the PROCEDURE FOR ICING CONDITIONS was to be applied, under which the airspeed was to be maintained at no less than ICING BUG +10 kt, indicated on the airspeed indicator by the RED BUG, plus an additional 10 kt.

The ICING BUG +10 kt speed represented the minimum speed for flight with the flaps retracted and was compatible with the HIGH BANK mode used during operations with the Autopilot (AP) engaged.

If the flight crew identified severe icing conditions, the minimum speed to be maintained was ICING BUG +30 kt.

1.6.5. Multi-Function Computer (MFC)

MFC-1 and MFC-2 were installed in the aircraft's electronics rack. Each MFC consisted of two independent modules (A and B) and each module monitored and controlled important aircraft systems, as well as managed failures and alerted the flight crew when necessary.

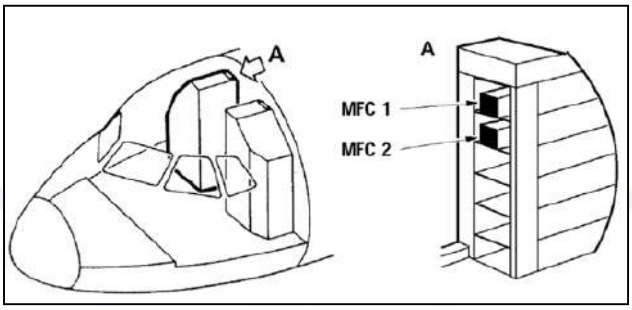


Figure 26 – Location of the MFC1 and MFC 2 in the ATR-72-212A aircraft.
Source: Aircraft Maintenance Manual (AMM).

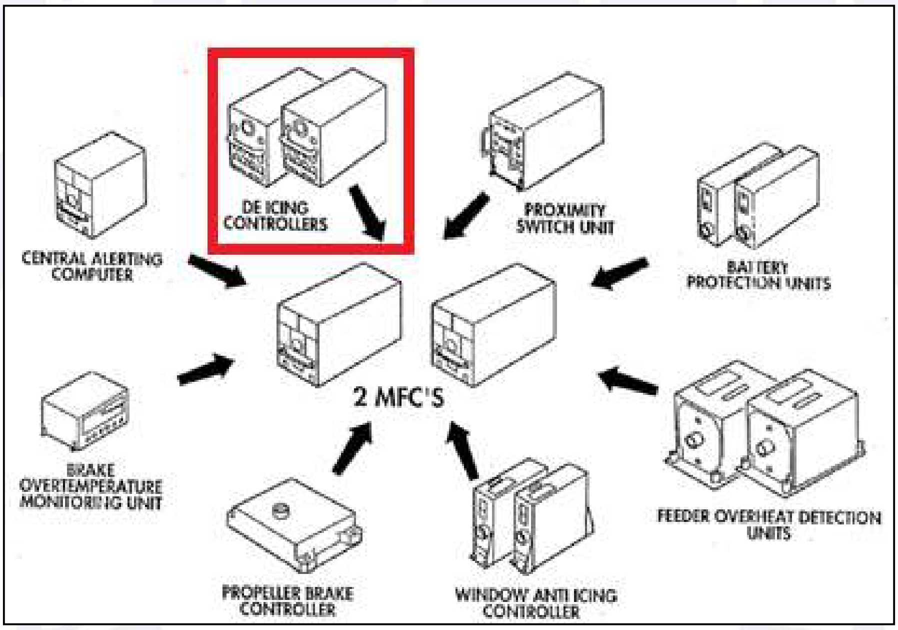


Figure 27 – Data supply from the De-Icing system for the monitoring and management of alerts by the MFC1 and MFC2.
Source: AMM.

The MFCs had three main functions:

- to monitor the aircraft systems and generate failure alerts for the flight crew;
- to control and monitor aircraft system parameters; and
- to perform Built-In Test Equipment (BITE) functions to detect failures in the systems and within the MFCs themselves.

One of the functions of the MFCs was to actuate and control the sequencing of the DDVs and to monitor the parameters of the De-Icing system, such as pneumatic pressure at different points.

In the event of a failure or malfunction, the corresponding alert was generated for the flight crew, and a message was stored with a specific coding (Fault Code) to assist maintenance personnel in diagnosing and resolving the issue.

The MFCs stored fault and/or malfunction codes in an Electrically Erasable Programmable Read-Only Memory (EEPROM) chipset, a non-volatile memory, retaining data even after the aircraft was powered down. The memory recorded both internal failures of the MFC itself and external failures of the monitored systems.

The aircraft's MFCs recorded external failures for up to 9 flights, with the current flight identified as "Flight 0" (Flight Zero) and the oldest as "Flight -8" ("Flight minus Eight").

1.6.6. Multi-Purpose Computer (MPC)

The aircraft was equipped with a Multi-Purpose Computer (MPC), installed in the electronics rack located in the cockpit.

The MPC integrated onboard hardware and software and performed several functions, including control of the APM system. In addition, it was responsible for the centralization and storage of aircraft maintenance data, also through dedicated onboard software.

The storage of these data was performed in a Flash Programmable Read-Only Memory (PROM), using a Personal Computer Memory Card International Association (PCMCIA) installed on the front of the MPC.

The PCMCIA card architecture allowed the recording of various types of operational and maintenance data, such as:

- data from the Quick Access Recorder (QAR) and
- reports generated by the Aircraft Condition Monitoring System (ACMS), which was responsible for monitoring the operational condition of the aircraft systems.

According to the operator's fleet aircraft Maintenance Program (Document F-MNT-MNT-013-19-01), periodic downloads of part of the data stored on the PCMCIA card were scheduled, specifically during Daily Check, through the maintenance task Download of Engine Condition and Trend Monitoring (ECTM):

> Perform download of engine condition and trend monitoring (ECTM) and QAR data from PCMCIA card. Share this data with *VoePass* Engineering Department.

1.6.7. Aircraft flight control system

The aircraft's flight control system was responsible for its controllability about the longitudinal, lateral, and vertical axes, governing the roll, pitch, and yaw motions, respectively.

The primary flight control system was entirely mechanical, consisting of mechanisms interconnected by rods, cables, pulleys, and other components, with no hydraulic or electrical power assistance. The primary flight control surfaces comprised:

- two ailerons, each located at the outboard trailing edge of each wing, operating asymmetrically—when one moved down, the other moved up;
- two elevators located on the trailing edge of the horizontal stabilizer, one on each side, interconnected by the pitch uncoupling mechanism—while connected, movement on one side of the elevator corresponded to movement on the other side; and
- a rudder on the trailing edge of the vertical stabilizer.

Trim in all three axes was accomplished by electric actuators that controlled a spring tab on each aileron, a trim tab on each elevator, and another spring tab on the rudder.

The flaps and spoilers, which are secondary flight control surfaces, were actuated by hydraulic actuators.

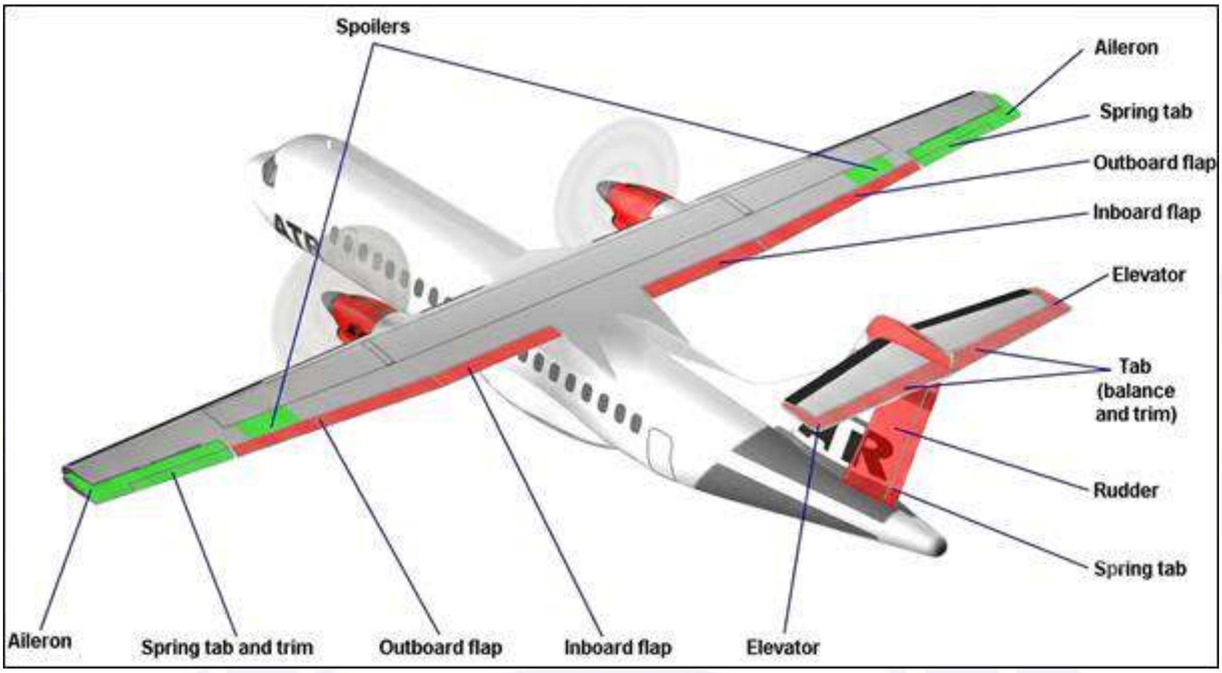


Figure 28. Primary and secondary flight control surfaces of the ATR aircraft.
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

1.6.7.1. Roll Control

With regard to the aircraft's roll control system, movements could be controlled manually through either the left- or right-hand control column, by rotating it clockwise or counterclockwise; both were interconnected and moved in unison. Additionally, roll could be controlled by the AP (autopilot) roll-axis electric actuator when engaged.

Position transmitters monitored the position of the ailerons. This data was sent to the Flight Data Recorder (FDR), where it was recorded as the Left Aileron Position and Right Aileron Position parameter.

In addition, depending on the aileron input, the spoilers could be automatically deployed to assist roll. For example, in a right turn command, once the aileron deflection reached the activation threshold, the right wing spoiler would be deployed. In the case of a left turn command, the left wing spoiler would be activated.

The indicated position of the spoilers was binary — retracted or extended — with no intermediate positions. When extended, a switch detected their position, and this information was made available to the pilots on the overhead panel.

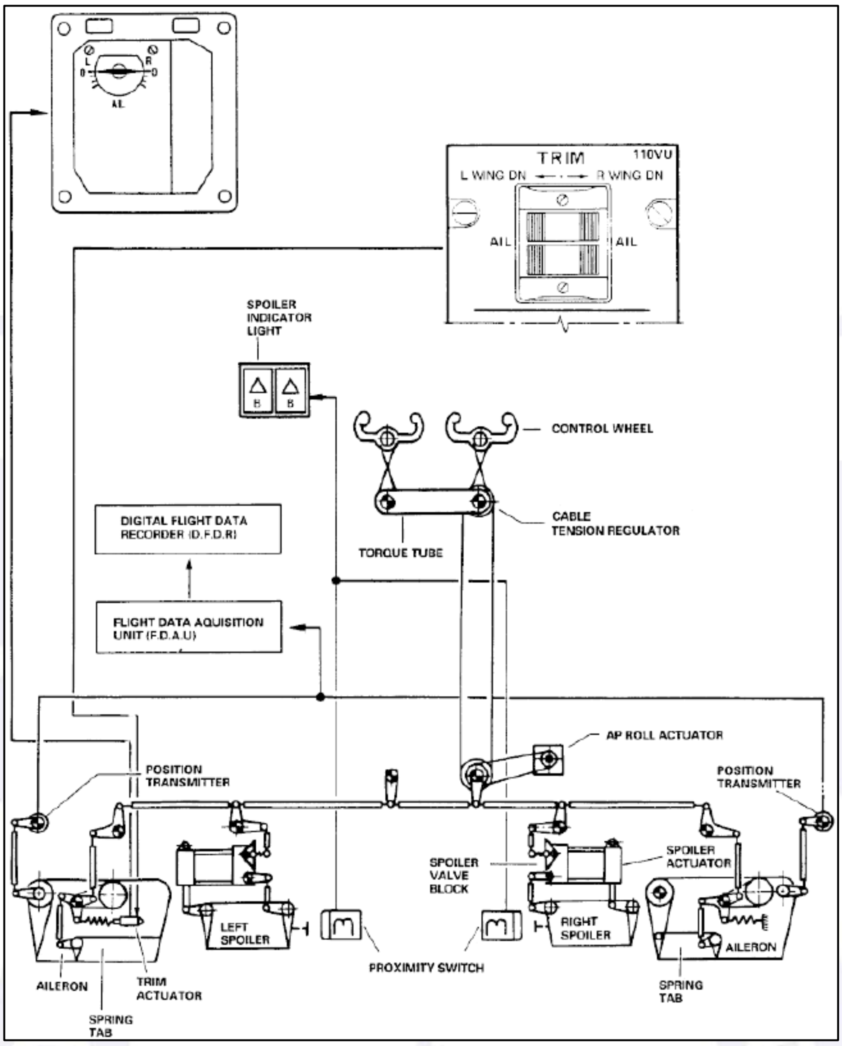


Figure 29. Diagram of the roll flight control system.
Source: Line Maintenance Manual MSN 908 ATR-A-27-1X-XX-01001-04CA-A – Aileron and Tab.

1.6.7.2. Pitch control

The aircraft’s pitch control was performed manually through pilot inputs on the control column, or automatically when the AP assumed control via its electric actuator.

A position sensor (position transmitter or synchro transmitter) was responsible for measuring the deflection angle of the left elevator only and providing this information for recording by the FDR. If the pitch uncoupling mechanism were engaged, the right elevator position would not be recorded by the FDR.

Attached to the two control columns were two force sensors that recorded this information in the FDR whenever the force applied to either column exceeded 10 daN.

Pitch trim, through the elevator trim tabs, could be performed manually by the pilots or automatically via the Automatic Pitch Trim (AUTO TRIM) function of the automatic flight control system. Trim position was indicated to the pilots by the Pitch Trim indicator and was also recorded by the FDR.

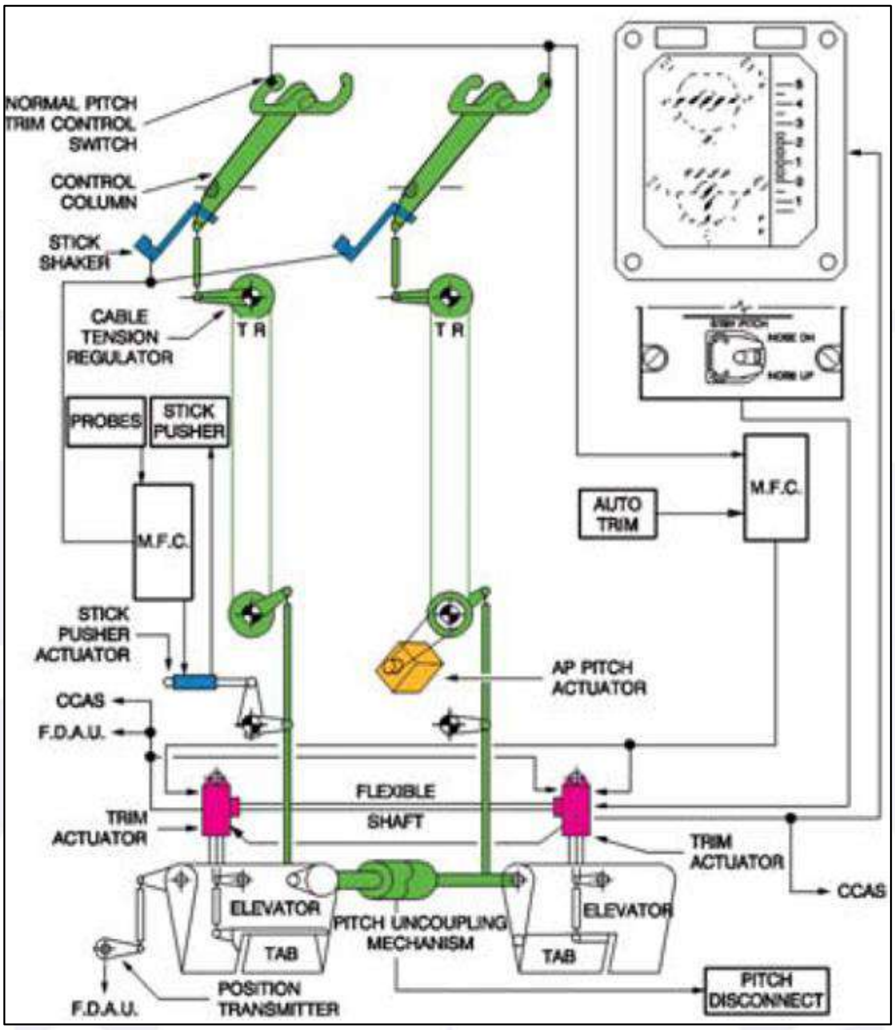


Figure 30. Diagram of the pitch flight control system.
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

- Pitch uncoupling mechanism

In the event of a jam in one of the elevators, uncoupling could be achieved by applying a differential force of 52 daN between the control columns. This mechanism allowed the disconnection of the left and right elevators.

If the elevators were disconnected, the following alerts would be generated in the cockpit for the pilots:

- the MASTER WARNING light would be activated;
- a continuous repetitive aural alert (continuous repetitive chime) would be emitted; and
- the red PITCH DISCONNECT warning message would be generated by the CCAS and displayed on the CAP.

With the elevators uncoupled, each control column would independently control its respective elevator surface.

1.6.7.3. Yaw control

The primary flight control about the aircraft's vertical axis (yaw) was entirely mechanical, achieved through deflection of the rudder.

The rudder had a maximum deflection of 27° to either side. It was controlled by the pilots through pedal inputs or by the Automatic Flight Control System (AFCS), acting through the AP and the Yaw Damper (YD).

In addition to the spring tab, the aircraft's rudder incorporated an aerodynamic feature known as a horn boost, which consisted of an extension of the rudder surface at its upper portion, ahead of the hinge line, intended to reduce the control forces required by the pilots when operating the rudder (Figure 31).

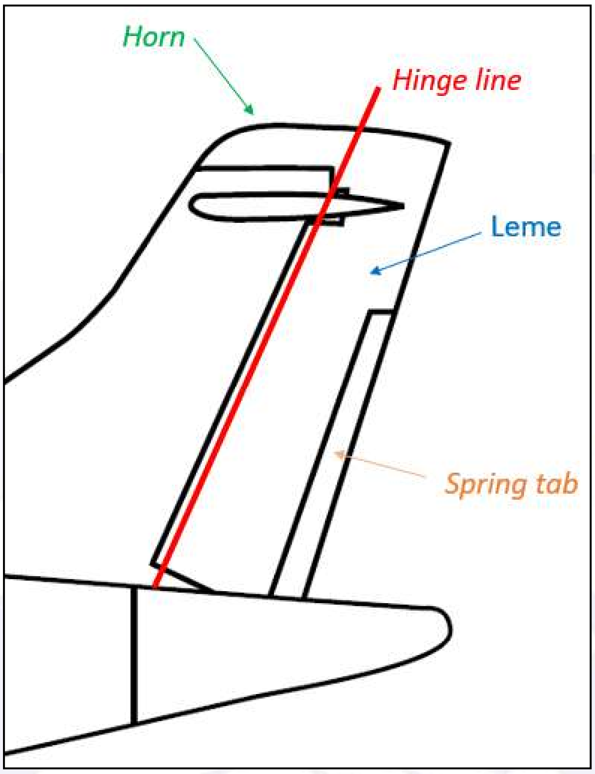


Figure 31. Directional control surface.

When a rudder deflection was commanded, the aerodynamic pressure exerted by the airflow over the horn generated a compensating force that reduced the effort required to move it. In simplified terms, the horn functioned as an aerodynamic balance, using the airflow itself to move the control surface with less force.

The aerodynamic balance, which ensured the rudder returned to its equilibrium position once the input ceased, depended on the ability of the aft section of the aircraft to generate a restoring moment greater than the moment produced by the horn, thereby maintaining the aerodynamic equilibrium of the surface about the neutral position (Figure 32).

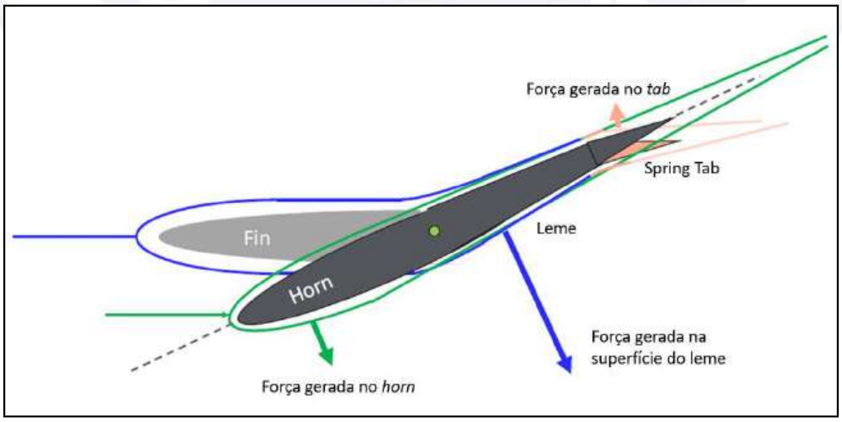


Figure 32. Top view of the rudder, highlighting the role of the horn boost in the rudder's aerodynamic balance.

The position of the rudder surface was monitored by a sensor (position transmitter), whose indication was sent to the FDR. This position sensor was located on the vertical stabilizer, near the rudder, in the aft section of the aircraft.

In addition, the system included a force transducer (force detector rod) that measured the loads applied to the control linkage, such that when 30 daN were reached, the automatic rudder control provided by the YD was disengaged.

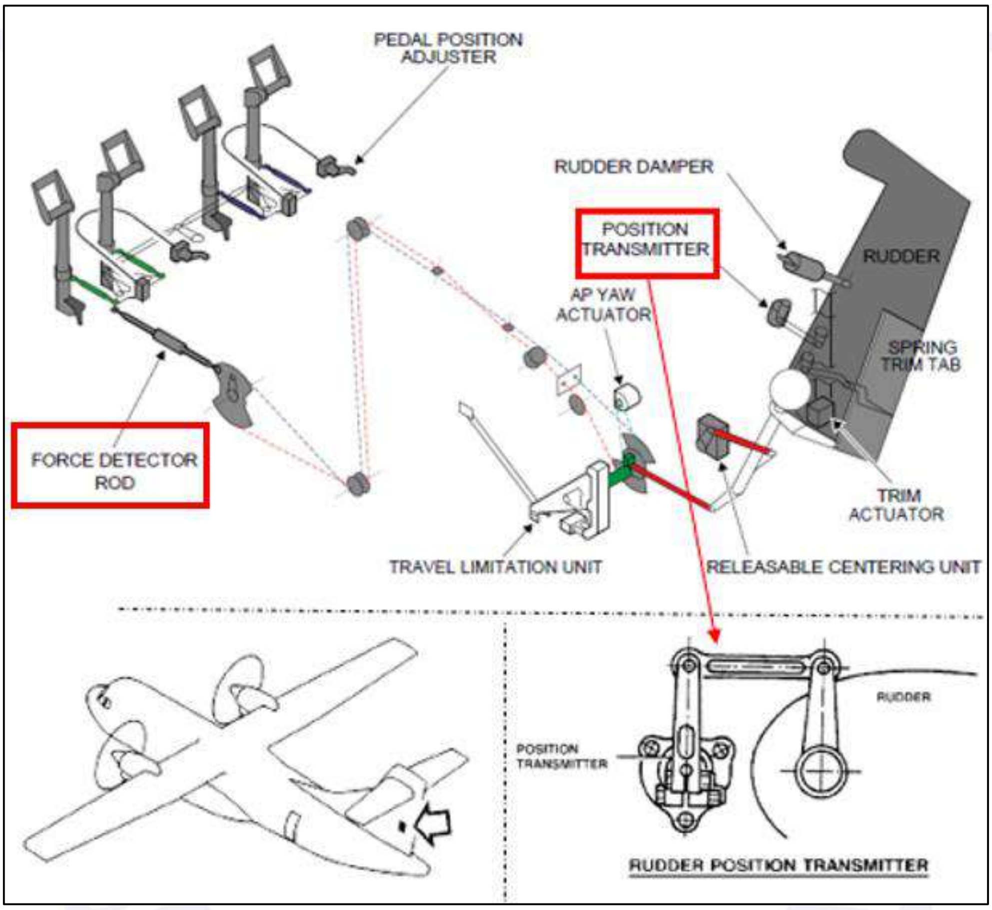


Figure 33. Diagram of the yaw flight control system, highlighting the position transmitter and force detector rod.
Source: Systems_42-500_72-500 ATR Training & Flight Operations Services.

1.6.8. AOA measurement

The AOA values were measured by two independent sensors installed on the forward external section of the aircraft's fuselage, one on each side (left and right).

Each alpha probe sensor consisted essentially of a movable vane coupled to an electrical potentiometer. The vane rotated freely about its axis, aligning itself with the relative wind. This movement was converted into an electrical signal by the potentiometer, providing the transduction of the measured angle of attack. The signals were sent to the aircraft systems, including the modules of the two MFCs, responsible for the activation of the SPS, and were also recorded in the FDR.

The parameters were computed locally on each side of the aircraft and sent separately to the FDR, being recorded as *local angle of attack 1*, (LH AOA LOCAL – AOA 1), corresponding to the left-side sensor, and *local angle of attack 2,* (RH AOA LOCAL – AOA 2), corresponding to the right-side sensor.

Additionally, each sensor was equipped with an electric heating system for the vanes, intended to prevent ice formation on their surfaces, a condition that could compromise the accuracy of the angle-of-attack measurement.

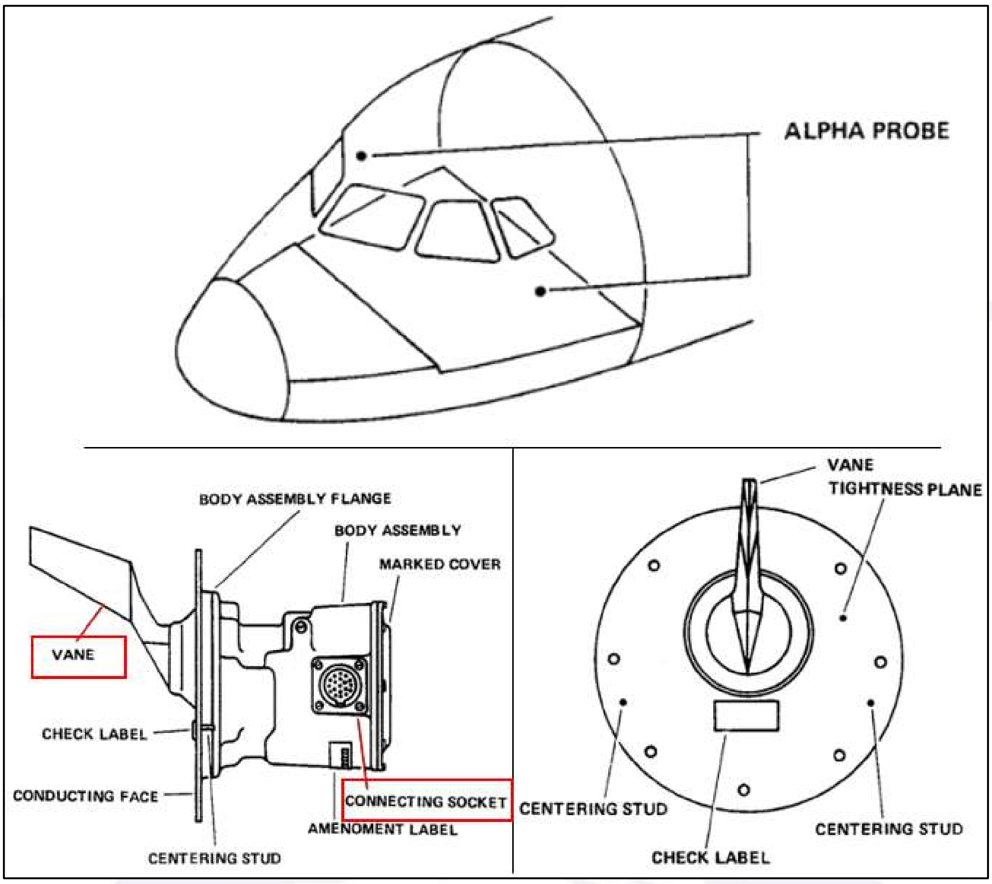


Figure 34. Location of the AOA (Alpha Probe) sensors on the aircraft fuselage. At the bottom, two detailed views of a sensor, highlighting the movable vane and the electrical connector.
Source: AMM ATR-A-27-36-XX-01001-04CA-A – Stall Warning.

1.6.9. Stall Protection System (SPS)

The SPS was composed of the stick pusher and the stall warning (SW), which included the stick shaker. The stall warning activated the electric motors of the stick shaker, located on both control columns, alerting the pilots that the critical AOA limit had been reached. When activated, the stick shaker caused vibration of the control columns, and a cricket-type aural alert sounded in the cockpit, simultaneously with a MASTER WARNING alert.

If the AOA continued to increase, the stick pusher would be activated, acting only on the left-hand control column and pushing it forward, with the objective of reducing the aircraft's pitch attitude and, consequently, decreasing the AOA value, thereby preventing entry into a stall and/or assisting in its recovery.

The activation threshold values for the stick shaker and stick pusher were reduced when level 2 of the Anti-Icing heating system for one of the horns was selected on the Anti-Icing panel located on the overhead panel. The green ICING AOA message would appear on the ICE DETECT panel, alerting the pilots that, under icing conditions, the AOA limits were lowered compared to those established for normal flight conditions.

Figure 35 highlights the manufacturer-defined thresholds for activation of the stall warning and stick pusher in cruise flight and under icing conditions (ICING AOA light illuminated).

Flaps	Icing conditions			
	Take-off (1)		Cruise	
	SW α_1 (°)	SP α_1 (°)	SW α_1 (°)	SP α_1 (°)
0°	11.2°	15.3°	11.2°	15.3°

Figure 35 - Activation threshold values for the stall warning (SW) and stick pusher (SP).
Source: Adapted from aircraft manufacturer information

As previously described, the AOA values were measured by two sensors that provided information to the MFCs, which processed and compared it against pre-established threshold values to activate the stall warning and the stick pusher.

If a difference greater than 4° between the AOA values measured by the sensors persisted for more than 5 seconds, a MASTER CAUTION alert would be activated, accompanied by a single chime and illumination of the FAULT light on the STICK PUSHER/SHAKER button. This information would be available to the pilots and would be stored in the non-volatile memory of the MPC's PCMCIA card.

Since the stick pusher actuator was installed only on the left control column, the command was transmitted to the right elevator only when both elevators were connected. In case of pitch uncoupling, the right-hand elevator would be disconnected from the stick pusher actuator. As a result, stick pusher authority would be maintained only on the left-hand side elevator.

With the activation of the stick pusher, two green lights illuminated, one on the left panel and the other on the right panel, displaying the message STICK PUSHER.

The demonstration of the aircraft's behavior in flight regimes with attitudes beyond the AOA limit that activated the stick pusher was not mandatory by the aeronautical certification.

Accordingly, the effectiveness of the stick pusher was designed, tested, and certified to prevent entry into a stall condition throughout the entire certified flight envelope.

It should be noted that the severe icing condition exceeded the aircraft's certified flight envelope. Under these circumstances, it was not possible to guarantee the reliability of the AOA limits established for activation of the stall warning and the stick pusher.

A radio altimeter (RALT) indication below 500 ft. inhibited activation of the stick pusher.

1.6.10. Autopilot (AP) and Yaw Damper (YD)

The aircraft was equipped with an AFCS that provided AP and YD functions. The system was activated by the AP button (Figure 36, indication 1) on the AFCS panel. In the basic mode, it maintained the aircraft attitude along the three axes—longitudinal, lateral, and vertical—through the connection of the pitch, roll, and yaw electric actuators to the flight control system, resulting in activation of the AUTO-TRIM function and consequent automatic longitudinal trim of the aircraft.

In the vertical mode (indication 3 in Figure 36), the AP was capable of providing the following functions:

- IAS – a mode used to maintain a constant indicated airspeed, even if the aircraft had to initiate a climb or descent;
- Vertical Speed (VS) – allowed the selection of a rate of climb or descent in feet per minute; and

- Altitude Mode (ALT) – comprising three functions:
    - ALT SEL ARM: In this function, the system recognized that there was a preselected altitude to be reached, used when the aircraft was climbing or descending toward the preselected altitude.
    - ALT SEL CAPTURE: In this function, the system captured the preselected altitude.
    - ALT HOLD: When the desired altitude was reached, the ALT SEL CAPTURE function was automatically canceled and the system transitioned to ALT HOLD mode, with a green ALT indication on the panel. The AP would then maintain a constant altitude by acting on the aircraft flight controls.

In the lateral mode (indication 4 in Figure 36), the AP could provide the following functions:

- Heading (HDG) – maintained the heading set on the heading selector;
- Navigation (NAV) – connected the autopilot to a navigation source, allowing it to automatically follow a defined route;
- Approach (APP) – armed or activated the approach mode to capture signals from a final approach path for landing;
- Back Course (BC) – allowed the tracking and capture of an ILS (Instrument Landing System) localizer signal in the reverse direction.

When the lateral LNAV mode used the Flight Management System (FMS) as the navigation data source, the AP coupled the Lateral Navigation (LNAV) function.

The AFCS panel also displayed the bank angle to be used in the HDG lateral mode through the BANK button (indication 5 in Figure 36), being:

- LOW BANK – maximum roll angle of 15°; and
- HIGH BANK – maximum roll angle of 27°, being the default mode after engagement of the AP.

LNAV mode is executed in high bank only.

The FCOM, in the DEGRADED PERF and SEVERE ICING procedures, established that if the aircraft was not able to accelerate and maintain airspeed above ICING BUG + 30 kt, the lateral mode should be selected to LOW BANK.

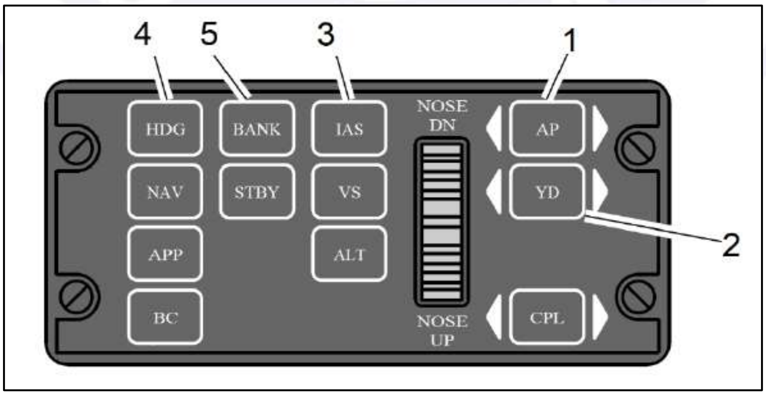


Figure 36 – AFCS panel.
Source: Adapted from the FCOM.

The AP could be disengaged either manually or automatically. One of the automatic disengagement modes occurred when the SW was activated. In this situation, the AP disconnect aural warning (*cavalry charge*) was generated.

When performing turns with the AP engaged, the roll electric actuator acted on the left and right ailerons. In the event of AP disengagement during a turn, the electric actuator ceased its action and the ailerons automatically returned to the “zero” hinge moment position.

In the pitch axis, in the event of AP disengagement, the electric actuator ceased its action; however, due to the AUTO-TRIM, the elevators tended to remain at the last commanded trim position.

The AFCS computer also acted through the YD on the aircraft’s vertical axis to provide the rudder inputs necessary for yaw damping and turn coordination.

The YD could be engaged manually without AP coupling (indication 2 in Figure 36), or it would be automatically engaged when the AP was activated. Once engaged, the YD would remain engaged unless:

- deactivated by the YD button on the AFCS panel; or

- there was a force greater than 30 daN applied to the directional control column.

In other words, upon engagement of the AP, the YD would also be automatically engaged; however, upon disengagement of the AP, the YD would remain engaged unless one of the above conditions occurred.

1.6.11. Minimum Equipment List (MEL)

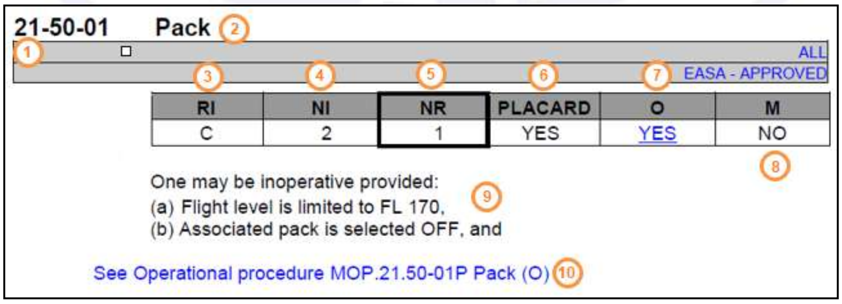
The Minimum Equipment List in effect was established in accordance with certification requirements developed by the aircraft operator and approved by ANAC.

The MEL allowed the dispatch of the aircraft with certain predefined components or systems inoperative, under specific conditions, provided that the remaining equipment and systems were capable of maintaining an acceptable level of safety.

Each inoperative item was associated with a specific code and included its dispatch requirements, among them the time limit for rectification of the failure condition.

Each discrepancy required specific conditions to be met for dispatch authorization, which could involve maintenance actions, specific operational conditions, or both. In all cases, these conditions were associated with a stipulated time limit for the rectification of the inoperative condition.

For clarification purposes, an explanatory table is presented below (Figure 37), outlining the parameters applicable to aircraft dispatch with one of the packs inoperative.


21-50-01 Pack (2)

(1) ALL

(3) (4) (5) (6) (7) EASA - APPROVED

RI	NI	NR	PLACARD	O	M
C	2	1	YES	YES	NO

(8)

One may be inoperative provided: (9)
(a) Flight level is limited to FL 170,
(b) Associated pack is selected OFF, and

See Operational procedure MOP.21.50-01P Pack (O) (10)

Figure 37 – Excerpt from the MEL related to the pack.
Source: Adapted from REV 08 of the operator’s MEL, dated 20FEB2024.

In the previous example, for dispatch of the aircraft with one pack inoperative, the MEL specified the following parameters to be observed:

- (1) Item number: identified the system according to the ATA classification, a standard established by the Air Transport Association and used worldwide in aviation to organize technical maintenance information into numbered categories. The numbering 21-50-01 identified the pack item;
- (2) Title: Indicated the name of the related item;
- (3) Rectification Interval (RI): indicated the category to which the item belonged for the purpose of defining the maximum time allowed for rectification of the condition. Category C referred to a period of ten consecutive days or 240 hours, excluding the day on which the failure or malfunction was discovered.
- (4) Number Installed (NI): indicated the number of equipment items, components, systems, or functions installed, corresponding to the aircraft's certified type design configuration.
- (5) Number Required (NR): specified the minimum number of equipment items, components, systems, or functions that had to be operational for dispatch in accordance with the MEL conditions.
- (6) Placard: the dispatch condition could require that inoperative components be clearly identified in the cockpit. The indication "YES" meant that placarding in the cockpit was required.
- (7) Operational Procedures (O): an inoperative item could require reference to an operational procedure. The indication "YES" meant that there was a corresponding operational procedure specified in parameter 10.
- (8) Maintenance Procedures (M): an inoperative item could require reference to a maintenance procedure. The indication "NO" meant that no such reference was required;
- (9) References: indicated the dispatch conditions to be complied with. In this case, they were as follows: flight level limited to FL170, and the associated pack selected to OFF.
- (10) MEL Operational Part (MOP) reference code: The code identified the operational procedures to be applied for dispatching the aircraft with one pack inoperative.

The MOP 21-50-01-P, referenced in the MEL for dispatch with one pack inoperative, required the following:

- the need to calculate fuel, considering aircraft consumption at FL100;
- a note highlighting that the torque of the engine associated with the inoperative pack would increase; and
- the necessary adjustment to the Power Lever (PL) for the affected engine.

21-50-01P Pack (O)

EASA - APPROVED

ALL

As an in-flight failure could imply total loss of pressurization, fuel consumption at FL 100 must be taken into account to compute the trip fuel.

Note

With a pack selected OFF, engine torque parameter of the related side will increase.

○ PL (affected engine)...ADJUST TO OTHER ENGINE

Figure 38 – Operational Procedure MOP 21-50-01P - Pack (O).

According to the records collected from the TLB (Technical Logbook) and the dispatch documents related to the aircraft's technical condition, there were a total of ten inoperative items, dispatched under the conditions established by the MEL:

- pack No. 1: failure recorded on 05AUG2024, with a rectification deadline of 15AUG2024.
- observer seat in the cockpit (jump seat): failure recorded on 19JUL2024, with a rectification deadline of 16NOV2024.
- passenger seats: inoperative conditions recorded for seats 13C, 16B, 16A, 17A and 17C, with rectification deadlines varying across different dates in November 2024.
- first officer windshield wiper: failure recorded on 30JUL2024, with a rectification deadline of 09AUG2024.
- wheel No. 4 brake (inoperative): failure recorded on 08AUG2024, with a rectification deadline of 18AUG2024.
- cockpit lights: failure recorded on 05AUG2024, with a rectification deadline of 12AUG2024.
- tail strobe lights: Failure recorded on 04AUG2024, with a rectification deadline of 02DEC2024.
- display of the Automatic Direction Finding (ADF): failure recorded on 05AUG2024, with a rectification deadline of 15AUG2024.
- Electronic Flight Instrument System (EFIS): registered a failure on the *Electronic Attitude Director Indicator* (EADI 1), failure recorded on 08AUG2024, with a rectification deadline of 18AUG2024, and
- Ignition System: Failure recorded in 06AUG2024, with a rectification deadline of 09AUG2024.

Figure 39 presents an excerpt from the dispatch documentation, showing the items with Deferred Corrective Action (ACR).

```
OFP COMPUTED WITH (FOR OPERATIONAL PROCEDURES CHECK MEL DESCRIPTION):
MEL/CDL Item: 21-50-01
Remarks: Pack
Description:  Fuel consumption at FL 100 must be taken into account
to compute the trip fuel (Fuel Deviation +18%)
Limitations: Max FL is 170, Fuel deviation 18 %

MEL/CDL Item: 25-11--02
Remarks: Jump Seat Inoperative

MEL/CDL Item: 25-31-01-01
Remarks: Passenger Seats
Description: Check ACR List for inoperative seat

MEL/CDL Item: 30-65-01-01
Remarks:  Windshields Wipers - No precipitation is forecasted
one hour before until one hour after TO and LDG

MEL/CDL Item: 32-42-01
Remarks: One Brake Inop (Check Runway Analysis)

MEL/CDL Item: 33-10-01
Remarks: Cockpit Lights
Description:  May be inoperative provided that: Sufficient lighting
to illuminate all instruments

MEL/CDL Item: 33-43-01
Remarks: TAIL STROBOLIGHT INOP. - CHECK MEIL RESTRICTIONS

MEL/CDL Item: 34-50-03
Remarks: ADF DISPLAY INOP
Description:  The navigation systems required for each segment
of the intended flight route are operative.

MEL/CDL Item: 34-71-01A
Remarks: Eletronic Flight Instrument System (EFIS)
Description: One may be inoperative provided that CAPT EADI is operative.

MEL/CDL Item: 74-21-01
Remarks: Ignition System
Description: Operations are limited to three calendar days
```

Figure 39 – ACR items related to the occurrence flight, reflecting the aircraft's technical condition at the time of dispatch.

With regard to the right-side windshield wiper (First Officer Windshield Wiper), the MEL established that one or both wipers could be inoperative, provided that the operational restriction was observed whereby, for aircraft dispatch, no precipitation could be forecast within the period from one hour before to one hour after the estimated times of departure and arrival at the departure and destination aerodromes. The rule established in the MEL also specified that this requirement applied to the alternate aerodromes (Figure 40).

30-65-01-01 Windshield Wiper System

ALL

EASA - APPROVED

RI	NI	NR	PLACARD	O	M
C	2	0	YES	NO	NO

One or both may be inoperative provided that:

(a) No precipitation is forecasted during a period from one hour before until one hour after the estimated time of departure and arrival at the take-off and destination aerodromes.

(b) Affected wipers are not part of the equipment required for the intended operation.

Note

1) Take-off and destination aerodromes include any take-off and destination alternate aerodromes required by the operational rules.

Figure 40 – MEL item 30-65-01-01 (Windshield Wiper System), related to aircraft dispatch with inoperative windshield wipers. Red arrows indicate the main restrictions.

Therefore, in the event of a precipitation forecast from one hour before the scheduled departure time at the departure aerodrome until one hour after the estimated landing time at the destination or alternate aerodrome, dispatch could not be authorized (NO GO).

It is further noted that there were no records in the TLB, nor dispatch information regarding MEL conditions related to components of the aircraft's Airframe De-Icing system.

1.7. Meteorological information

During the period between 14:56 UTC and 16:26 UTC on 09AUG2024, corresponding to the final segment of the accident flight, a well-defined frontal system was observed to be active over the southeastern region of Brazil.

This system was associated with a low-pressure center positioned over the Atlantic Ocean, off the coast of *Santa Catarina*, interacting with a jet stream at high levels of the troposphere. The dynamics between these two atmospheric systems promoted intense instability, responsible for the formation of an extensive cloud band, precipitation, and significant changes in the thermal and hygrometric profile of the atmosphere.

The observed weather scenario was typical of air mass transitions, in which cold air of polar origin advanced over regions under the influence of tropical air. This interaction intensified the horizontal temperature gradient and favored the development of deep convective clouds, as well as the maintenance of thick stratiform cloud layers. The presence of the jet stream at higher altitudes also contributed to vertical wind shear, a determining factor for the occurrence of turbulence at altitude.

The images collected by the GOES-16 (Geostationary Operational Environmental Satellite), specifically from channel 13 (thermal infrared centered at 10.3 µm), at 16:00 UTC on 09AUG2024, provided important evidence regarding the extent and nature of the cloud formations present in the region of interest during the timeframe of the event. The use of this channel allowed for the estimation of cloud-top temperatures and, consequently, the inference of their approximate altitude.

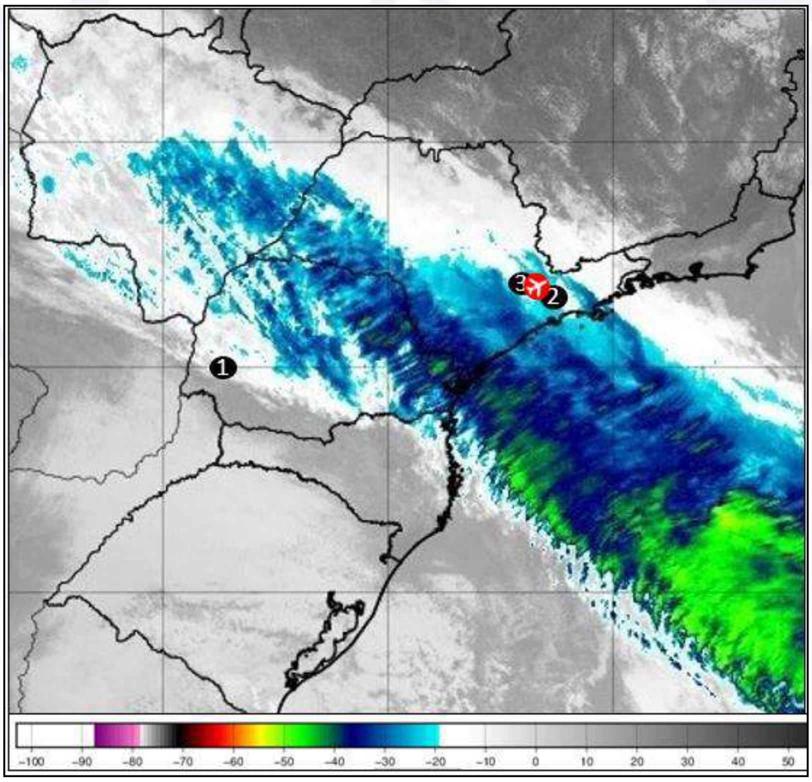


Figure 41 - Enhanced GOES-16 satellite image at 16:00 UTC on 09/AUG/2024, highlighting: (1) SBCA; (2) SBGR; (3) Viracopos Aerodrome (SBKP), Campinas, São Paulo State, and the occurrence site (red circle with aircraft symbol).

Across the States of *Mato Grosso do Sul*, the southwest of *Mato Grosso*, the north-central and eastern portions of *Paraná*, *São Paulo*, and the southernmost part of *Minas Gerais*, widespread cloud coverage with cold tops was identified, with temperatures ranging from 0°C to -35°C, a thermal range compatible with mid-level formations such as Altocumulus (AC) and Altostratus (AS).

In specific areas, particularly between the south of *São Paulo and* the east-central region of *Paraná*, convective cells embedded within the stratiform cloud layer were detected. These formations, of the Towering Cumulus (TCU) type, exhibited even colder tops, ranging from -35°C to -45°C, indicating moderate vertical development.

Furthermore, the presence of isolated and intense Cumulonimbus (CB) clouds was observed extending across a broad area from the Atlantic Ocean to the State of *Mato Grosso do Sul*. In some areas, the cloud tops reached temperatures as low as -50°C.

These convective cells exhibited significant vertical activity, as indicated by the extremely low temperatures (depicted in light green shades in the processed images). Although their distribution was not continuous, it reflected latent atmospheric instability and the potential for rapid development of localized thunderstorms.

The images were consistent with a system containing overlapping cloud types, predominantly mid- and high-level layers, with active convective cores at altitudes above the aircraft's flight level (FL170).

For the analysis of the vertical structure of the atmosphere in the region of the occurrence, data from soundings conducted at 12:00 UTC on 09AUG2024 by the Upper-Air Meteorological Station (EMA) located in SBMT (*Campo de Marte, São Paulo,* SP) were used. The selection of this station was based on its geographic location, encompassing the area affected by the frontal system in the vicinity of the occurrence.

The SBMT station revealed atmospheric conditions of high relative humidity between the pressure levels of 670 hPa (approximately FL110) and 420 hPa (FL230). Within this range, the difference between air temperature and dew point temperature (T - Td) was less than 2°C, a typical condition of saturation or near-saturation of the atmosphere.

The mixing ratio (the proportion of water vapor per kg of dry air) exceeded 1 g/kg, indicating an environment conducive to icing, especially when temperatures were below 0°C.

In the graph shown in Figure 42, the solid black line on the right indicates the air temperature, while the solid black line on the left indicates the dew point temperature. The 0°C isotherm was identified around 650 hPa (FL120), with temperatures reaching as low as -7°C observed at FL170.

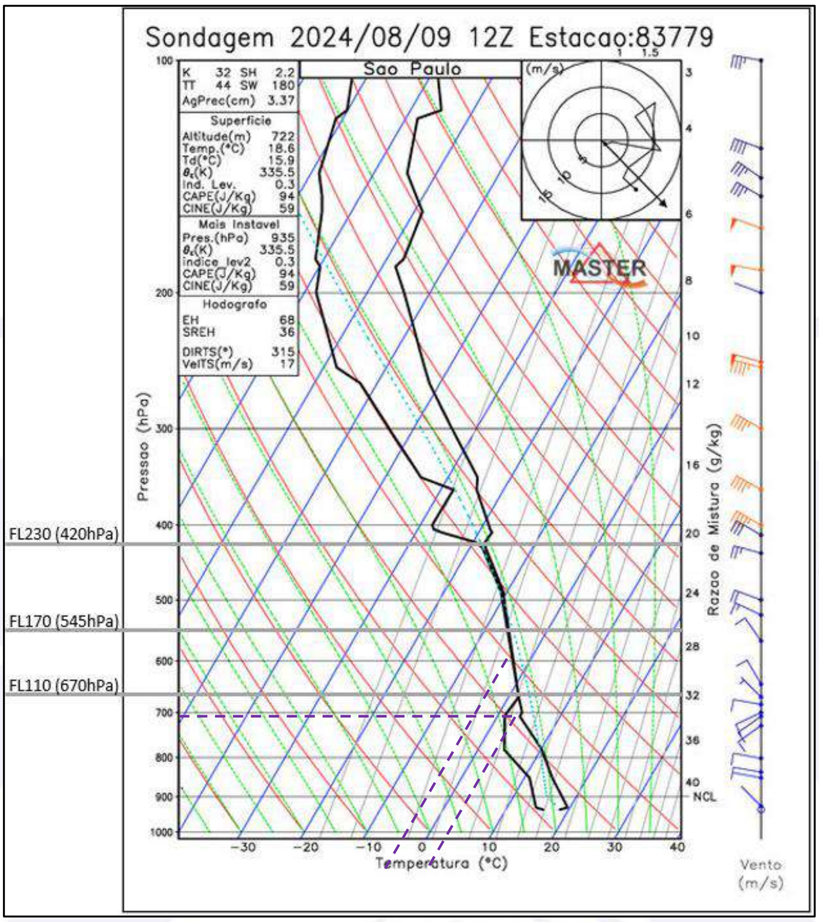


Figure 42 – Skew-T log-p diagram with upper-air sounding data from SBMT, 12:00 UTC, 09AUG2024.

These combined conditions indicated the presence of severe Icing (FGA) between FL120 and FL230.

Meteorological warning messages for significant en-route weather phenomena (SIGMET) were issued for the FIRs (Flight Information Regions) of *Curitiba* (CW) and *Brasília* (BS), covering the area of the occurrence. Specifically, SIGMETs No. 09 (FIR-CW) and No. 02 (FIR-BS) were valid between 15:30 UTC and 19:30 UTC on 09AUG2024, coinciding with the timeframe of the flight.

SBBS SIGMET 2 VALID 091530/091930 SBBS - SBBS BRASILIA FIR SEV ICE FCST WI S1809 W05326 - S2020 W05127 - S2220 W04955 - S2307 W04734 - S2338 W04639 - S2314 W04552 - S2248 W04546 - S2140 W04452 - S1804 W05226 - S1809 W05326 FL120/210 STNR NC=

SBCW SIGMET 9 VALID 091530/091930 SBCW - SBCW CURITIBA FIR SEV ICE FCST WI S2024 W05806 - S2204 W05801 - S2221 W05549 - S2359 W05525 - S2349 W05440 - S2418 W05416 - S2422 W05417 - S2439 W05316 - S2848 W04527 - S2645 W04345 - S2356 W04006 - S2140 W04452 - S2248 W04546 - S2314 W04552 - S2338 W04639 - S2307 W04734 - S2220 W04955 - S2020 W05127 - S1809 W05326 - S1823 W05638 - S2045 W05321 - S2209 W05437 - S2024 W05806 FL120/210 STNR NC=

Both advisories forecast the occurrence of severe icing (SEV ICE) between FL120 and FL210, with no apparent movement and constant intensity. The areas covered by the SIGMETs included the route of the aircraft and its final approach in the *São Paulo* metropolitan area.

Figure 43 shows the severe icing areas of SIGMET messages, shaded in blue, issued for SBCW and SBBS; in (1), the aerodrome of SBCA; in (2), the aerodrome of SBGR; and in (3), the aerodrome of SBKP. In the red circle with the aircraft symbol, the location of the aeronautical occurrence.

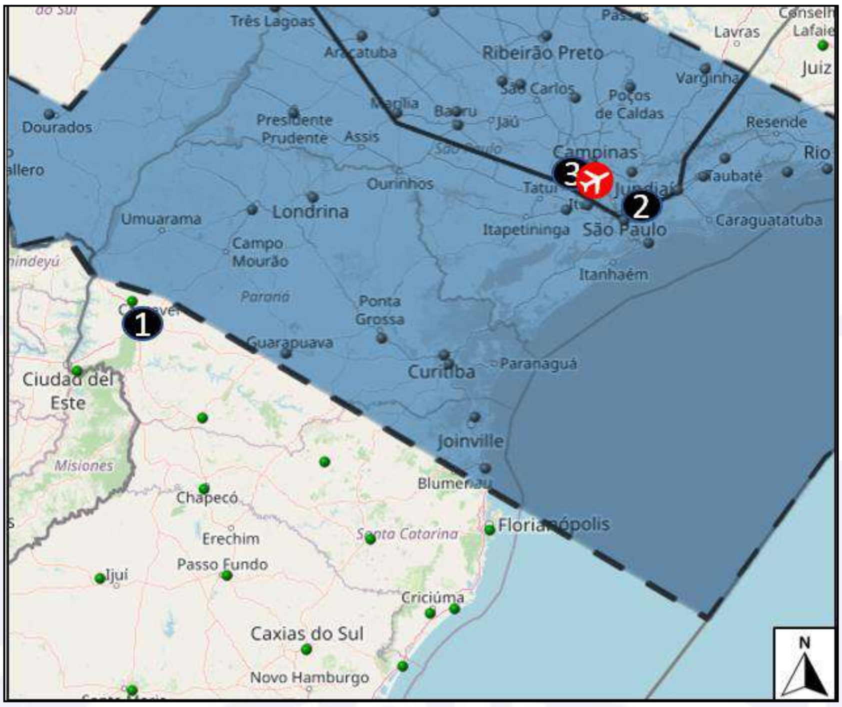


Figure 43 – Area of the SEV ICE SIGMET messages, highlighting (1) SBCA, (2) SBGR, (3) SBKP and the site of the occurrence (red circle with aircraft).

The *Significant Weather* Chart (SIGWX), prepared by CIMAER (*Centro Integrado de Meteorologia Aeronáutica*) at 18:00 UTC on 09AUG2024, depicted the forecast significant meteorological conditions for the period between 15:00 UTC and 21:00 UTC. For the area of interest, the following meteorological elements were forecast

- presence of a cold front moving over the State of *São Paulo*, associated with a low-pressure center of 1012 hPa;
- TCU clouds with bases at 2,000 ft and tops reaching FL200;
- isolated and embedded CBs, with bases at 2,500 ft and tops above FL250;
- stratified cloud layers, including Stratus (ST), Cumulus-Stratocumulus (CUSC), Altocumulus, and Altostratus, forming a cloud cover between 300ft and FL180;
- continuous precipitation and intermittent showers of rain;
- occurrence of SEV ICE between FL140 and FL180; and
- moderate to severe turbulence above FL200.

Figure 44 presents the Significant Weather Chart (SIGWX) depicting significant meteorological conditions for the period between 15:00 UTC and 21:00 UTC, with emphasis on the area of interest.

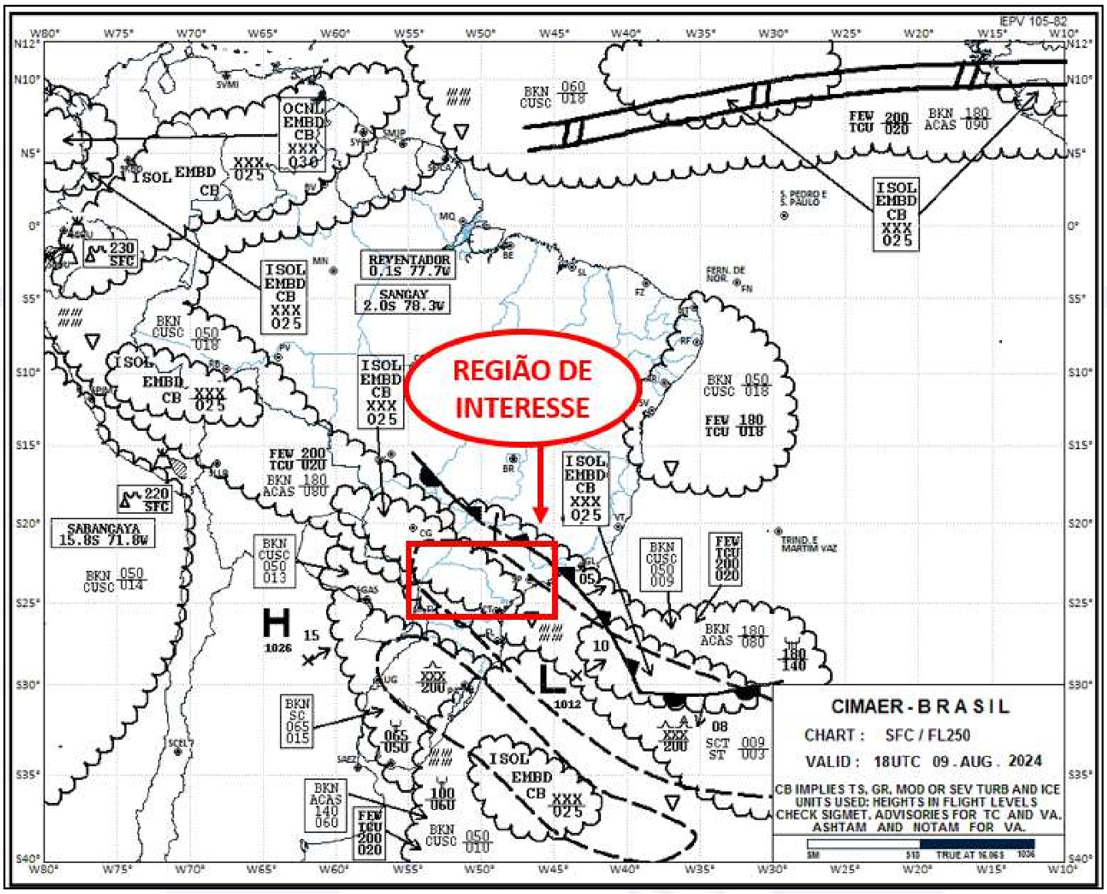


Figure 44 – SIGWX from the surface to FL250, 18:00 UTC / 09AUG2024, highlighting the area of interest.

These data reinforce that the atmospheric environment along the aircraft’s route and at its altitude (FL170) presented multiple adverse factors, including icing, extensive cloud cover, and isolated convective potential.

The combination of surface observational data with upper-level data and SIGMET advisories showed that the route and flight level flown by the aircraft on the day of the accident presented meteorological conditions conducive to the occurrence of SEV ICE.

With the objective of contextualizing the atypical nature of the meteorological conditions encountered, a study was conducted on the frequency of the SEV ICE SIGMET messages covering the State of *São Paulo* from August 2023 to August 2024.

It was found that, during the month of August 2023, 24 occurrences of SEV ICE were reported through SIGMETs in the region, a figure slightly lower than the 25 occurrences observed in the same month of 2024 (Figure 45).

Figure 45 – Monthly variation of SEV ICE in relation to the number of occurrences and the number of hours.

Upon analyzing the vertical distribution of the recorded phenomena, it was observed that FL170 was the most affected, both in terms of absolute number of messages and the total duration, in hours, of the advisories' validity windows. Figure 46 presents the distribution of the recorded phenomena as a function of flight level.

Figure 46 – Flight level affected in relation to the number of occurrences and the number of hours (sum of SIGMET validity periods)

This pattern indicated that the conditions encountered by the aircraft were not unprecedented from a climatological standpoint and represented a concrete operational threat that was identifiable through the meteorological forecasting and alert systems in use in Brazilian aviation.

1.8. Aids to navigation

The navigation and landing aids were operating normally during the flights on the day of the accident.

All technical resources and navigation aids covering the area of interest where the accident occurred, as well as those within the Area Control Center, were operating without any technical or operational restrictions.

1.9. Communications

According to the transcripts of the audio communications between aircraft PS-VPB and the air traffic control units, it was verified that the crew maintained radio contact with the appropriate control units as required. The aircraft's callsign was *Passaredo* 2283 (PTB2283).

In order to clarify the sequence of events preceding the aircraft's impact with the ground, the SIPAER Investigation Commission highlighted selected recordings extracted from the cockpit voice recorder (CVR) and transcripts of communications between the aircraft and the air traffic control units that may assist in understanding the dynamics of the accident.

For the recordings of the times described in this section, Universal Time Coordinated (UTC) was used as the reference.

15:14:58 – a single chime aural alert associated with the activation of the MASTER CAUTION light was heard.

15:15:42 – another single chime aural alert associated with the activation of the MASTER CAUTION light was heard.

15:15:44 – the PIC commented that the Airframe De-Icing had failed and then indicated that the system was already inoperative.

15:16:09 – the SIC stated that the Airframe De-Icing system malfunction was not recorded in the TLB, and that, in order to avoid icing, they would have to conduct the flight at FL110. No response from the PIC to the SIC's remark was recorded on the CVR.

15:17:10 – another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded.

15:17:14 – the PIC stated that the aircraft was climbing well.

For a few minutes, the pilots engaged in personal conversation.

15:20:49 – APP-SP instructed Passaredo 2283 to contact *Curitiba* Center on frequency 127.200 MHz.

15:20:56 – the SIC acknowledged that he would contact *Curitiba* Center on the frequency 127.200 MHz.

15:21:09 – the SIC made a call on the assigned frequency to *Curitiba* Center.

15:21:14 – *Curitiba* Center instructed *Passaredo* 2283 to climb to and maintain FL170.

15:21:19 – The SIC read back that he would maintain FL170.

For a period, the pilots engaged in personal conversation.

15:23:00 – the PIC stated that if the aircraft climbed a little further, they would exit those weather conditions.

15:23:43 – another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded.

15:27:47 – the PIC stated that he could see a bit of the sky and the sun. Shortly thereafter, he added that the aircraft was at 310 kt of ground speed.

15:32:09 – the PIC requested that the SIC ask *Curitiba* Center for direct routing to BUXUK position.

Three minutes after the coordination between *Curitiba* Center and APP-SP, the aircraft was cleared to proceed to the requested position.

Shortly thereafter, the PIC requested that the flight attendant remain in the cockpit while he went to the lavatory. The PIC returned to the cockpit at 15:45:21.

Subsequently, the PIC began filling out the TLB, discussing the required information with the SIC.

During this same period, the pilots engaged in personal conversation.

16:03:44 – The SIC interrupted the PIC during a personal remark to prompt him to check the weather radar. The PIC replied that he would look but continued the personal conversation and did not verbalize any response to the SIC's request.

16:05:58 – the SIC made the first call to APP-SP on 120.925 MHz.

16:06:01 – APP-SP instructed the aircraft to maintain FL170.

16:06:07 – the SIC read back the instruction.

16:06:26 – both pilots began monitoring the *Automatic Terminal Information Service* (ATIS), information SIERRA for SBGR.

16:08:59 – the monitoring of the ATIS was concluded.

16:09:03 – the SIC relayed to the PIC the ATIS information regarding the aerodrome's meteorological conditions.

16:11:03 – another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded. Immediately thereafter, the SIC stated that he had forgotten to turn on the Airframe De-Icing System.

Subsequently, the PIC stated that he could turn on all the De-Icing systems. The SIC asked the PIC to clarify what he had said. The PIC then concluded that he had already turned on all the systems. After this exchange, the pilots resumed personal conversation.

16:14:21 – APP-SP instructed *Passaredo* 2283 to contact on frequency 135.75 MHz.

16:14:30 – the SIC read back the message.

16:14:38 – the SIC made a call on the frequency 135.75 MHz, stating that he had received ATIS information Sierra for SBGR.

16:14:41 – APP-SP asked about the quality of the reception on that frequency. The SIC replied that he was receiving the transmissions with echo.

16:14:49 – APP-SP instructed *Passaredo* 2283 to return to frequency 120.925 MHz. The SIC read back that he would return to that frequency.

16:15:02 – the SIC made a call on frequency 120.925 MHz.

16:15:03 – APP-SP acknowledged and instructed the aircraft to maintain FL170.

16:15:10 – the SIC read back that he would maintain the flight level.

16:15:16 – the SIC requested that the PIC take over the radio communications with APP-SP.

16:15:19 – the SIC made an initial call on VHF2 to the company base in SBGR but did not receive a response.

16:15:29 – the SIC made another call on VHF2 to the company base.

Subsequently, the SIC engaged in communications with the company base at SBGR regarding the need for a wheelchair for one of the passengers. During this interval, the flight attendant initiated conversations with the pilots concerning the coordination of this assistance for the passenger.

16:17:26 – the PIC initiated a passenger address (PA), informing that the descent would begin shortly, providing the meteorological conditions at the destination, and giving instructions regarding the procedures to be followed by the passengers during the remainder of the flight.

16:17:33 – during the PIC's passenger address, another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded. The PIC did not interrupt his PA following the activation of the alert.

16:18:09 – the SIC resumed communications on VHF2 with the company base. On that occasion, he informed the base that a wheelchair would be required.

16:18:24 – the PIC, on VHF1, reported that *Passaredo* 2283 was at the top of descent. At that moment, the SIC was still coordinating via VHF2 with the company base at SBGR.

16:18:26 – APP-SP instructed the aircraft to maintain FL170, and the instruction was duly read back by the PIC on VHF1, while the SIC continued coordinating on VHF2 with the company base.

16:18:42 – the communication between the SIC and the company base at SBGR was concluded.

16:18:47 – the PIC informed the SIC that he had reviewed the Standard Instrument Arrival (STAR) and reiterated that they should reach position UTKUG at 6,000 feet.

16:18:57 – APP-SP instructed *Passaredo* 2283 to contact on frequency 123.25 MHz. At that moment, another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded.

16:19:03 – the SIC resumed radio communications with APP-SP and replied that he would contact on the assigned frequency.

16:19:09 – the SIC made an initial call on frequency 123.25 MHz to APP-SP but did not receive a response.

16:19:19 – the SIC made another call to APP-SP.

16:19:23 – APP-SP instructed him to maintain FL170 due to traffic.

16:19:28 – another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded. At that moment, the SIC was communicating with APP-SP, stating that he was awaiting clearance to initiate the descent.

16:19:35 – the PIC initiated the arrival briefing for SBGR, reviewing with the SIC the altitudes to be achieved at the respective fixes on the arrival chart, as well as the necessary preparations and system settings to be configured on the aircraft.

16:20:00 – the PIC requested the execution of the Descent Checklist.

16:20:04 – the SIC commented on the presence of significant icing.

16:20:05 – the SIC stated that he would turn on the Airframe De-Icing system.

16:20:06 – the PIC remarked that the Airframe De-Icing system was not functioning.

16:20:08 – the SIC initiated the reading of the Descent Checklist, which was completed at 16:20:25.

16:20:33 – APP-SP instructed *Passaredo* 2283 to proceed direct to SANPA position while maintaining FL170. It also advised that descent would be authorized in two minutes.

16:20:41 – the SIC read back the previous instruction, which was the last communication between the aircraft and APP-SP.

16:20:56 – another single chime aural alert associated with the activation of the MASTER CAUTION light was recorded. At that moment, the aircraft had initiated a right turn toward SANPA fix.

16:21:01 – vibration (buffeting) sounds were recorded.

16:21:06 – the SIC stated that there was icing.

16:21:08 – the cricket-type aural alert, associated with the stall warning, was activated. Shortly thereafter, the cavalry charge aural alert, associated with AP disconnection, was also recorded.

16:21:36 – APP-SP cleared *Passaredo* 2283 to descend to FL090, proceeding on a heading toward SANPA.

16:21:55 – APP-SP requested the aircraft to confirm the heading it was maintaining.

From 16:22:02 to 16:22:49, APP-SP made five calls to *Passaredo* 2283 but did not receive a response.

The CVR recordings ended at 16:22:30.

1.10. Aerodrome information

The occurrence was outside the aerodrome area.

1.11. Flight recorders

The aircraft was equipped with a digital FA2100 L3 Flight Data Recorder, MODEL 2100-2/4043, SN 000585479. This piece of equipment had a minimum recording capacity of 25 hours. Data acquisition was performed through the Flight Data Acquisition Unit (FDAU), PN ED34A350, installed on the aircraft.

Figure 47 – FDR of the PS-VPB aircraft.

ANAC had granted a temporary exemption, through Decision No. 600, dated 01 MAR 2023, allowing the operator to operate the ATR-72-212A (ATR-72-500) model without recording eight flight data parameters in the FDR, establishing an exception to the requirements of Section 121.344 of RBAC 121 for a defined period of 18 months.

The temporary exemption was allowed because technical modifications to the aircraft were required in order to comply with national requirements, since the aircraft had previously operated in another country where the recording of such parameters was not mandatory. Nevertheless, the absence of these data on the FDR did not impair the investigation of this accident.

The aircraft was also equipped with a digital FA2100 CVR-L3 Cockpit Voice Recorder (CVR), PN 2100-1020-02 and SN 01753, *software* PN 840-E1657-01. The piece of equipment featured recording capability distributed across three high-quality (HQ) channels, each with a duration of 30 minutes; one high-quality combined (HQC) channel with a duration of 30 minutes; and two standard-quality (SQ) channels, each with a duration of 120 minutes.

Figure 48 – CVR of the PS-VPB aircraft.

The readout procedures for both recorders were conducted at the Flight Recorder Data Readout and Analysis Laboratory (LABDATA), operated by CENIPA (*Centro de Investigação e Prevenção de Acidentes Aeronáuticos*).

The CVR data were successfully retrieved and contained audio recordings from the accident flight, as well as a segment from the previous flight.

The FDR data were successfully extracted, fully preserving the records corresponding to the accident flight, with approximately 313 hours of recordings available for analysis.

Among all the FDR parameters used during the investigation process, those listed in Table 2 were highlighted to provide a better understanding.

Parameter	Description	Unit of measurement	Reference
Altitude	Altitude	ft	Numerical value
Roll Attitude	Aircraft bank angle	degree (°)	>0, right/down
Pitch Attitude	Pitch attitude	degree (°)	>0, nose up
Local Angle of Attack 1	Left AOA sensor measurement (LH AOA – AOA1)	degree (°)	>0, positive AOA
Local Angle of Attack 2	Right AOA sensor measurement (RH AOA – AOA2)	degree (°)	>0, positive AOA
Indicated Airspeed	Indicated airspeed	kt	Numerical value
Vertical Acceleration	Vertical acceleration (aircraft Z-axis)	G	Numerical value
Lateral Acceleration	Lateral acceleration (aircraft Y-axis)	G	Numerical value
Magnetic Heading	Magnetic heading	degree (°)	Numerical value

Left Elevator Position	Left elevator position	degree (°)	Numerical value, >0, nose down
Rudder Position	Rudder position	degree (°)	Numerical value, >0, rudder left
Right Aileron Position	Right aileron position	degree (°)	Numerical value, >0, right aileron down
Left Aileron Position	Left aileron position	degree (°)	Numerical value, >0, left aileron down
Engine Torque	Engine torque	%	Numerical value from 0 to 100
Propeller Speed - NP	Propeller RPM	%	Numerical value from 0 to 100
Power Lever Angle (PLA) Position	Power lever angle position	degree (°)	Numerical value
Low Pressure Spool Speed (NL)	Low-pressure turbine RPM	%	Numerical value from 0 to 100
High Pressure Spool Speed (NH)	High-pressure turbine RPM	%	Numerical value from 0 to 100
Inter Turbine Temperature (ITT)	Inter-turbine temperature (ITT)	°C	Numerical value
Fuel Flow (FF)	Engine fuel flow	kg/h	Numerical value
Pitch Captain Axis Effort	Force greater than 10 daN on the left control column	-	Forward force (DOWN) Aft force (UP)
Pitch F/O Axis Effort	Force greater than 10 daN on the right control column	-	Forward force (DOWN) Aft force (UP)

Table 2 – FDR parameters used during the investigation process.

As the FDR did not record MASTER CAUTION alert activation events, the SIPAER Investigation Commission used the records stored by the aircraft's MFCs.

1.12. Wreckage and impact information

The wreckage was located approximately 38 nautical miles away from SBGR and 7 nautical miles away from SBKP.

Figure 49 – Location of the impact site in relation to SBKP and SBGR.
Source: Adapted from *Google Earth*.

The aircraft impacted the ground in a residential area in the municipality of *Vinhedo*, *São Paulo* State.

Figure 50 – Accident site within the residential area.
Source: Adapted from Google Earth.

The aircraft impacted the ground with high vertical speed and low horizontal speed, resulting in a compact wreckage distribution within an area approximately 30 meters in diameter.

Part of the tail cone separated from the rest of the aircraft at the moment of impact due to the presence of a wall dividing two plots of land with an elevation difference of approximately two meters between them. The remainder of the aircraft came to rest on the lower portion of the terrain.

Figure 51 – Approximate view of the accident site.

At the moment of impact, the radome was projected forward, striking a wall approximately 30 meters from the accident site. The right wingtip was severed upon impact with a tree and was projected ahead of the location where the remainder of the wing came to rest. The engines remained in their original positions. No evidence of in-flight structural separation was found.

The wings, engines, and the rear section of the aircraft were affected by post-impact fire. The cockpit and the forward portion of the passenger cabin, although sustaining substantial damage from the ground impact, were not consumed by the flames. Likewise, the rudder, vertical stabilizer, and horizontal stabilizer showed no evidence of fire damage.

The fire suppression efforts were carried out by the *São Paulo* State Military Fire Department (CBMSP - *Corpo de Bombeiros Militar do Estado de São Paulo*); however, due to the difficulty in controlling the fire, a large portion of the aircraft was consumed by the flames.

The degree of destruction and carbonization hindered the examination of certain parts and systems of the aircraft. Figure 52 shows the main components of the airplane and their post-fire locations.

Figure 52 – Illustration showing the location of aircraft components after the impact.

1.13. Medical, ergonomic and pathological information

1.13.1. Medical aspects

The autopsy findings established that all occupants of the aircraft died from multiple trauma resulting from blunt force sustained in the impact with the ground.

Toxicological testing was performed on the pilots, with negative results for various medications. Blood alcohol concentration testing was also conducted, yielding negative results.

The pilots' most recent medical examinations contained no records of the use of continuous medications. Laboratory tests, electrocardiograms, and psychological evaluations revealed no abnormalities that could have affected their performance.

According to statements from individuals who knew both pilots, they were not undergoing treatment for any illnesses.

On the day prior to the accident, the PIC, who was on standby duty, was called to perform the flights scheduled for the following day. On the night before the accident, the PIC was alone at home and maintained his last contact via message with close acquaintances until 22:30 (local time throughout this item of the report).

As for the SIC, based on information gathered by the SIPAER Investigation Commission, it was determined that he went to sleep at approximately 22:00 and left his residence at around 04:30 toward the airport.

On the day of the accident, both pilots began their duties at approximately 06:30 with their arrival at SBGR. The departure, scheduled for 08:20, occurred at 09:06, with landing at SBCA at 11:15. After a 43-minute ground stop for refueling and passenger boarding, the aircraft departed at 11:58, with a delay of 18 minutes in relation to the ETD proposed in the flight plan, and flew until the time of the accident, which occurred at 13:22 local time.

The operation was conducted in accordance with RBAC 117, Amendment 01, which establishes requirements for the management of human fatigue risk.

There was no evidence that fatigue-related aspects contributed to the occurrence under investigation.

1.13.2. Ergonomic information

During flight simulator sessions conducted at the aircraft manufacturer's facilities, members of the Investigation Commission observed conditions related to the cockpit layout, the arrangement of panels and alerts/alarms, as well as the cognitive perception of simulated discrepancies and failures, considering the Dark Cockpit Philosophy adopted in the ATR-72-212A models.

The most relevant observations regarding visual and cognitive perception during flight were as follows:

- ICING light on the Ice Detect panel

This light exhibited a flashing cycle when ice accretion was detected by the Electronic Ice Detector with the Anti-Icing and/or De-Icing systems turned off. After activation of these systems, the light remained steadily illuminated as long as ice detection persisted.

The indicator location was on the central instrument panel, just below the CAP, within the field of view of both pilots. Its activation resulted in an amber flashing light accompanied by a single chime, providing both visual and aural attention cues.

- ANTI-ICING light on the CAP

This amber light was activated in the event of a failure in the Anti-Icing or De-Icing system. Its activation was accompanied by a MASTER CAUTION alert and a single chime. The light was within the pilots' field of view.

During the simulator sessions, this light was triggered every time failures in the Airframe De-Icing system were simulated. Following activation, as per training, the crew locally identified the source of the failure on the overhead panel, in the section corresponding to the anti-ice protection system.

- APM advisory/alert lights (CRUISE SPEED LOW, DEGRADED PERFORMANCE, and INCREASE SPEED)

The three lights associated with the APM system were arranged in an L-shaped configuration on the APM alert panels located on the glare shield (Figure 23) of both pilot stations.

Activation of any of the APM lights provided a clear, simultaneous (activation at both pilot stations) and perceptible alert, with strong visual salience due to their position within the pilots' forward field of view.

Although the manufacturer's FCOM described the APM alerts at three distinct levels, with the first classified as an advisory (CRUISE SPEED LOW) and the following two as cautions (DEGRADED PERFORMANCE and INCREASE SPEED), it was found that, in practice, the two cautions were treated at the same severity level by the aircraft system, meaning both were associated with the amber MASTER CAUTION annunciation, accompanied by a single chime.

Therefore, despite the conceptual differentiation presented in the manual, the DEGRADED PERFORMANCE and INCREASE SPEED cautions remained within the same category (CAUTION); the only differentiation was related to the presentation of the light, which in the DEGRADED PERFORMANCE caution remained steadily illuminated, whereas the INCREASE SPEED caution light was presented as flashing.

- Airspeed indicator

The cockpit was equipped with two analog airspeed indicators, one positioned in front of each pilot. As previously mentioned, these instruments featured adjustable bugs used to mark reference speeds throughout the flight.

In accordance with the normal operating procedures set forth in the FCOM, once the aircraft stabilized in cruise flight, the orange SPEED BUG was to be set to the calculated cruise speed.

This setting allowed the identification of the effects of increased drag on aircraft performance in the event of ice accretion. Thus, from a human-machine interaction perspective, it was possible to perceive performance degradation through direct observation of the airspeed indicator needle, since, under such conditions, the indicated airspeed needle would move away from the SPEED BUG toward the ICING BUG, or RED BUG, which had been set prior to takeoff.

Figures 53 and 54 illustrate the excerpt from the normal procedure for setting the SPEED BUG, as described in the aircraft's FCOM, as well as the visual behavior of the analog airspeed indicator when a reduction in indicated airspeed occurred during cruise.

NOR.17.1 Climb - Cruise

PF	PM
At Cruise FL/ALT	
	▶ CRUISE PARAMETERS... ... ANNOUNCE
▶ SPEED BUG ....SET TO CRUISE IAS	▶ SPEED BUG ....SET TO CRUISE IAS
The computed reference cruise speed enables to identify drag effect on aircraft performance in case of ice accretion.	*The computed reference cruise speed enables to identify drag effect on aircraft performance in case of ice accretion.*
	▶ TQ BUGS .... SET TO CRUISE TQ

Figure 53– Excerpt from the FCOM showing the procedure for setting the SPEED BUG in cruise and for identifying the effects of drag on aircraft performance in the event of ice accretion.
Source: FCOM.

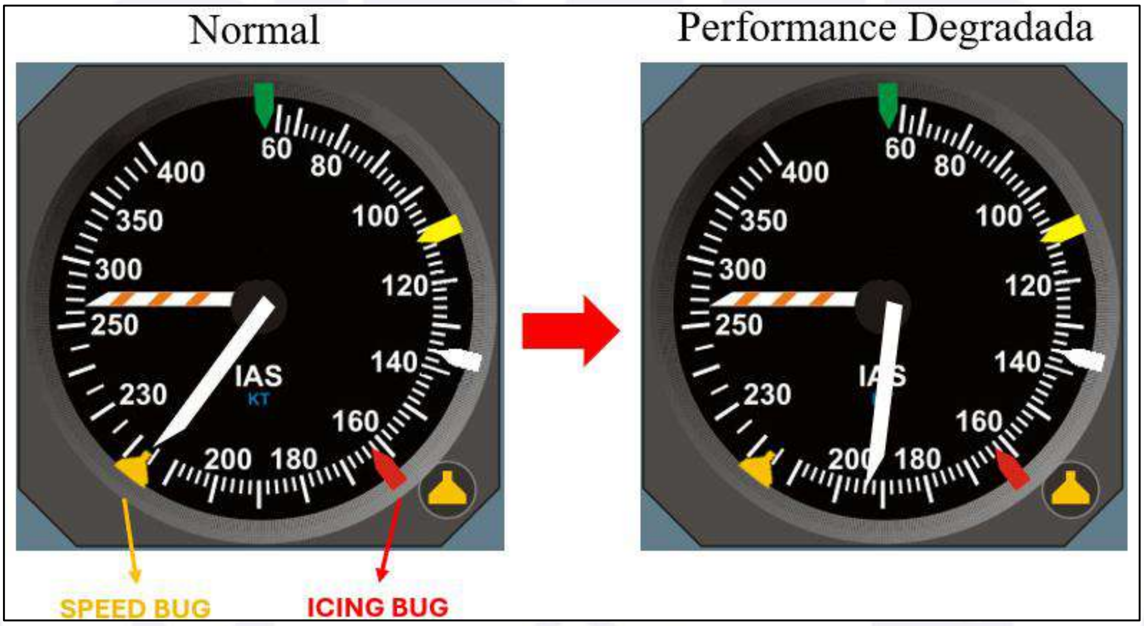


Figure 54 – On the left, airspeed indicator with the Indicated Airspeed (IAS) needle aligned with the SPEED BUG, set to the cruise reference speed. On the right, the needle in an intermediate position between the SPEED BUG and the ICING BUG, indicating performance degradation.

Although the FCOM and the operator's SOP required the setting of the SPEED BUG, this information was not included in the Operator Normal Checklist ATR-72-500, code L-POR-FST-004-20-01, Version 02.00 (Figure 55), nor was there a cruise flight phase. This document was used by the operator as an approved checklist based on the manufacturer's operational manuals.

IN CASE OF ICING CONDITIONS REFER TO QRH.ICE.1
IN CASE OF SEVERE ICING REFER TO QRH.E99.08

FINAL COCKPIT PREPARATION	
PARKING BRK	ON / PRESS CHECK
ALTIMETERS	SET & CHECK
LANDING ELEVATION	SET
✦ GNSS / COM / NAV	SET
FUEL QTY / FOB	CHECK
ENG F/U	RESET
MEMO PANEL	CHECK
PWR MGT	TO
NWS	OFF
BEFORE PROPELLER ROTATION	
CDLS	ON
T/O BUGS	SET & CHECK
TRIMS	SET & CHECK
TAIL PROP	REMOVED / ON BOARD
DOORS	CLOSED
SEAT BELTS	ON
BEACON	ON
BEFORE TAXI	
PROP BRAKE	OFF
COM HATCH	CLOSED
CL 1 + 2	AUTO
PROBES	ON
ANTI-ICING	AS RQD
ANTI-SKID TEST	PERFORMED
FLAPS	15º
NOSE SAFETY PIN	IN SIGHT
NWS	ON
TAXI	
TAXI & T.O. LIGHTS	ON
BRAKES	CHECK
AFCS	SET & CHECK
T.O. CONFIG TEST	PERFORMED
TAKE OFF BRIEFING	COMPLETED
BEFORE TAKE OFF	
✦ RNP	[_RNP / _ANP] CHECK
GUST LOCK	OFF
FLIGHT CONTROLS	CHECK
XPDR / TCAS	CHECK
CCAS	RCL / T.O. INHIB
APM	SET AND CHECK
AIR FLOW	NORM
••••••••••••••••••••••••	
CABIN CREW	ADVISED
BLEED VALVES	OFF
EXT LIGHTS	ON
FD BAR WHEN LINED UP	CENTER
RUDDER CAM	CENTER
AFTER TAKE OFF	
LDG GEAR	UP
FLAPS	0º
PWR MGT / NP	CLB / CHECK
BLEED VALVES	ON
TAXI & T.O. LIGHTS	OFF
••••••••••••••••••••••••	
ALTIMETERS	SET & CHECK

DESCENT	
CCAS	RCL
LDG ELEVATION	CHECK
✦ GNSS	SET & CHECK
LDG BUGS	SET & CHECK
ARRIVAL BRIEFING	COMPLETED
APPROACH	
SEAT BELTS	ON
LANDING LIGHTS	ON
ALTIMETERS	SET & CHECK
CABIN ALTITUDE	CHECK
✦ RNP	[_RNP / _ANP] CHECK
BEFORE LANDING	
CABIN CREW	ADVISED
LDG GEAR	DOWN 3 GREENS
FLAPS	CHECK
PWR MGT	TO
TLU LO SPD	CHECK
ICING AOA LIGHT	AS RQRD
✦ EHSI 2NM TO FAF	APP
EXT LIGHTS	ON
AFTER LANDING	
RADAR	STBY
FLIGHT CONTROLS	LOCKED
FLAPS	0º
TRIMS [3 AXES]	RESET
XPDR	STBY
LANDING LIGHTS	OFF
ANTI-/DE-ICING	OFF
PROBES	OFF
■ **IF LAST FLIGHT OF DAY**	
ATPCS DYNAMIC TEST	PERFORM
● **AFTER AT LEAST 2 MINUTES**	
CL1	FTR THEN FUEL S.O.
PARKING	
PARKING BRK	ON
TAXI & T.O LIGHTS	OFF
CL 2	FTR
PROP BRAKE	ON
BEACON	OFF
TAIL PROP	ON POSITION
SEAT BELTS	OFF
LEAVING THE AIRCRAFT	
OXYGEN MAIN SUPPLY	OFF
ICE & RAIN PROTECTION	OFF
EXT LIGHTS	OFF
EMER EXIT LIGHT	DISARM
RADAR / EFIS / COM / NAV	OFF
CL 2	FUEL S.O.
FUEL PUMPS 1 + 2	OFF
CDLS	OFF
EXT PWR	OFF
BAT	OFF

✦ ITEM REQUERIDO PARA OPERAÇÃO PBN

Figure 55 – Extract from the Normal Checklist ATR-72-500, code L-POR-FST-004-20-01, Version 02.00.

1.13.3. Psychological aspects

During the analysis of psychological aspects, information obtained from the CVR and FDR was considered, as well as data provided by the operator, interviews with company personnel, and with the crew's family members.

The PIC was 35 years old, was married, and lived in the city of *São Paulo*. According to family members, he was described as a dedicated, responsible, and committed professional.

It was reported that the PIC was experiencing personal difficulties at the time of the occurrence. Aware of this situation, the operator reportedly offered him the possibility of a temporary leave from flight duties.

The PIC declined the offer, stating that the flight routine contributed positively to his emotional well-being, helping him keep his mind occupied. Information regarding the handling of personal issues was corroborated by excerpts from the CVR, which revealed informal conversations between the pilots during the flight.

The professional history of the PIC indicated prior experience as a copilot on jet aircraft, specifically on the Airbus A320, during the period in which he worked in Kazakhstan.

The PIC joined the operator in November 2022, and worked for the company until the date of the accident. He was initially hired as a copilot, with the expectation of being promoted to captain in the short term.

During the selection process, he demonstrated strong performance in the simulator and underwent a psychological attention test, with results considered favorable. His promotion to captain occurred approximately one year prior to the accident.

Interviews indicated that, over time, the PIC developed good interpersonal relationships and was well regarded among colleagues. Despite this, he reported dissatisfaction to close contacts regarding organizational aspects of the operation, particularly with respect to the condition of the aircraft. He also expressed interest in seeking new opportunities abroad and held a valid certification issued by the Federal Aviation Administration (FAA), with the intention of resuming jet aircraft operations outside Brazil.

From the perspective of coworkers, he was regarded as self-confident, composed, diligent, good-humored, and communicative.

With regard to the company's Training Program, the PIC demonstrated performance considered satisfactory, with no records of significant observations.

The SIC was 61 years old, was married, and lived in the metropolitan region of *São Paulo*. According to family members and colleagues, he was a person with well-defined personal convictions, guided by values such as faith, family, and work. He demonstrated ease in establishing interpersonal relationships and was regarded as a good listener, helpful, and empathetic. He valued family time and maintained healthy habits, such as walking, engaging in recreational activities with his youngest child, and participating in religious activities.

He joined the operator as a copilot in August 2019 and remained in that role until the date of the accident. Colleagues described him as polite, calm, responsible, optimistic, and technically competent. However, a passive attitude in critical situations was also reported.

Like the PIC, the SIC demonstrated satisfactory performance in the company's Training Program, with no records of significant observations.

Regarding the interactions between the PIC and the SIC, CVR data revealed conversations of a personal nature, involving the PIC's private issues. Such conversations occupied significant portions of the flight.

Additionally, it was verified that, during the occurrence flight, the pilots did not comply with Crew Resource Management (CRM), particularly during periods that required increased attention, as non-operational conversations were maintained, contrary to the guidance to prioritize operational tasks and maintain focus on flight conduct.

Another aspect that warranted attention in this occurrence concerned the deleterious effects of the startle effect[1] on the crew's ability to respond to critical events. It is an involuntary neurological and physiological response triggered by sudden and unexpected stimuli.

The surprise resulting from exposure to a sudden and intense event may lead pilots to take instinctive and, in some cases, inappropriate actions, which can compromise situation management. This occurs due to an automatic physiological response of the body, in which stimuli perceived as threatening are processed in a brain region known as the amygdala,

---

[1] *Martin, W. L., Murray, P. S., & Bates, P. R. (2012). The Effects of Startle on Pilots During Critical Events: A Case Study Analysis. Griffith University Aerospace Strategic Study Centre, Brisbane, Australia*.

rather than through the brain's natural information processing pathway, which takes place in the prefrontal cortex.

Psychological responses may also occur, such as fear, anxiety, and uncertainty, along with impairments in the performance of cognitive tasks due to a reduced information-processing capacity, which may affect decision-making, problem-solving ability, and the crew's situational awareness.

Finally, two flight attendants were also part of the crew, both demonstrated satisfactory performance in the company's training and were described as dedicated to their work and families and, according to reports, spoke about aviation activities with enthusiasm.

The interactions between the flight attendants and the pilots, as recorded on the CVR, reflected cordiality in an environment without hierarchical barriers.

Crew cognitive readiness

Despite the structured logic of the alerting system and the dark cockpit philosophy adopted in the aircraft, crew performance in response to a failure scenario requires not only technical knowledge of the system, but also a state of cognitive and emotional readiness that enables the correct interpretation of cues and the proper execution of procedures.

The CCAS, in conjunction with the MFC, provided a robust alerting architecture distributed across three layers: MASTER WARNING/MASTER CAUTION, CAP, and local lights. This structure established a sequential decision-making process.

Proper response to level 2 (CAUTION) or level 3 (WARNING) alerts depended not only on the pilots perceiving the visual and aural cues, but also on correctly understanding the severity of the situation, correlating it with the aircraft's behavior, and executing the appropriate response actions within an adequate time window.

In other words, even if the system clearly indicated a failure through a flashing amber CAUTION light, for example, associated with a single chime, the success of the corrective action was directly dependent on the crew's perception, judgment, and coordination. If any disruptive factors were present—such as fatigue, prior expectations, distractions, or task overload—the likelihood of delayed, omitted, or improperly executed procedures increased.

Furthermore, it should be considered that the system also required that, following the initial alert, the pilots should observe the CAP and then perform a local check on the corresponding system panel. This process required sustained attention, a working memory, coordination between crew members, and cognitive functions that are sensitive to the influence of fatigue, altered emotional state, and fragmentation of situational awareness.

Thus, although the aircraft incorporated a design philosophy focused on clarity and the prioritization of alerts, the final link in this chain was the pilots' decision-making, which remained vulnerable to human limitations. The interface could provide the data, but action depended on the pilot's ability to correctly interpret, prioritize, and respond within a dynamic environment that often involved concurrent tasks.

Mack and Rock (1998)[2] describe the phenomena of inattentional blindness and inattentional deafness as cognitive limitations that occur when an individual, while directing attention to specific tasks or stimuli, fails to perceive other relevant visual or auditory cues. These manifestations do not imply voluntary neglect and are associated with the limited capacity of attentional processing. They become more evident in high mental workload environments, where multiple demands compete for the same cognitive resources.

- Inattentional Blindness: pilots focused on specific visual tasks—such as checklists, navigation instruments, external scanning, and the activation of

[2] *MACK, A.; ROCK, I. Inattentional Blindness. Cambridge: MIT Press*, 1998.

visual alerts—may fail to consciously integrate visual information from the respective panels, even when it is within their field of view; and

- Inattentional Deafness: The simultaneity of auditory stimuli—such as radio communications, non-operational conversations, engine noise, and cabin sounds—may lead to attenuation or even non-perception of aural signals associated with aircraft warnings.

In the case of the PS-VPB flight crew, it was found that, at certain moments, the pilots' attention was fragmented among internal communications regarding personal issues, external communications, the execution of briefings, and system management, coinciding with the issuance of warnings/alerts related to ice accretion and degradation of aircraft performance.

1.14. Fire

The fire started immediately after impact. The combustion material was the aircraft's fuel, and the ignition source resulted from the intense friction between the aircraft and the ground, as well as between aircraft components themselves.

The post-impact fire caused a high degree of destruction to the materials comprising parts of the aircraft. Metallic components made of aluminum alloys, such as those in the wings and fuselage, were melted, and the polymer matrix structures of composite materials were disintegrated.

Considering the degree of destruction of the materials comprising the parts of the aircraft consumed by the fire, and the minimum melting temperature of these materials, the SIPAER Investigation Commission estimated that the fire generated heat producing temperatures on the order of at least 660°C.

No evidence of in-flight fire was identified.

1.15. Survival aspects

Due to the characteristics of the impact with the ground, the high energy involved in the collision, and the substantial damage sustained by the aircraft, no conditions compatible with the survival of the occupants were identified.

The characteristics of the wreckage indicate that the severity of the impact and the damage resulting from the collision were incompatible with the possibility of evacuation or survival.

1.16. Tests and research

The SIPAER Investigation Commission segregated selected aircraft and engine components deemed relevant for examinations, tests, and laboratory analyses. The objective was to collect data on the functioning of the aircraft systems that could support the investigation.

Based on the information that could complement the data from the flight recorders, the Commission selected the following items to tests and research:

- MFC1 and MFC2;
- MPC;
- cockpit panel lamps;
- stick pusher actuator;
- elevator synchro transmitter;
- AOA sensors;
- two DDVs; and

- two engines.

Additionally, the Commission assessed other pieces of evidence identified during the course of the investigation, including examination involving the aircraft's electrical bus and the pitch uncoupling mechanism. Finally, flight simulator sessions were conducted, and a demonstration flight was monitored at the aircraft manufacturer's facilities.

1.16.1. Multi-Function Computer (MFC)

The BITE data memories from modules A and B of MFC1 (MFC1A and MFC1B) and from module A of MFC2 (MFC2A) were recovered from the damaged computers. However, the memory from module B of MFC2 (MFC2B) was not located. The decoding software provided by Airbus Avionics assisted the SIPAER Investigation Commission in reading and analyzing the recovered memories.

Figure 56 – General condition of the MFC1 prior to disassembly.

The MFC1A board was removed, and it was verified that the memory component remained attached to it (Figure 57). The data readout was successfully completed, generating files with complete and consistent data (Figure 58).

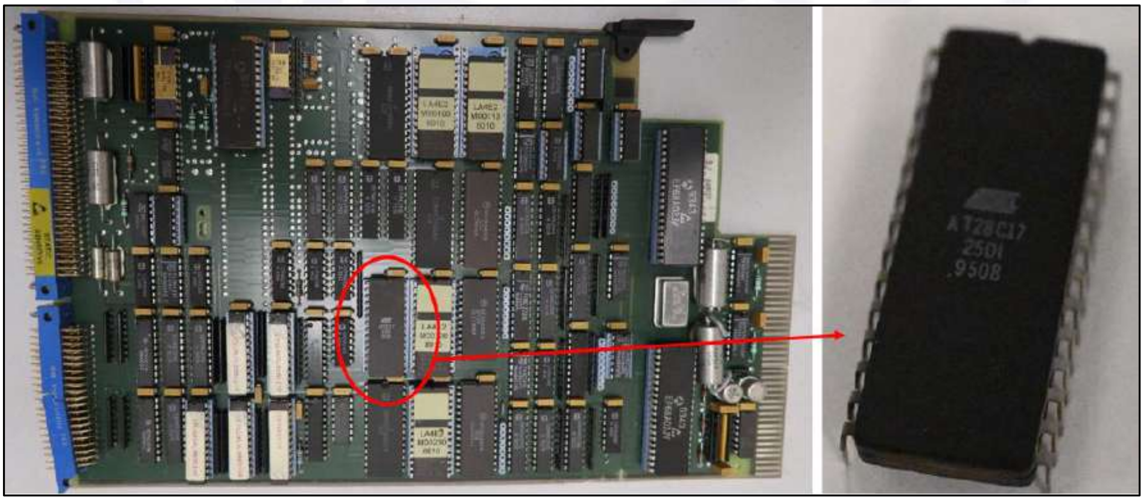


Figure 57 – MFC1A board with the memory component highlighted in red;
on the right, a detail of the component.

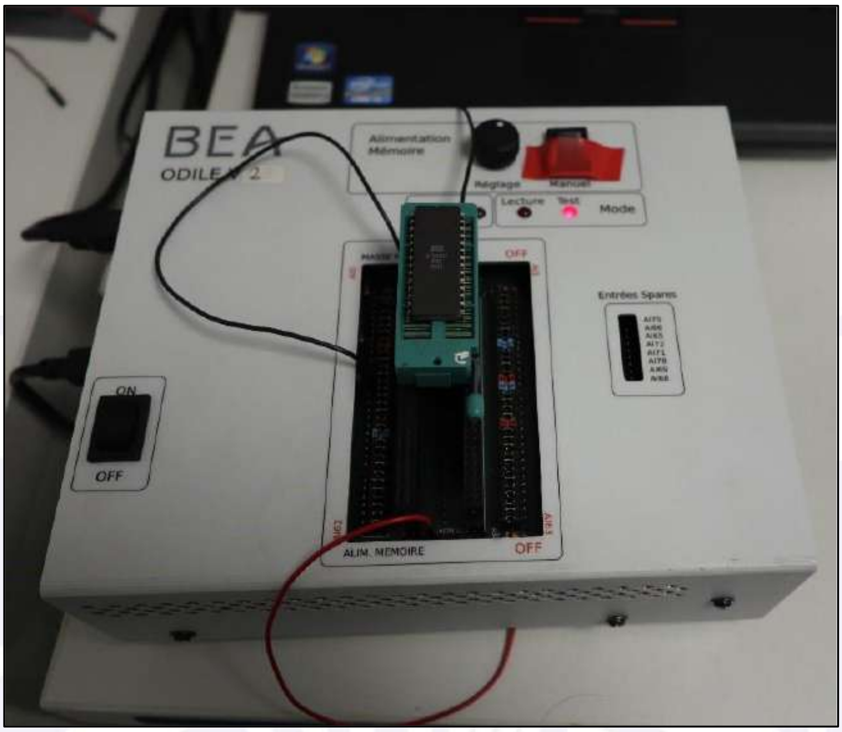


Figure 58 – MFC1A memory component connected to a dedicated test and download tool.

The memory from the MFC1B board was found detached at the accident site. The component was subjected to a detailed visual inspection using a stereoscope, which identified the presence of all pins, although some exhibited damage. The pins were repaired (Figure 59), and the item was subjected to the same testing and readout procedures applied to the MFC1A memory component. The data readout was successfully completed, generating files with intact and consistent data.

Figure 59 – On the left, MFC1B memory with damaged pins; on the right, the same component after pin repair for the execution of tests and data readout.

The MFC2 exhibited more severe deformation of its housing, and the front cover was missing (Figure 60).

Figure 60 – General condition of the MFC2 prior to disassembly.

The electronic boards of the MFC2 were severely damaged. On the MFC2B board, the memory component slot was empty. On the MFC2A board, the memory was in its slot, but with most of its pins disconnected from the contact holes (Figure 61).

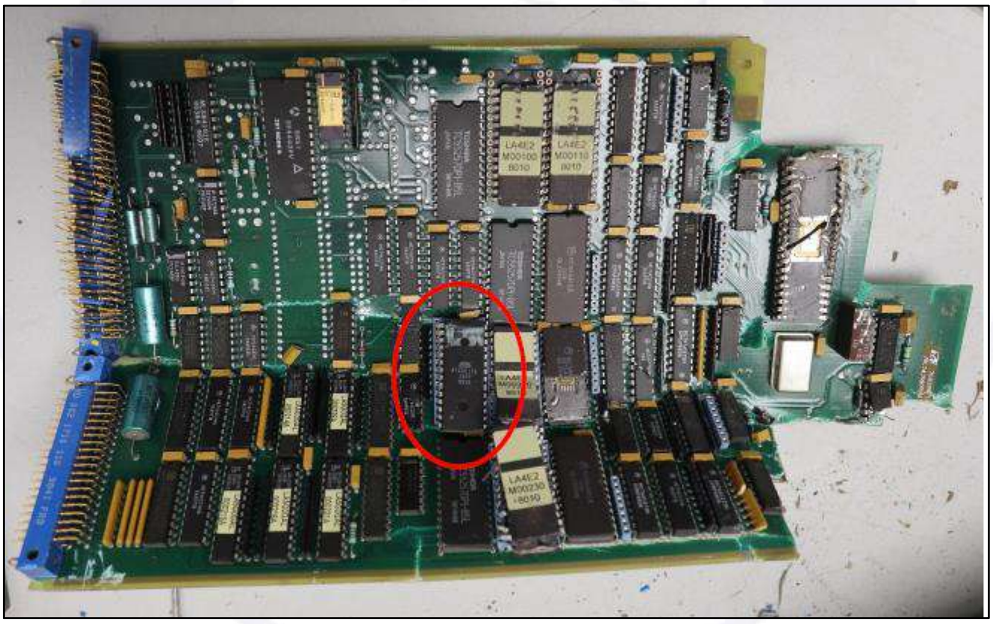


Figure 61 – MFC2A board with the memory component circled in red.

The component was removed from the board and subjected to a detailed visual inspection using a stereoscope, which confirmed the presence of all pins, although some were bent. The pins were repaired (Figure 62), and the item was subjected to the same testing and readout procedures applied to the MFC1A memory component. The data readout was successfully completed, generating files with intact and consistent data.

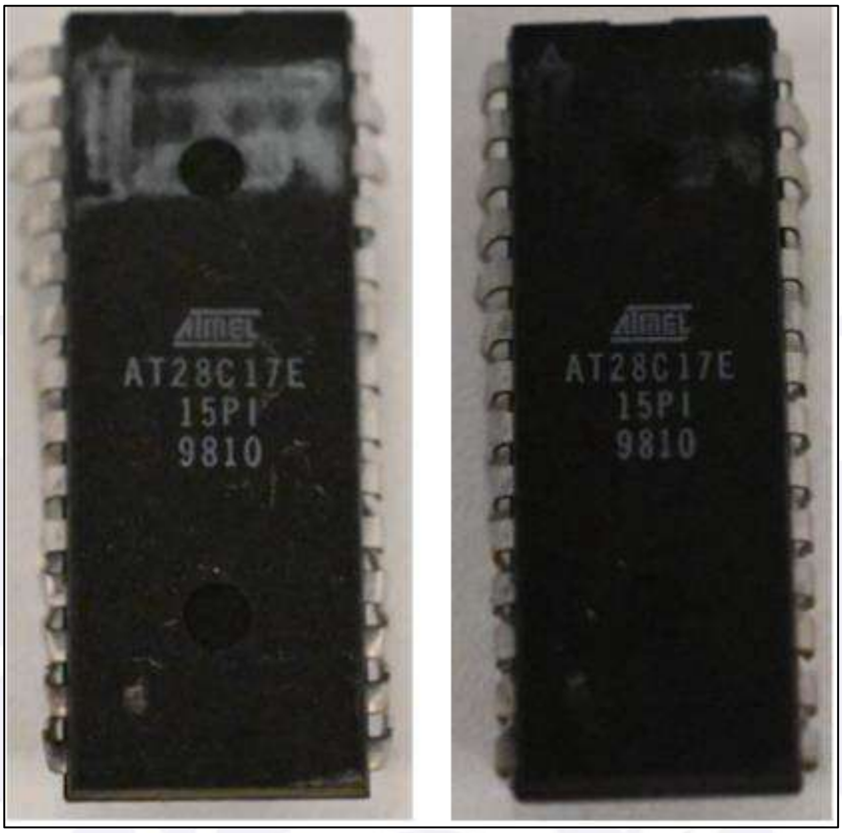


Figure 62 – On the left, MFC2A memory component with damaged pins; on the right, the same component after pin repair for testing and data readout.

Therefore, three of the four memory components (MFC1A, MFC1B, and MFC2A) were successfully recovered, decoded, and read.

Each module monitored and controlled important aircraft systems, as well as managed failures and alerted the flight crew when necessary.

Whenever a system fault code was detected by the MFCs, it was recorded in the memory components, allowing the generation of a fault history covering the last nine flights, designated from “flight zero” to “flight -8.”

Based on this history, the aircraft manufacturer issued Technical Report reference V-339/24, containing all faults computed and stored by the MFCs. The report highlighted the detection of faults related to certain aircraft systems, including the Airframe De-Icing system.

The SIPAER Investigation Commission considered the faults detected from “flight 0” to “flight -8”, as follows:

Airframe De-Icing System Boot Faults

- fault description: Right Wing Boot B Fault.
    - flights in which this fault was detected: “flight 0” (accident flight), “flight -1”, “flight -2”, and “flight -3”.
- fault description: Left Wing Boot B Fault
    - flights in which this fault was detected: “flight -3”.

System	Detected failure description	Flight 0	Flight -1	Flight -2	Flight -3	Flight -4	Flight -5	Flight -6	Flight -7	Flight -8
Boots	Right Wing Boot B Fault	Failure detected	Failure detected	Failure detected	Failure detected					
	Left Wing Boot B Fault				Failure detected					
	Right Engine Boot A Fault									
	Right Median Wing Boot A Fault									

Figure 63 – History of external faults computed by the MFCs.
Source: Adapted from Technical Report Reference V-339/24
issued by the aircraft manufacturer.

Based on the data extracted from the MFCs, it was determined that, during the accident flight, a fault associated with the operation of the Airframe De-Icing system boots was detected. This fault triggered a MASTER CAUTION alert, accompanied by a single chime aural warning, an ANTI-ICING message on the CAP, and a FAULT indication on the AIRFRAME push button on the De-Icing system local panel, located on the overhead panel.

The system activated and detected this fault when the Airframe De-Icing push-button switch was selected to the ON position and an inconsistency existed between the command to inflate the boots and its pneumatic pressure. This inconsistency could occur either due to the detection of low pressure during the inflation (opening) command, or due to the detection of high pressure during the deflation (closing) command.

The recorded data indicated that the fault was associated with the command of the B chambers of the right-wing outer boots, controlled by the DDV located at FIN 10 DM (Figure 64). The probable reasons for the detected fault were pneumatic leaks in the boots, pneumatic leaks in the distribution line, pressure sensor failure, or DDV failure.

The fault identified during the accident flight was also detected in the three preceding flights.

System	Detected failure description	Associated FIN and designation	MFC internal BITE trigger & MFC pin allocation	MFC internal alert trigger	Master lights	Aural alert	CAP ind.	Local ind.	Failure triggering condition and local alert description
Boots	Right Wing Boot B Fault	10DM VALVE-DE-ICING DUAL DISTRIBUTOR, RH EXTERNAL WING	BITE trigger : MN3BO.8.1A Pin allocations: MFC2 AD-15D / MFC2 AA-15B	CAP alert trigger: WWCAPDEICINGLT Local alert trigger: ICFAULTSTRUC	MC	SC	ANTI-ICING	FAULT	Failure detected when "P/BSW-DE ICING/AIRFRAME" (7DM) is selected ON in case of an inconsistency between boot inflation command and boot pressure (either if low pressure is detected during an inflate command or if high pressure is detected during a deflate command) if no bleed low pressure condition is active. Possible cause: deicer leakage, deicer supply line leakage, pressure switch failure, dual distributor valve failure Associated local alert: Illumination of the FAULT legend on the "P/BSW-DE ICING/AIRFRAME" (7DM) on "ANTI ICING/DE ICING/SIGNS OVERHEAD PANEL" (24VU)

Figure 64 – Excerpt from the table containing the descriptions of external faults
computed by the aircraft's MFCs.
Source: Technical Report Reference V-339/24 issued by ATR.

1.16.2. Multi-Purpose Computer (MPC)

The MPC exhibited severe structural damage, with visible deformation of its housing.

Figure 65 – Images of the MPC installed on aircraft PS-VPB, showing damage and deformation of its housing.

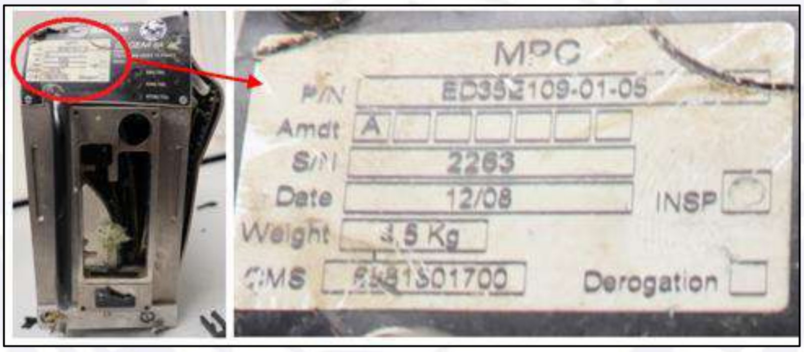


Figure 66 – Front face of the MPC with a detail of its identification placard.

The PCMCIA card was removed from its slot in the MPC and sent for laboratory examination (Figure 67).

Figure 67 - On the left, rear face; on the right, front face of the PCMCIA card removed from the MPC slot of aircraft PS-VPB.

Initially, external visual inspections, electrical tests, and an X-ray scan were performed to assess the internal condition of the card (Figure 68).

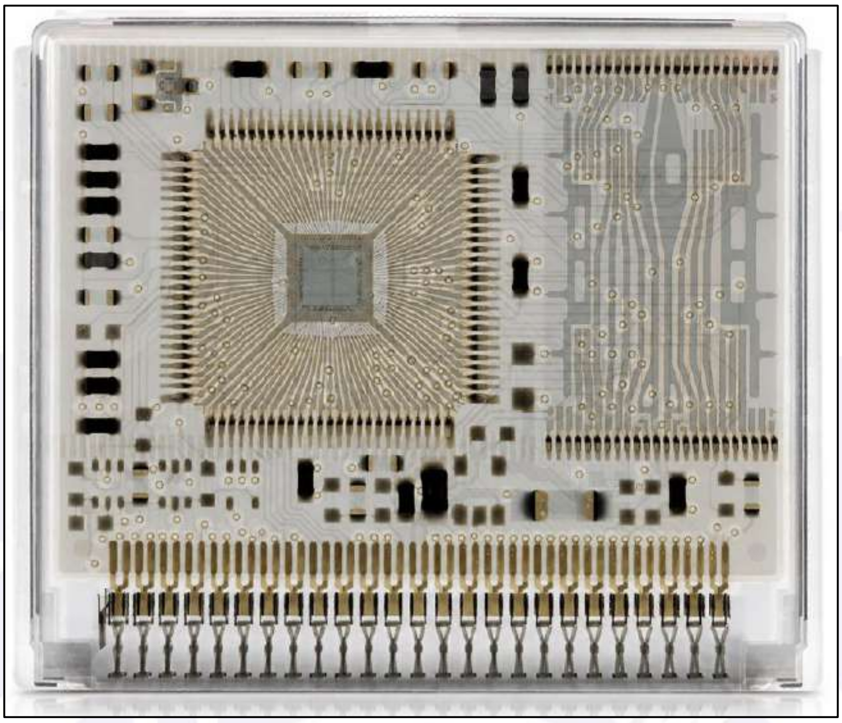


Figure 68 – X-ray view of the PCMCIA flash memory.

As no damage to the PCMCIA flash memory was observed, the card was connected to a computer using a specialized adapter. The files from the MPC's PCMCIA card were successfully recovered, containing data from flights "0", "-1", and "-2".

Among the data recorded on these three flights, the following are highlighted:

- QAR frame: copy of the FDR frame in .dat format;
- Digital ACMS Recorder (DAR) frame: Digital frame containing APM parameters and report data in .dat format; and
- Reports:
  - R02 – *Cruise*: average values of certain engine parameters during the cruise phase;
  - R03 – *Exceedance*: generated when the values of certain engine parameters exceeded predefined limits;
  - R15 – *Vertical acceleration*: generated at the end of each flight and presented the maximum vertical acceleration values during the flight and at touchdown;
  - R22 – *Flight Central Maintenance Computer* (CMC): recorded all aircraft alerts associated with MASTER WARNING or MASTER CAUTION that occurred during the flight. This report was generated at the end of each flight and listed the alerts detected by the MFCs; and
  - R24 – *Instant Flight* CMC: generated during the flight when a MASTER WARNING or MASTER CAUTION was activated, recording all alerts detected during the five minutes following the activation of the alert.

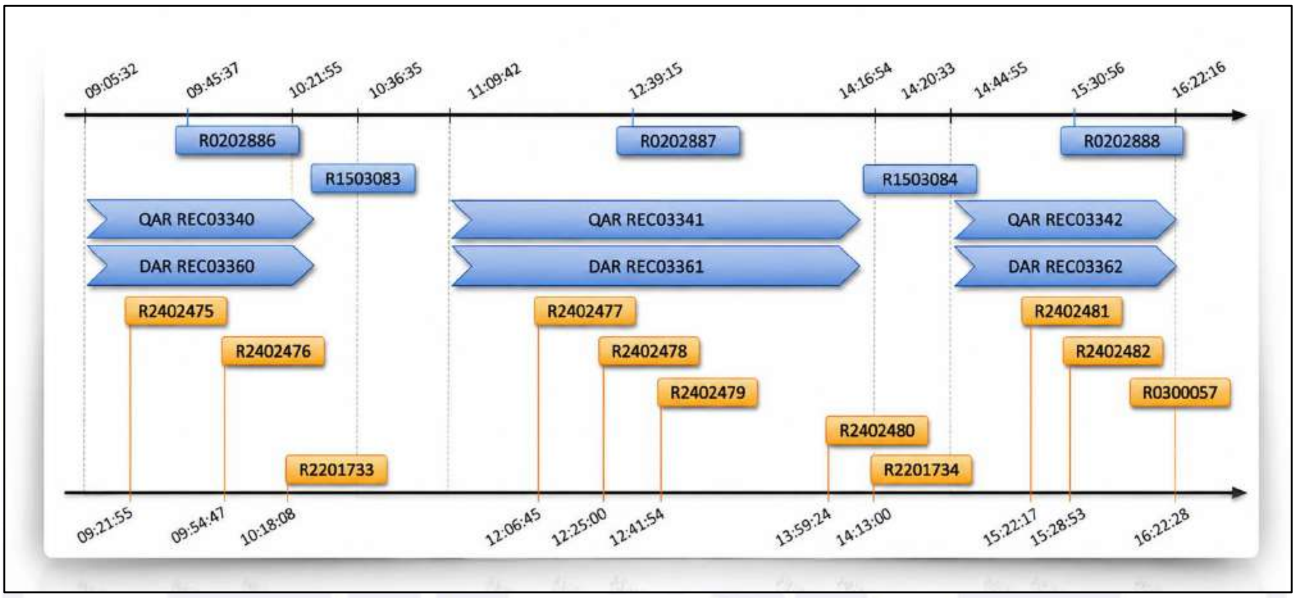


Figure 69 - Data from the MPC's PCMCIA card, organized by report type, including the timestamps recorded across the three flights.

Three R02 reports were generated for the cruise phases of the three recorded flights (flights "0", "-1", and "-2"), and one R03 report related to an ITT exceedance on the left engine. The data corresponding to the R02 and R03 reports are presented in Section 1.16.8, Engines.

Two R15 reports were generated for flights "-1" and "-2", presenting the aircraft's vertical acceleration values during the flight and at landing. These reports did not contain data relevant to the context of this accident.

The files corresponding to the R22 reports contained the same alerts recorded in the R24 reports. Due to the MPC logic, the R22 report for the accident flight was not generated, as the flight was not completed. Alerts corresponding to the five minutes preceding the aircraft's impact with the ground were also not generated.

1.16.2.1. Instant Flight CMC R24 Reports

The Instant Flight CMC R24 reports presented the active alerts following the occurrence of an in-flight event (activation of a MASTER CAUTION or MASTER WARNING), including timestamps corresponding to the moment the alert was generated. Each R24 report contained information related to the alerts, such as:

- report generation time, corresponding to the "end of the event";
- occurrence time of each event, repeated for each alert active at that moment;
- the warning light that triggered the event;
- flashing MASTER CAUTION (MC);
- flashing MASTER WARNING (MW);
- alert general heading; and
- alert description, containing the message recorded in the report.

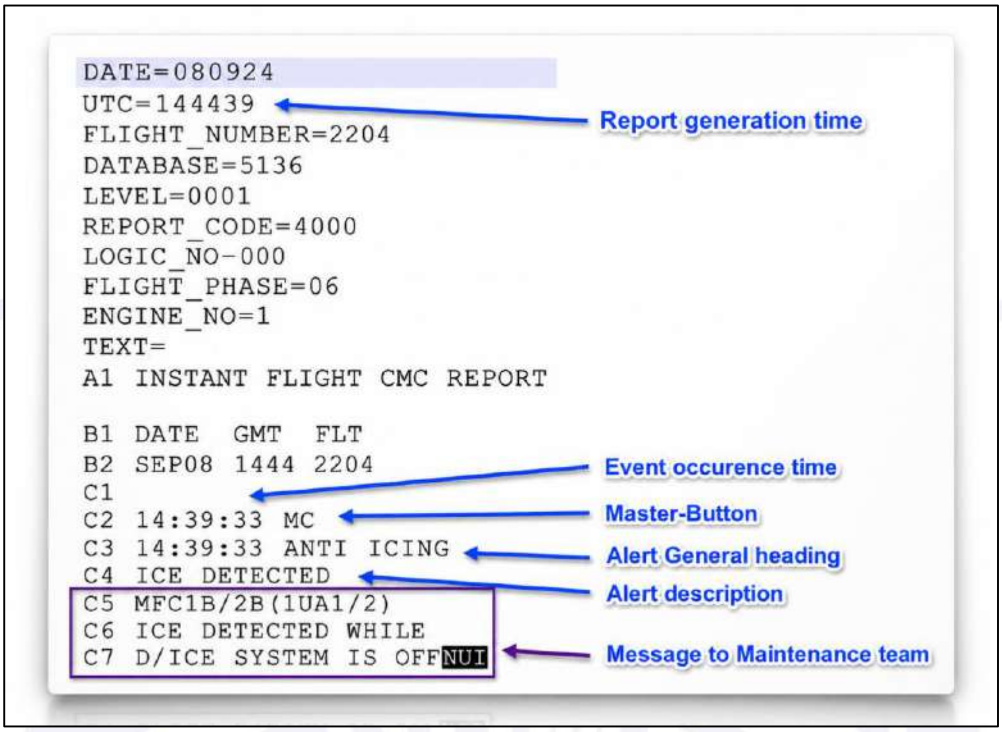


Figure 70 - Example of an Instant Flight Report (R24) with annotations highlighting the information related to the triggered alert.

Eight R24 reports were stored in the MPC, corresponding to flights “0”, “-1”, and “-2”, as described below:

- “Flight -2”: reports with identification codes R2402475 and R2402476;
- “Flight -1”: reports with identification codes R2402477, R2402478, R2402479, and R2402480; and
- “Flight 0”: reports with identification codes R2402481 and R2402482.

In total, the eight R24 reports described above indicated the occurrence of eight distinct types of fault alerts triggered at different moments. The descriptions of the alerts recorded in these R24 reports, along with an explanation of their respective activation conditions, are presented below:

- ICE DETECTED: the Electronic Ice Detector detected the presence of ice, and the DE ICING/AIRFRAME selector push button was in the OFF position;
- AIRFRAME FAULT: the MFCs detected a fault in the Airframe De-Icing function of the boots of the aircraft structure;
- FLIGHT COMPT RECIRCULATION FAN FLT: The recirculation system detected a temperature above 110°C, or the COMP TEMP/RECIRC FAN 1 selector push button was in the OFF position;
- RIGHT FRONT WINDOW HEAT: the right windshield temperature controller detected an overheat condition;
- F/O ALPHA PROBE HEAT: the AC current detector of the right AOA sensor (First Officer Alpha Probe) did not detect current in the probe heating circuit;
- F/O TAT PROBE HEAT: the AC current detector of the right TAT sensor (F/O TAT Probe) did not detect current in the probe heating circuit;
- APM CAUTION: the APM function was operative (with no failure in the APM), and the APM detected degradation in aircraft performance (DEGRADED PERF or INCREASE SPEED alert) and

- STICK PUSHER FLT: the MFC detected a functional failure in the STICK PUSHER function.

Figure 71 presents, in full, texts associated with these alerts contained in the R24 reports of flights “0”, “-1”, and “-2”. The Alert Description column presents the descriptions of the alerts, while the Alert Activation Trigger column details the activation criteria, including information on the location of each component associated with the alert, with the objective of assisting the mechanic in the investigation of the fault.

Alert description	Alert activation trigger
ICE DETECTED	Ice detector (FIN 3DD) detected ice. AND Pushbutton switch "DE ICING/AIRFRAME" (FIN 7DM) set to OFF
AIRFRAME FAULT	The MFCs (FIN 1UA1 / 1UA2) detects a fault in the airframe boots de-icing function
FLIGHT COMPT RECIRCULATION FAN FLT	The FAN recirculation system (FIN 31HB) detects a temperature above 110°C OR The pushbutton switch "COMP TEMP / RECIRC FAN 1" is set to OFF
RIGHT FRONT WINDOW HEAT	The Right Windshield Temperature Controller (FIN 12DG) detects a temperature overheat
F/O ALPHA PROBE HEAT	The "F/O Alpha Probe" AC-current sensor (FIN 40DA) detects no current on to F/O Alpha probe (FIN 20FU) heating circuit.
F/O TAT PROBE HEAT	The "F/O TAT Probe" AC-current sensor (FIN 69DA) detects no current on to F/O TAT probe (FIN 8FL2) heating circuit.
APM CAUTION	the APM (Aircraft Performance Monitoring) function is operative (no APM fault) AND The APM detects an aircraft performances degradation (DEGRADED PERF alert or INCREASE SPEED alert).
STICK PUSHER FLT	The MFC detects a fault in the stick-pusher function.

Figure 71 – Alerts contained in the R24 reports of the accident flight and the two preceding flights (flights “0”, “-1”, and “-2”).

The eight R24 reports stored in the MPC totaled sixty-six alerts, with eleven in “flight -2”, fifty-one in “flight -1”, and four in “flight 0”.

	Voo “-2”	Voo “-1”	Voo do acidente
ICE DETECTED	2x	4x	3x
AIRFRAME FAULT	2x	10x	1x
FLIGHT COMPT RECIRCULATION FAN FLT	6x	-	-
RIGHT FRONT WINDOW HEAT	1x	-	-
F/O ALPHA PROBE HEAT	-	16x	-
F/O TAT PROBE HEAT	-	15x	-
APM CAUTION	-	2x (Degraded Perf + Increase Speed)	-
STICK PUSHER FLT	-	4x	-

Figure 72 – Number and types of alerts stored on the MPC’s PCMCIA memory card of the PS-VPB aircraft, separated in each of the three reference flights.

It is important to note that, during the accident flight, the R24 reports did not record all the events that occurred, because, according to the MPC logic, although an R24 is created at each activation of a MASTER CAUTION or MASTER WARNING, it is only recorded five minutes after the event. Thus, due to the short interval between the last alerts and the aircraft's impact, the APM alerts in the final phase of the flight were not recorded.

1.16.3. Cockpit panel lamps

The SIPAER Investigation Commission conducted laboratory examinations using stereoscopy on lamps from the central panel, the overhead panel, and the stick pusher on the right panel (SIC). The stick pusher lamps on the left panel (PIC) were not found in the wreckage.

The purpose of the examinations was to determine the condition (illuminated or not) of the lamps indicating system operation and alerts.

All lamps analyzed had double-helix or coiled-coil filaments, in addition to similar technical specifications. These lamps were basically composed of a base, electrical contact posts, filament support posts, a tungsten filament, and a glass envelope (bulb).

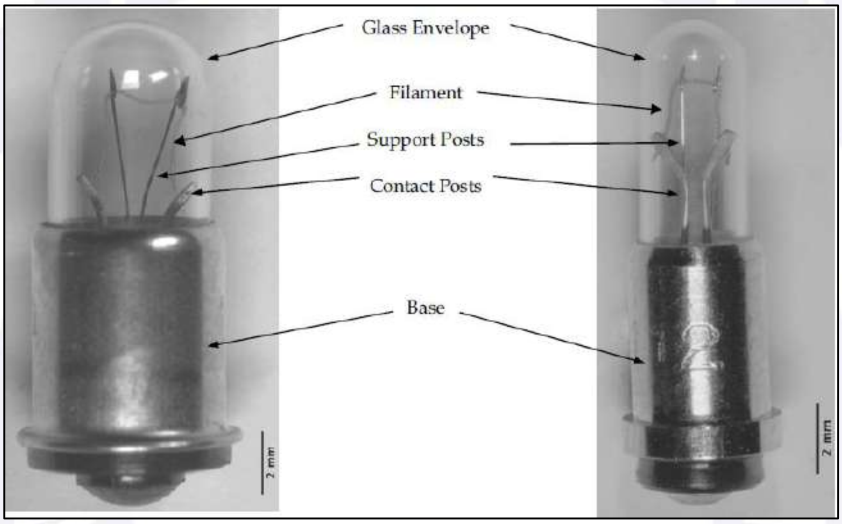


Figure 73 – Image of two types of incandescent lamps with the indication of their main subcomponents.
Source: Guide to the Impact Behaviour of Aircraft Instrument Panel Lamp Filaments – B. Grison, Air Vehicles Division Defence Science and Technology Organisation DSTO-TR-2217[3].

3: Available at https://apps.dtic.mil/sti/tr/pdf/ADA494227.pdf. Access on 19MAR2026.

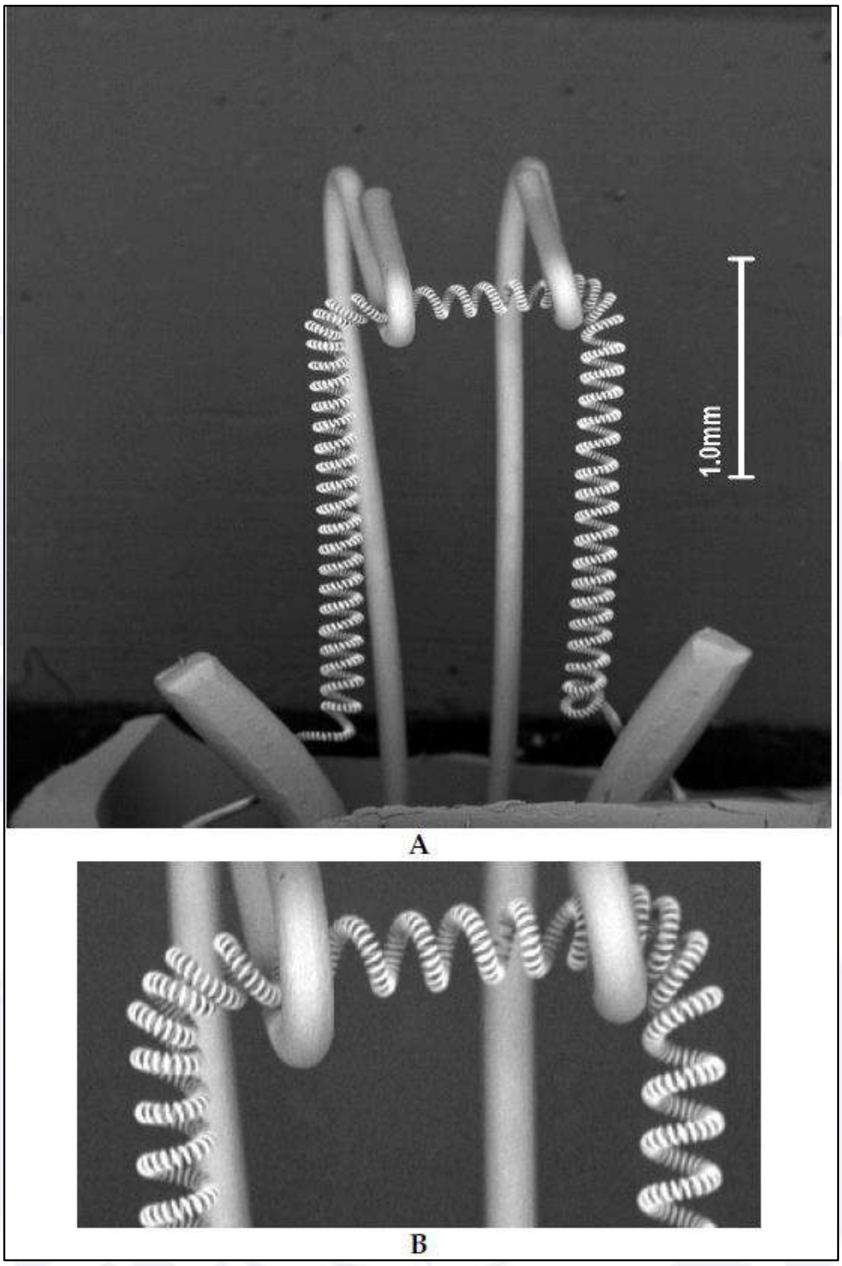


Figure 74 – Images of an incandescent lamp filament of the double helix or coiled-coil type. (A) image of the filament in its original position and (B) close-up view of the filament. Source: *Guide to the Impact Behaviour of Aircraft Instrument Panel Lamp Filaments – B. Grison, Air Vehicles Division Defence Science and Technology Organisation* DSTO-TR-2217.

The main parameters used in the examinations were local deformation (minor helix deformation), overall deformation (major helix macro-wrapping), and filament fracture.

A total of 34 indicator lamps corresponding to 16 cockpit indications were selected and subjected to stereoscopic examination in the laboratory, as highlighted in Figures 75 through 83.

Figure 75 – Central panel showing the positions of the indicator lights from which the lamps were removed for laboratory examination.

Figure 76 – Overhead panel showing the positions of the indicator lights from which the lamps were removed for examination.

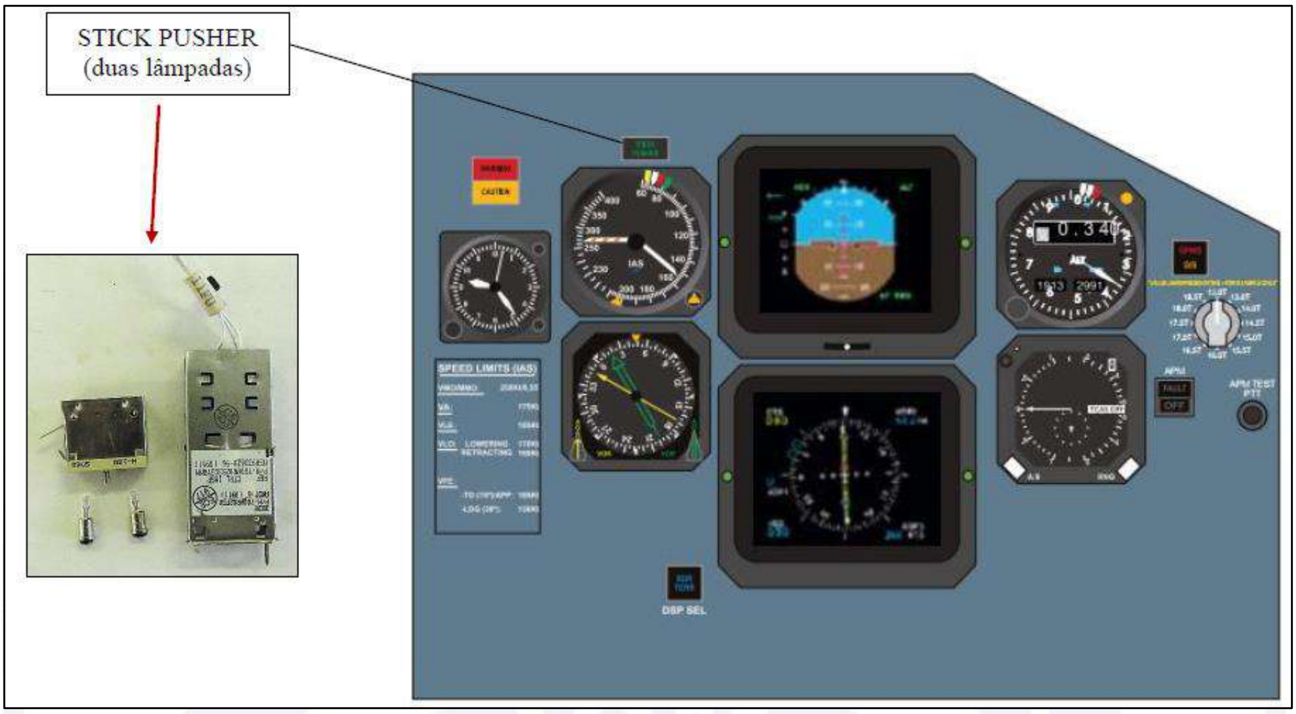


Figure 77 – Right-side instrument panel showing the location of the STICK PUSHER indicator light removed for examination.

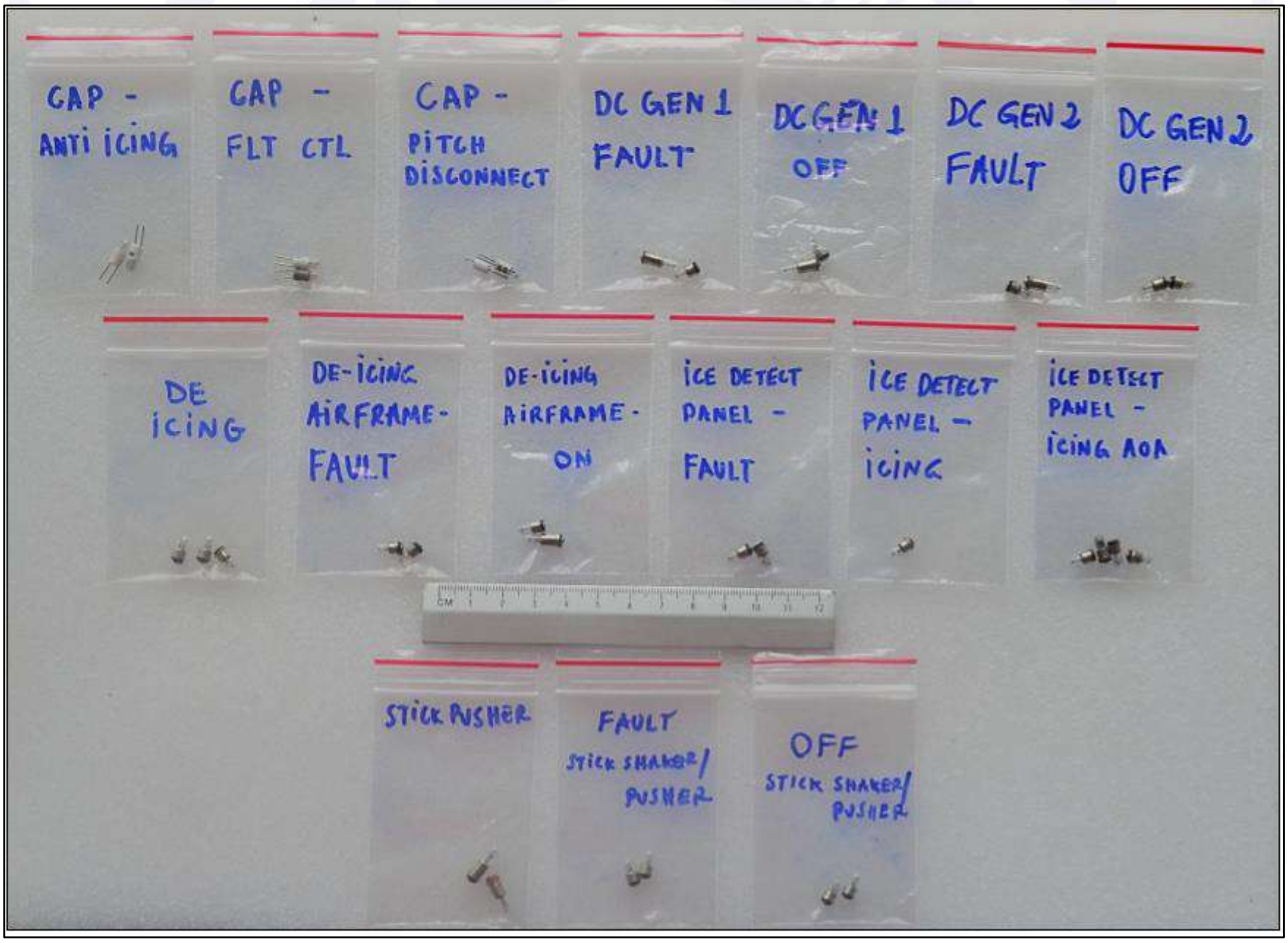


Figure 78 – Image of the 34 lamps that were removed, with their respective identifications.

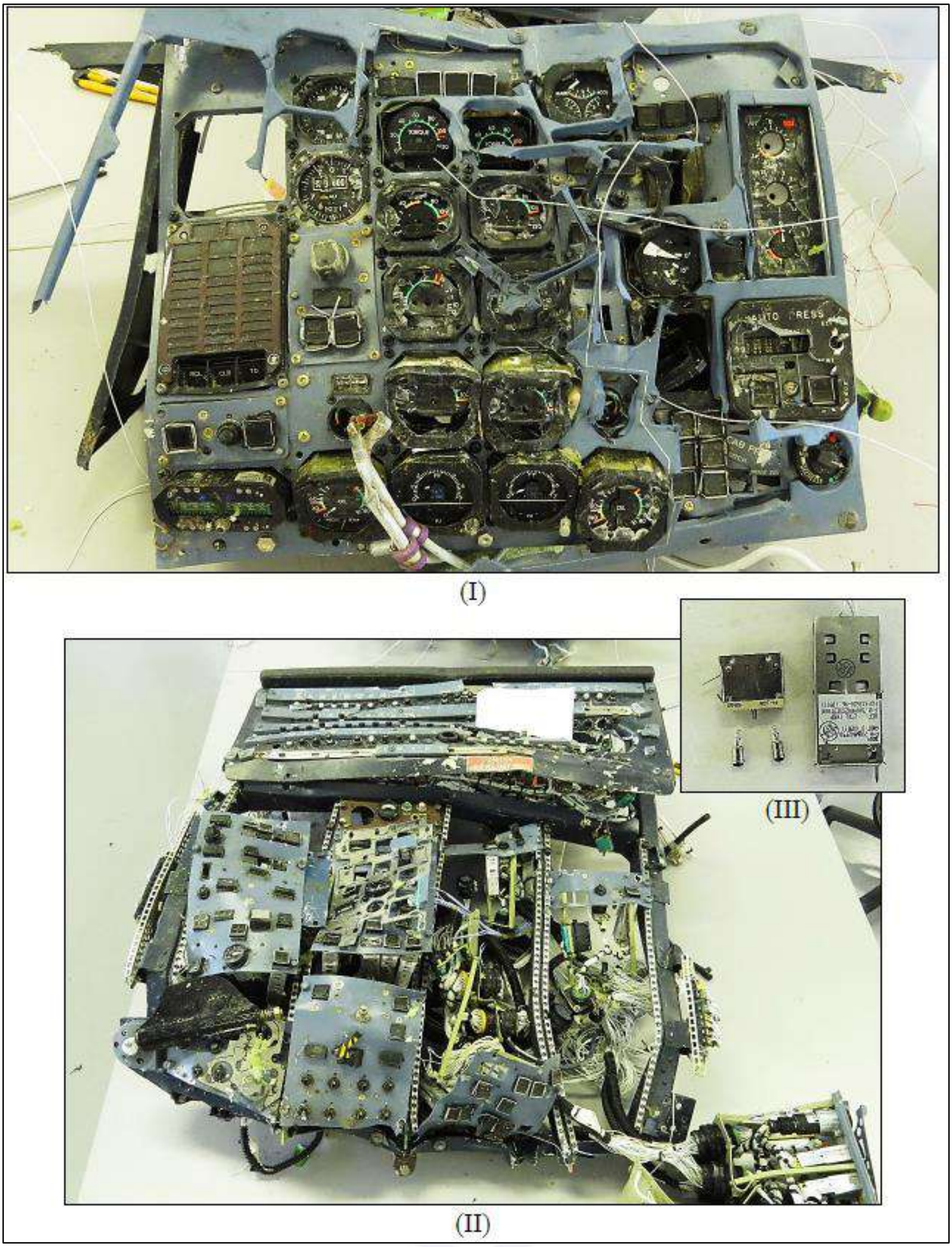


Figure 79 – (I) *Central panel*, (II) *overhead panel* and (III) STICK PUSHER indicator lamp removed from the right-side instrument panel.

For the examinations of the CAP lamps, it was necessary to remove them from the central panel.

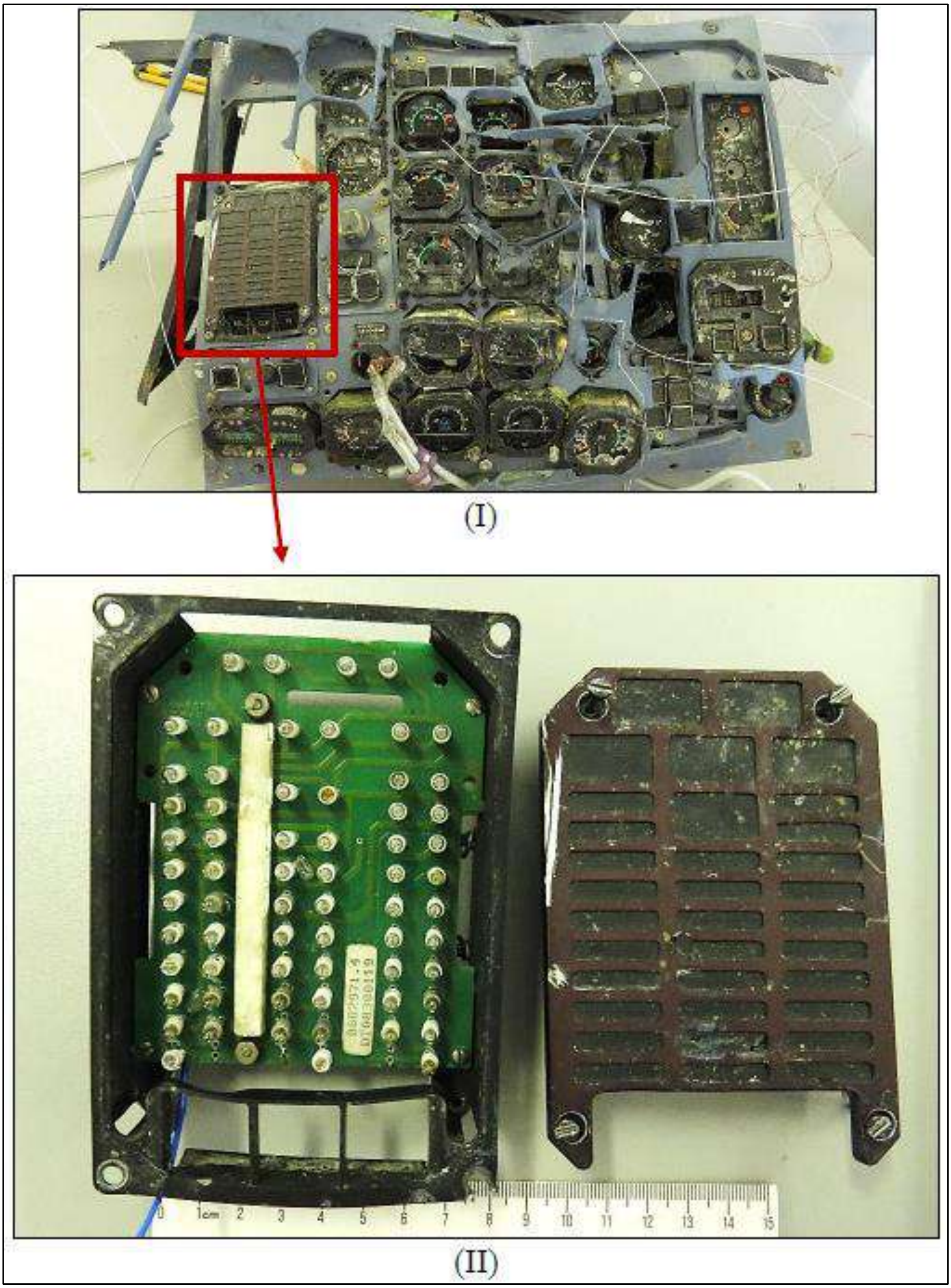


Figure 80 – Images indicating the location of the CAP on the central panel and the sequence of steps for its removal.

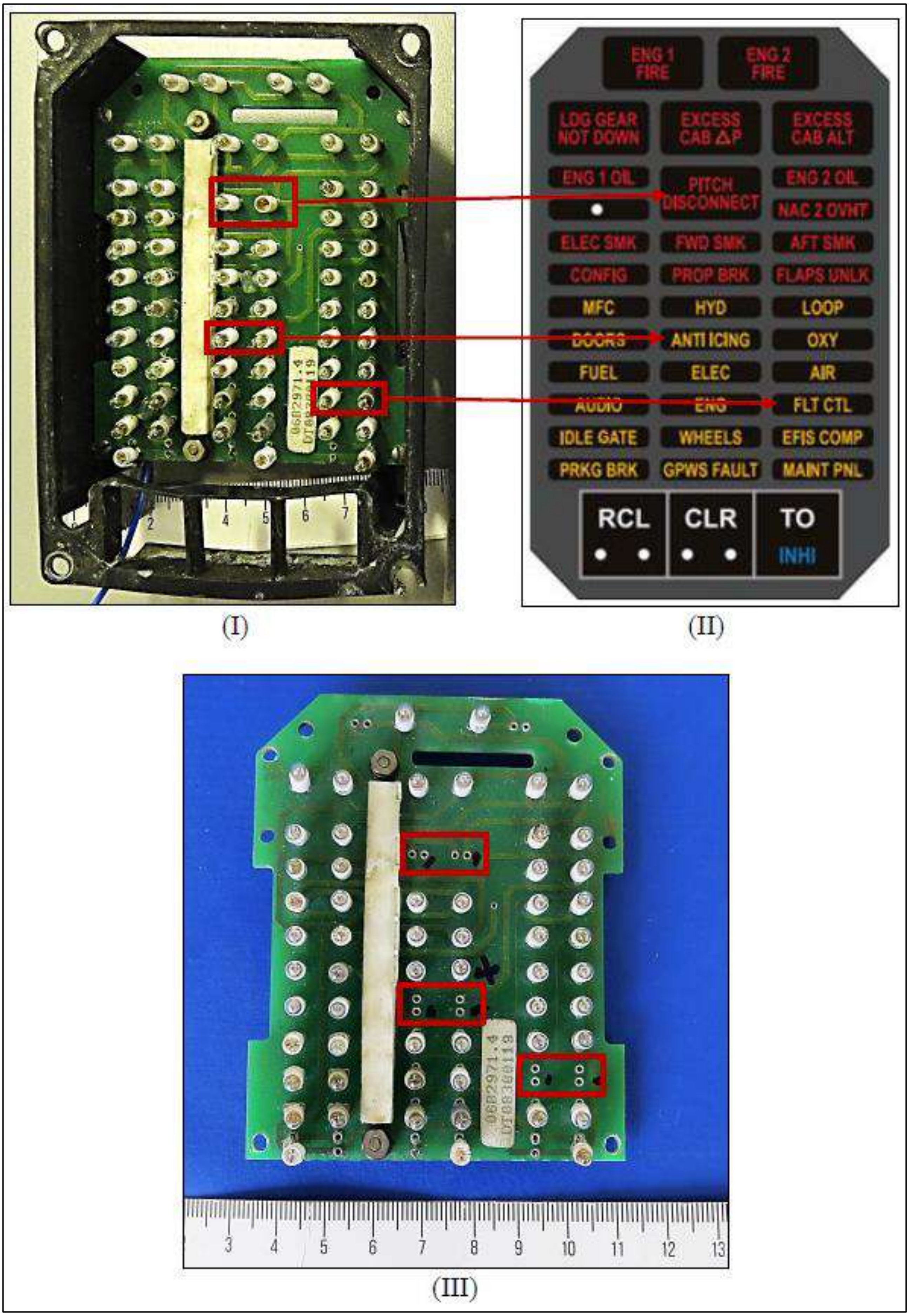


Figure 81 – (I and III) Photographs indicating the location of the lamps removed from the CAP and (II) diagram showing the corresponding indications.

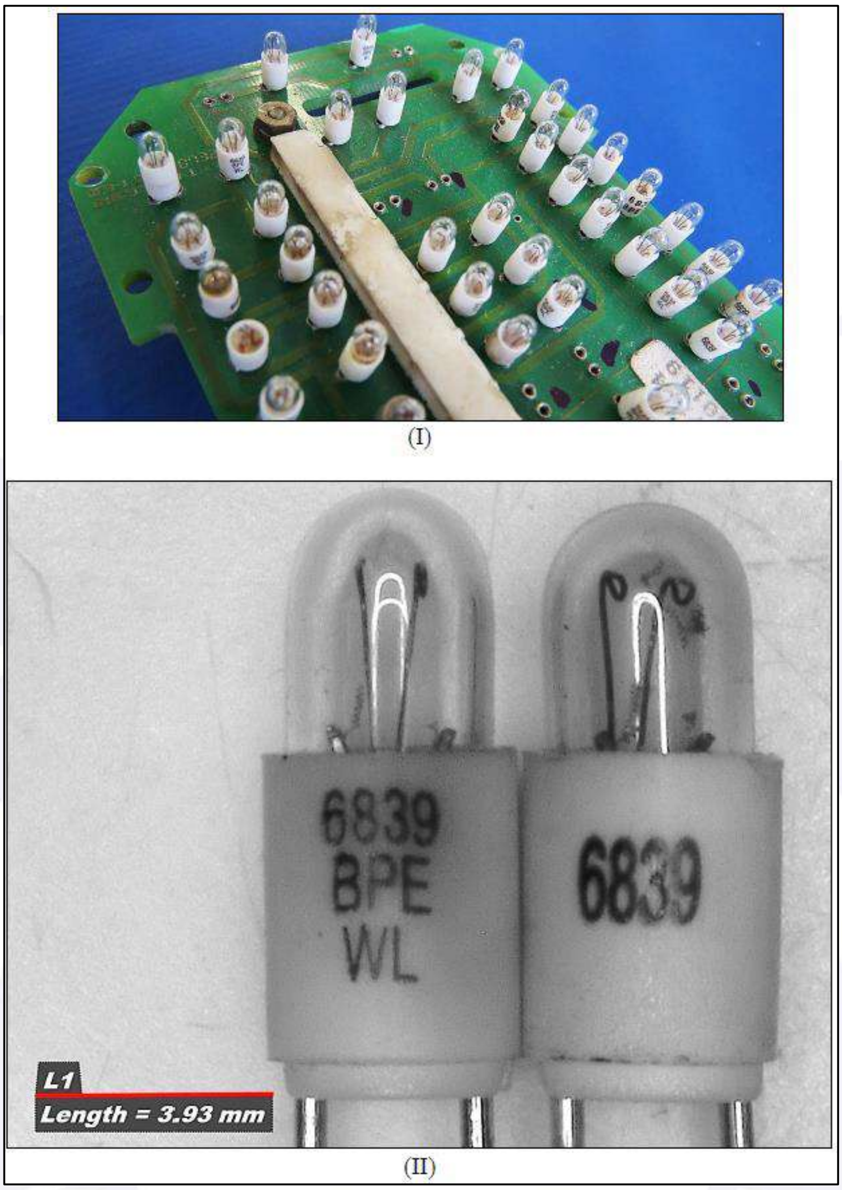


Figure 82 – (I) Detail of the CAP lamps and (II) stereoscopic photograph representative of this type of lamp with size scale. The red line corresponds to 3.93 millimeters.

Figure 83 highlights the steps for the removal of the DE-ICING indication lamps from the memory panel (memo panel), which consists of six indications, with the DE-ICING indication located in the upper right corner.

The image illustrates the location of the memo panel on the central panel and the sequence of steps for removing the DE-ICING indication lamps, as well as a detail of the location of the upper lamp socket. It is also noted that one of the four lamps was not found. Finally, confirmation that it was the DE-ICING indication light was established through the use of external illumination (flashlight).

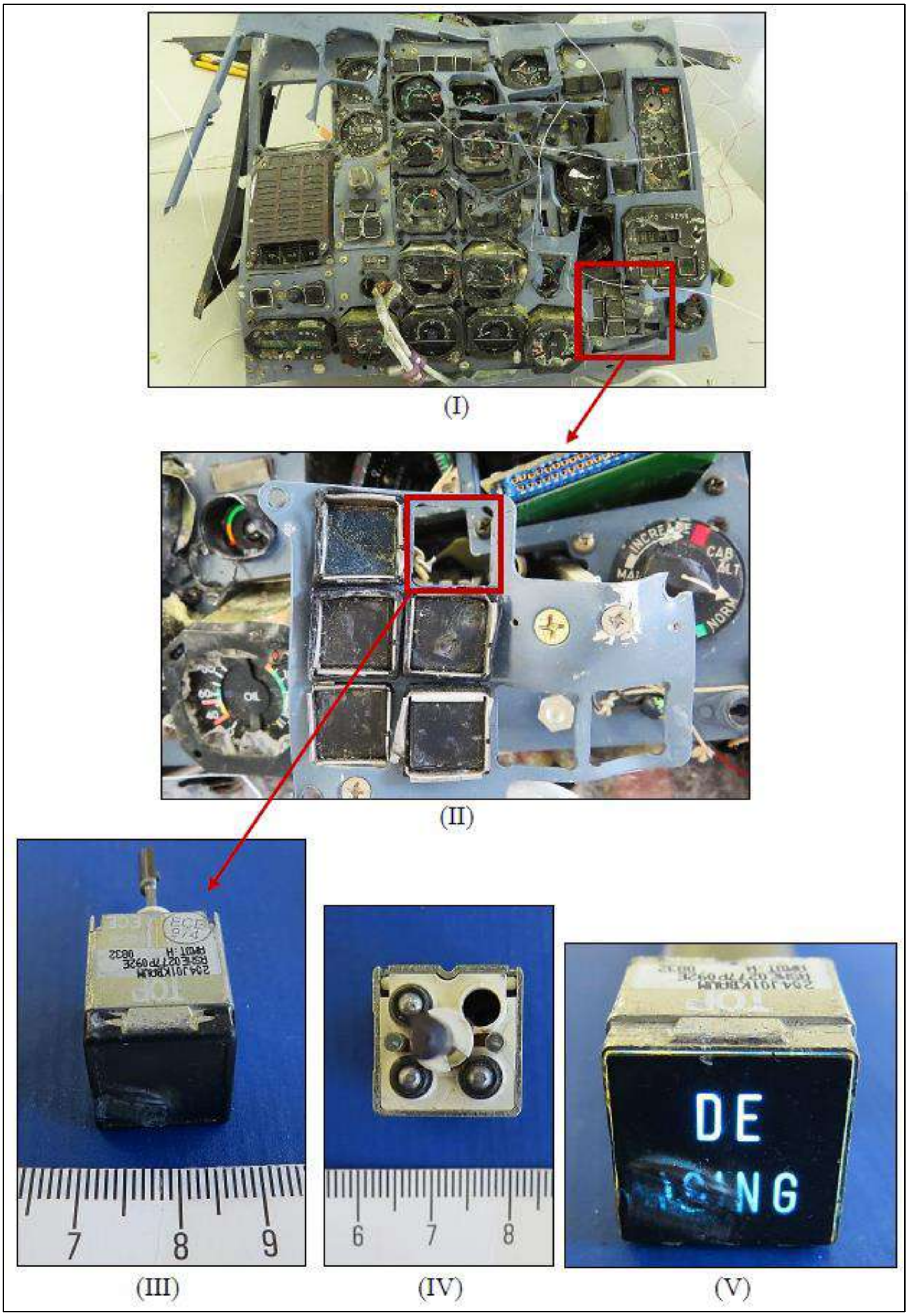
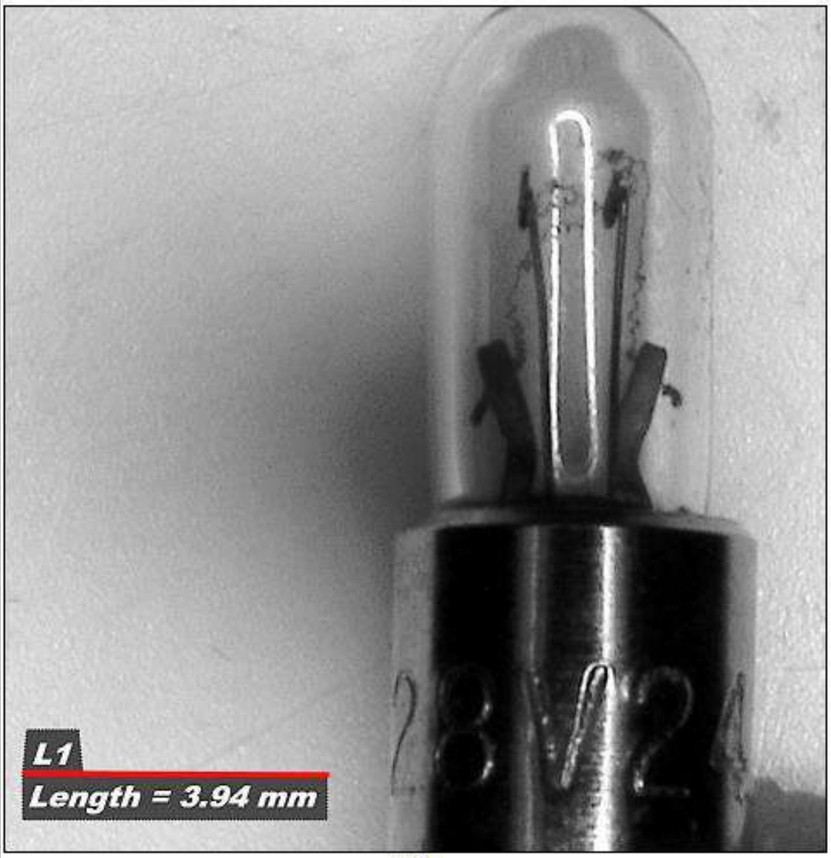


Figure 83 – (I, II and III) Photographs illustrating the location of the memo panel on the central panel and the sequence of steps for removing the DE-ICING indication lamps; (IV) detail of the location of the lamp socket in the upper section and the absence of one of the lamps; and(V) confirmation obtained using external illumination (flashlight).

Figure 84 highlights the image of the DE-ICING indication composed of four lamps, without the front cover, as well as a photograph of one of the lamps.

The same procedures used for the removal and confirmation of the CAP and DE-ICING lamps were applied to the remaining lamps segregated for laboratory examination.


(I)



(II)

Figure 84 – (I) DE ICING indication composed of four lamps and (II) photograph of one of the lamps.

From the examination of the lamp filaments, it was possible to obtain indications regarding the probable condition (illuminated or not) of some of the cockpit indicator lights at the moment of impact. However, in some cases, it was not possible to determine the condition using the available examination techniques.

The images in Figure 85 show the filaments of lamp number 1 for the DC GEN1 FAULT and STICK PUSHER indications for comparison.

Although the filaments of the examined lamps exhibited fractures, distinct characteristics can be observed between them. It is possible to identify macro- and micro-deformations (major and minor helices of the double helix) prior to fracture in the filaments of the STICK PUSHER indication lamps (images I and II on the right). In contrast, the lamps of the DC GEN1 FAULT indication (images I and II on the left) exhibited more brittle fractures, with little visible deformation.

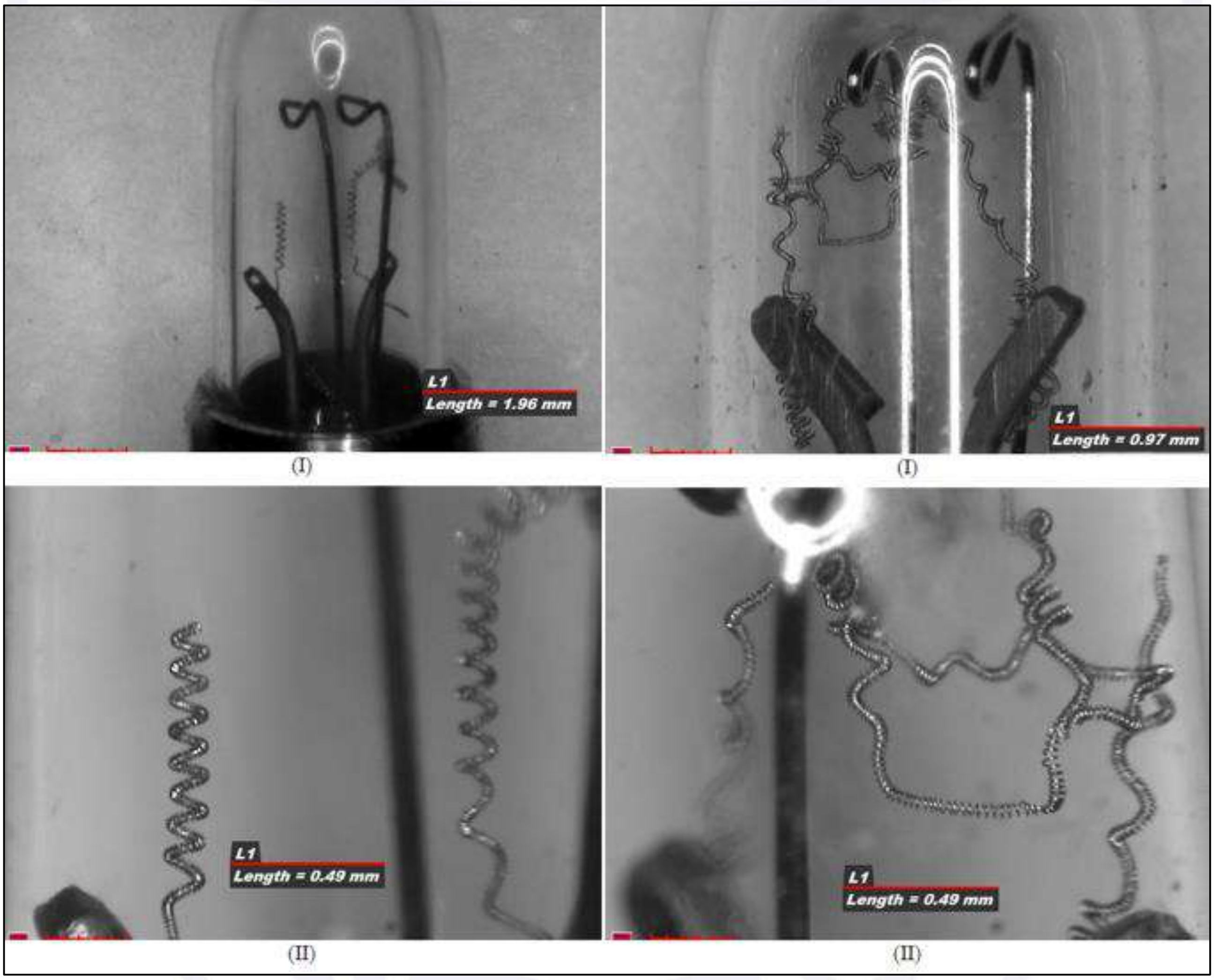


Figure 85 – On the left, (I and II), lamp 01 of the DC GEN 1 FAULT indication, with little deformation at the filament fracture. On the right (I and II), lamp 01 of the STICK PUSHER indication with high deformation at the filament fracture.

With regard to the results, the SIPAER Investigation Commission made a few considerations.

The stereoscopic images showed that the two lamps illuminating the STICK PUSHER indication on the right panel (SIC) exhibited fractures with high overall and local deformation in their filaments, consistent with the ON (illuminated) condition at the moment of fracture.

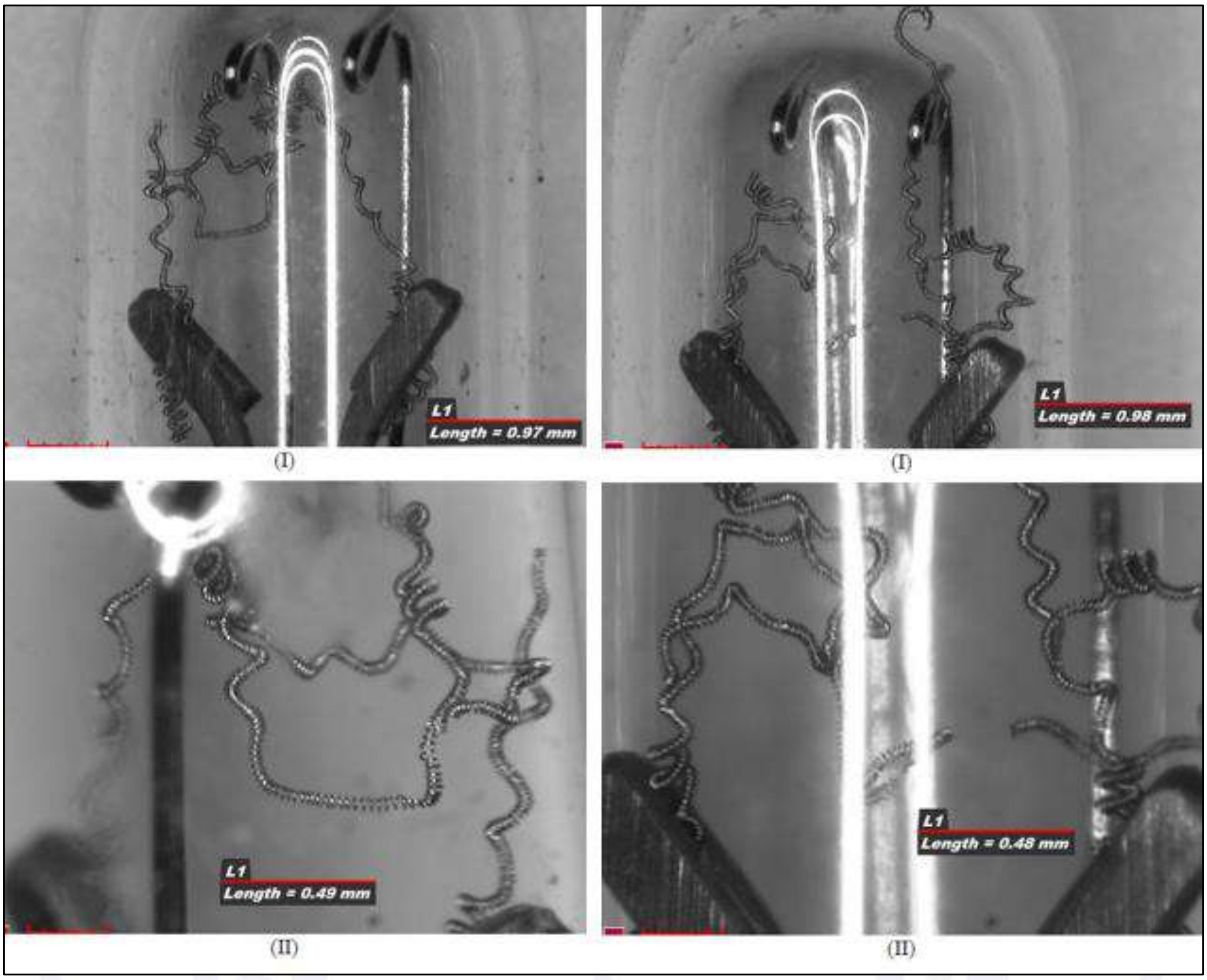


Figure 86 – Stereoscopic images of lamps 01 (left) and 02 (right) of the STICK PUSHER indication on the right panel.

On the other hand, the stereoscopic images of the two lamps that illuminated the PITCH DISCONNECT indication on the CAP showed different conditions.

Neither of them was fractured. Lamp 01 exhibited moderate overall deformation and low local deformation, so the result was inconclusive. Lamp 02, however, exhibited high overall and local deformation, consistent with the ON (illuminated) condition at the moment of deformation.

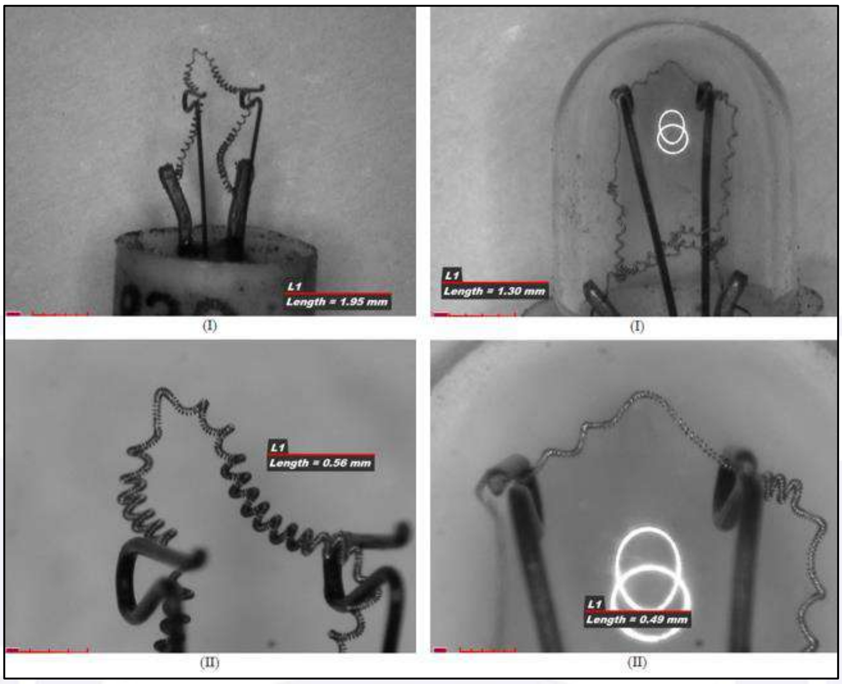


Figure 87 – Stereoscopic images of lamps 01 (left) and 02 (right) of the PITCH DISCONNECT indication on the CAP panel.

For better understanding of the results presented in the table, it is important to note that most indications had two lamps, but some had a different number of lamps. The ICING AOA indication, green in color, on the ice detect panel, for example, had four lamps.

It should also be noted that some indicative messages had missing lamps, such as the DE ICING indication mentioned previously.

Finally, it is important to note that, in the CAP, the electrical current path to the lamps of the same indication was arranged in parallel. Thus, for various reasons, such as interruptions in the electrical power supply, it was possible for one lamp to illuminate while another, belonging to the same alert message (same indication), remained unlit.

In this condition, it is worth noting that if one of the lamps exhibited poor contact or an interruption in the electrical power supply, it would not prevent the other from illuminating, since the electrical circuit between them was arranged in parallel. Figure 87 shows alarm indications in which only one of the lamps was illuminated during the CAP light test on another ATR-72-212A aircraft.

Although the difference in deformation between lamps 01 and 02 was notable, lamp 02, with characteristics consistent with being illuminated, allowed the inference that the lamp assembly was ON at the moment of the filament deformation.

Figure 88 shows alarm light indications in which only one of the lamps was illuminated during the CAP light test of another ATR-72-212A aircraft.

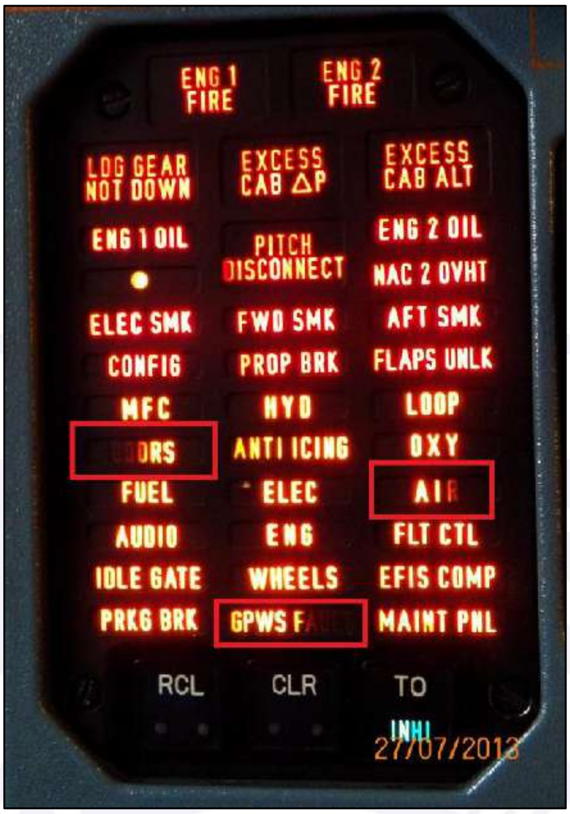


Figure 88 – Example image of a CAP in test mode, showing three indications in which only one of the lamps was illuminated.

Figure 89 presents the table with the results of the examinations and indicates the condition of the indicator light at the moment of filament fracture. The ON condition indicates a filament with a high level of deformation, ductile, consistent with characteristics typical of hot deformation. In other words, the filament fracture occurred with the lamp illuminated. Conversely, the OFF condition indicates a filament with a low level of deformation, brittle, consistent with characteristics typical of cold deformation; that is, the filament fracture occurred with the lamp unlit.

In cases classified as INCONCLUSIVE or identified with a question mark, (?), it was not possible to determine the condition of the filament using the available examination methods. The indications OFF (possibly), OFF/BURNT OUT, and ON (possibly) express a presumed condition, but without conclusive confirmation.

IDENTIFICAÇÃO	LÂMP. Nº	FRATURA DO FIL.	DEFORMAÇÃO GERAL	DEFORMAÇÃO LOCAL	COMENTÁRIOS *	INDICAÇÃO (provável) *
CAP ANTI ICING	1	SIM	BAIXA	BAIXA	OFF	OFF
CAP ANTI ICING	2	SIM	BAIXA	BAIXA	OFF	
CAP FLT CTL	1	SIM	MÉDIA	BAIXA	INCONCLUSIVO	?
CAP FLT CTL	2	SIM	MÉDIA	BAIXA	INCONCLUSIVO	
CAP PITCH DISCONNECT	1	NÃO	MÉDIA	BAIXA	INCONCLUSIVO	ON
CAP PITCH DISCONNECT	2	NÃO	ALTA	ALTA	ON	
DC GEN 1 FAULT	1	SIM	BAIXA	BAIXA	OFF	OFF
DC GEN 1 FAULT	2	SIM	BAIXA	BAIXA	OFF	
DC GEN 1 OFF	1	SIM	BAIXA	BAIXA	OFF	OFF
DC GEN 1 OFF	2	SIM	BAIXA	BAIXA	OFF	
DC GEN 2 FAULT	1	SIM	BAIXA	?	OFF (possivelmente)	?
DC GEN 2 FAULT	2	SIM	MÉDIA	MÉDIA	INCONCLUSIVO	
DC GEN 2 OFF	1	SIM	BAIXA	BAIXA	OFF	OFF
DC GEN 2 OFF	2	SIM	BAIXA	BAIXA	OFF	
DE ICING	1	SIM	ALTA	MÉDIA	ON	ON
DE ICING	2	SIM	MÉDIA	MÉDIA	ON (possivelmente)	
DE ICING	3	SIM	ALTA	MÉDIA	ON	
DE-ICING AIRFRAME FAULT	1	SIM	BAIXA	BAIXA	OFF	OFF
DE-ICING AIRFRAME FAULT	2	NÃO	BAIXA	BAIXA	OFF	
DE-ICING AIRFRAME ON	1	NÃO	ALTA	ALTA	ON	ON
DE-ICING AIRFRAME ON	2	NÃO	ALTA	ALTA	ON	
ICE DETECT PANEL FAULT	1	NÃO	MÉDIA	BAIXA	OFF	OFF
ICE DETECT PANEL FAULT	2	SIM	BAIXA	BAIXA	OFF	
ICE DETECT PANEL ICING	1	NÃO	ALTA	ALTA	ON	ON
ICE DETECT PANEL ICING AOA	1	NÃO	ALTA	ALTA	ON	ON
ICE DETECT PANEL ICING AOA	2	SIM	ALTA	ALTA	ON	
ICE DETECT PANEL ICING AOA	3	?	BAIXA	?	OFF / QUEIMADA	
ICE DETECT PANEL ICING AOA	4	SIM	ALTA	ALTA	ON	
STICK PUSHER	1	SIM	ALTA	ALTA	ON	ON
STICK PUSHER	2	SIM	ALTA	ALTA	ON	
STICK SHAKER-PUSHER FAULT	1	SIM	MÉDIA	BAIXA	INCONCLUSIVO	?
STICK SHAKER-PUSHER FAULT	2	SIM	MÉDIA	BAIXA	OFF (possivelmente)	
STICK SHAKER-PUSHER OFF	1	SIM	MÉDIA	MÉDIA	INCONCLUSIVO	?
STICK SHAKER-PUSHER OFF	2	SIM	MÉDIA	MÉDIA	INCONCLUSIVO	

Figure 89 – Results of the examinations of the lamp filaments.

1.16.4. Stick pusher actuator

The Stick Pusher electric actuator was a two-position actuator. When in the standby position, the Stick Pusher was not activated, and the actuator rod remained extended. When in the activated position, the actuator rod was retracted, compressing a return spring with specific mechanical characteristics.

The Stick Pusher actuator was found installed in its position and with its mechanical integrity apparently preserved. The actuator rod was in the extended position, corresponding to the non-activated condition, and the desiccant cartridge was blue, indicating the absence of moisture saturation.

Figure 90 – On the left, a red arrow indicating the desiccant cartridge in blue; on the right, a red arrow indicating the extended position of the actuator rod, consistent with the non-actuated condition.

The actuator was subjected to examinations and tests conducted by the SIPAER Investigation Commission at the component manufacturer's facilities. Electrical and insulation tests were performed on the component, with results within specifications and no discrepancies.

Figure 91 – Stick Pusher actuator prior to the start of examinations and tests, with the actuator rod in the extended position.

An immersion test of the actuator in a water bath was conducted to verify the sealing of the actuator and its internal electrical components. During this procedure, leaks were identified at different points of the actuator casing; however, the desiccant capsule showed no signs of internal moisture. Considering the electrical tests previously performed, the investigators concluded that the leakage was a consequence of the aircraft's impact with the ground.

Subsequently, no-load tests were performed (Figure 92), including the microswitch activation test, which showed normal operation of the activation indication light when the actuator left the standby position. The electrical signal from this microswitch was responsible for illuminating the green Stick Pusher indication lamps on the PIC's left panel and the SIC's right panel.

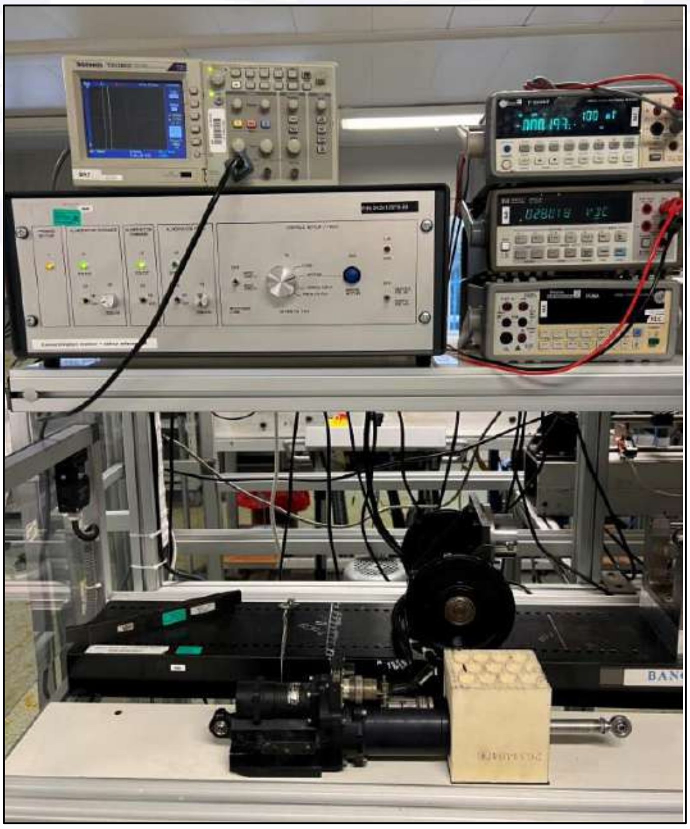


Figure 92 – No-load test of the Stick Pusher actuator.

Bench tests identified that the measured time for the actuator retraction (activation) cycle (stroke) was slightly outside the tolerance, with a value of 0.45 seconds instead of 0.40 seconds, but without impact on system operation.

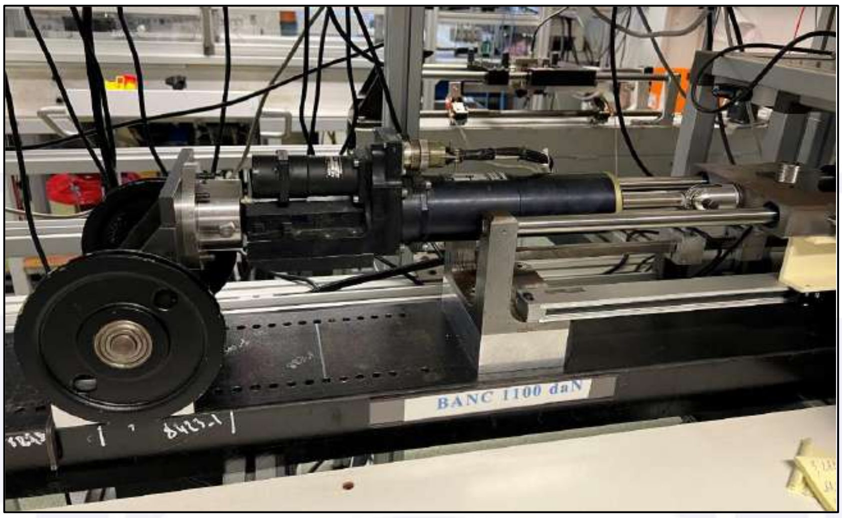


Figure 93 – Test bench of the Stick Pusher actuator under mechanical load.

The mechanical characteristics of the compression spring were within the established parameters, ensuring that the counterforce effort by the pilots was within the expected levels.

The maintenance documentation revealed that this equipment was repaired at the component manufacturer's facilities in 2022. During this repair, the connector and the desiccant were replaced, but the equipment had not been opened since its manufacture in 2007.

The examinations and tests performed on the Stick Pusher actuator did not reveal any discrepancies that could have compromised its operation in the aircraft.

Additionally, since the activation of the Stick Pusher was not recorded by the FDR, the SIPAER Investigation Commission decided to conduct a search in the BEA's audio database. The purpose was to obtain a selection of CVR recordings from flight tests and ground tests of aircraft of that type in order to compare them with the audio data from the CVR of aircraft PS-VPB.

The objective was to identify sequences in the audio containing specific sounds related to the activation of the Cricket aural warning, associated with the Stick Shaker, followed by the activation of the Stick Pusher. In these events, the audio sequence of interest—Cricket plus Stick Shaker plus Stick Pusher—was primarily captured by the Cockpit Area Microphone (CAM). After a preliminary assessment, four CAM recording samples were selected for analysis.

The activation of the stall warning began with the emission of the Cricket sound, which was captured by the CAM. The cricket aural warning typically masked the sound of the control column vibrations generated by the stick shaker system. The sound of the stick pusher activation was, at times, masked by both the cricket alert and the noise produced by the stick shaker.

At the CENIPA investigators' request, the audio laboratory performed cleaning, suppression of the stall aural warning (cricket), and noise reduction on the four audio samples. The reduction of the masking effect of these two concurrent events — cricket plus stick shaker — helped to highlight the sound of the stick pusher.

Despite the greater difficulty in perceiving the sound associated with the activation of the Stick Pusher, due to the noisy cockpit environment, it was possible to identify an increase in the perception of the stick shaker vibration.

From a spectral analysis standpoint, this phenomenon was characterized by an increase in broadband noise in the 2.5 to 7 kHz range and the emergence of a narrow band in the 400 to 600 Hz range, consistent with the characteristic signal generated by the activation of the Stick Pusher, which reinforced the expected sequence of operation.

The buffeting phenomenon, which occurred as the aircraft approached the stall, was not perceptible in the spectral analysis.

The audio recordings captured by the CAM of the accident aircraft were consistent with the characteristic alert sequence found in the BEA's audio database under stall approach conditions, consisting of Cricket, Stick Shaker, and Stick Pusher.

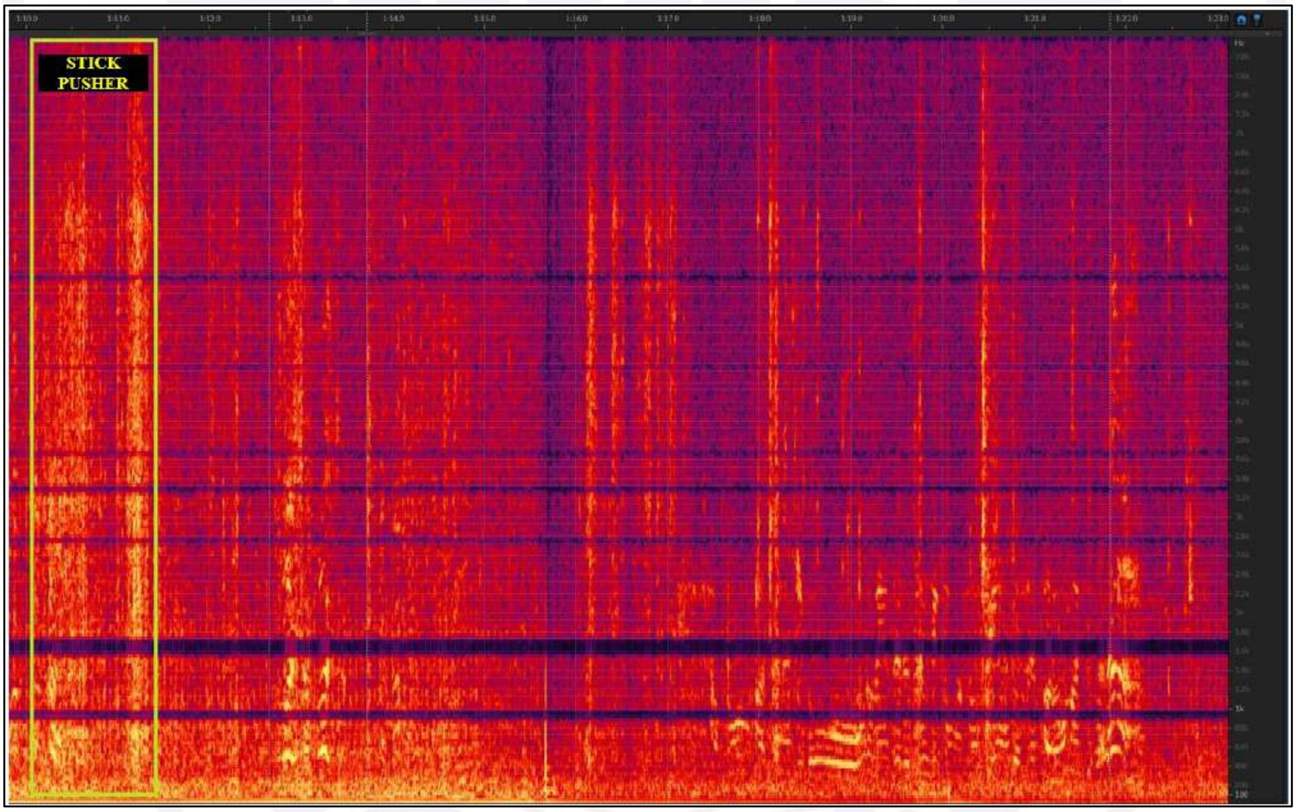


Figure 94 –Excerpt from the spectral analysis of aircraft PS-VPB CAM. Yellow rectangle consistent with the characteristic signal of Stick Pusher activation.

Considering that the radio altimeter (RALT) indication below 500 ft inhibited stick pusher activation, and that the stick pusher was found in the non-actuated position after the accident, the Investigation Commission tested the component at the manufacturer's facilities to verify its proper functionality prior to the inhibition. The tests demonstrated that the component was functioning normally during the accident flight.

1.16.5. Elevator Synchro Transmitter

As presented in subitem 1.6.7.2, flight controls in pitch, the synchro transmitter was the position sensor installed on the horizontal stabilizer structure, responsible for measuring the deflection angle of the left elevator and providing this information for recording in the FDR (Left Elevator Position parameter).

With the Pitch Uncoupling Mechanism in its normal flight condition, both elevators moved together, so the left elevator reading represented the position of both control surfaces.

However, if the Pitch Uncoupling Mechanism were activated (PITCH DISCONNECT), the elevators would move independently, and the FDR would record only the position of the left elevator, as measured by the synchro transmitter, with no information regarding the right elevator.

Preliminary analyses of the flight data recorded by the FDR indicated that the left elevator position values were inverted relative to the data frame used and required the application of a correction factor, although they exhibited trends consistent with normal operation of the control surface.

The Data Frame was a technical document provided by the flight data recorder manufacturer and was essential for the correct decoding and interpretation of the raw information extracted from the FDR.

From the analysis of the FDR data, it was possible to observe that, while the aircraft was still on the ground, with the elevator deflected downward, the signal for this parameter indicated negative values. According to the Data Frame, this value should be positive in this situation, as shown in Table 2, which indicated an inversion in the sign convention.

During the flight, particularly during rotation on takeoff and in turns, this inversion remained evident in the recorded behavior of the left elevator.

The discrepancy observed in the FDR data regarding the left elevator position would hinder the correct interpretation of this surface’s deflections during the flight. This finding led the SIPAER InvestigationCommission to submit the synchro transmitter to more in-depth laboratory examinations.

Initially, the synchro transmitter was disassembled, and the subcomponents responsible for the connection between the transmitter and the elevator (links) were inspected.

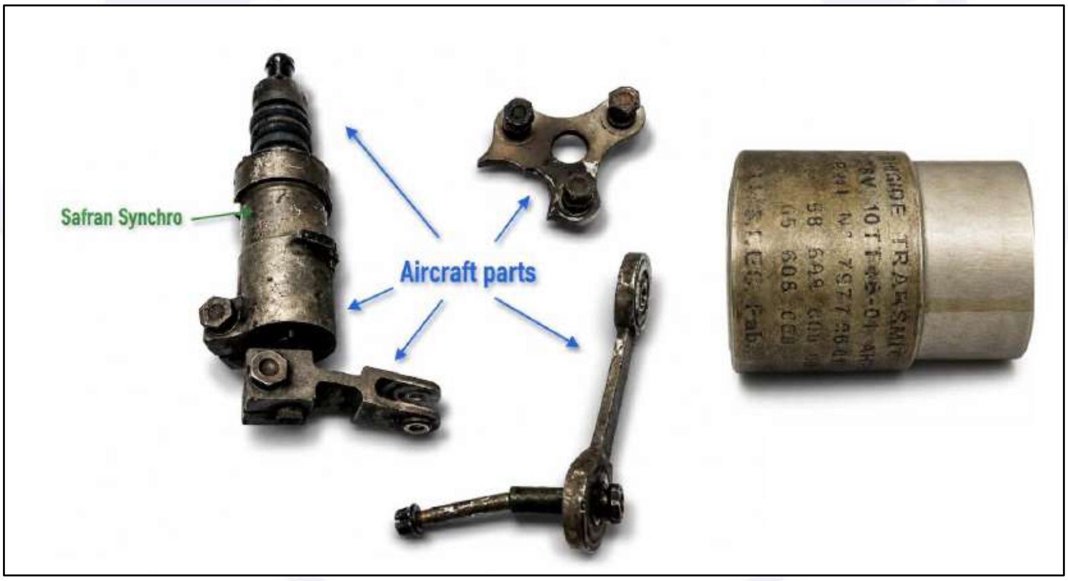


Figure 95 – Images of the Synchro Transmitter, its linkage interfaces with the elevator (links), and its identification label.

During the inspection, significant soot contamination, fractures in the casing, and visible damage—such as plastic deformation in the linkage rods (Figure 96)—were observed. The damage identified in the component was assessed as consistent with the mechanical effects of the aircraft’s impact with the ground and exposure to fire.

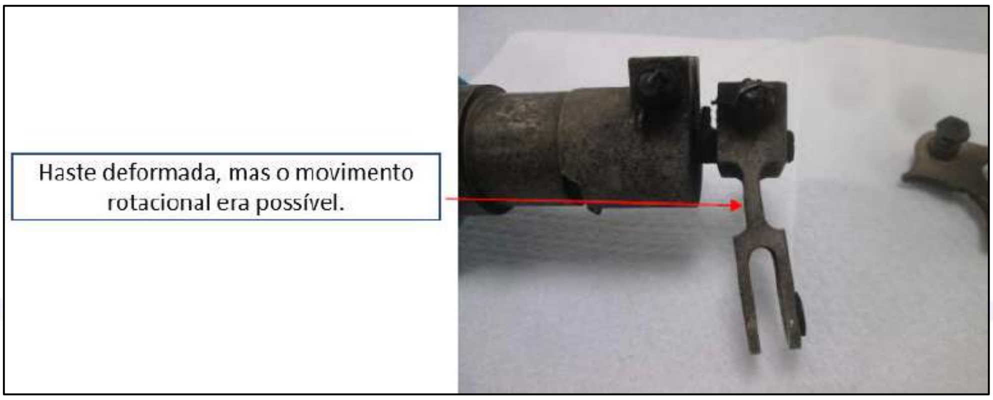


Figure 96 – Synchro transmitter linkage rod deformed, yet still functional.

Even so, these damages did not impair the movement of the rod responsible for the mechanical transmission of the elevator motion to the sensor, allowing the synchro transmitter to adequately perform the signal transduction to the FDR.

Subsequently, the component was installed on a test bench for functional testing (Figure 97). During the tests, free rotation of the Synchro Transmitter was confirmed. Although friction was higher than expected for a new unit, this condition did not compromise its functional performance.

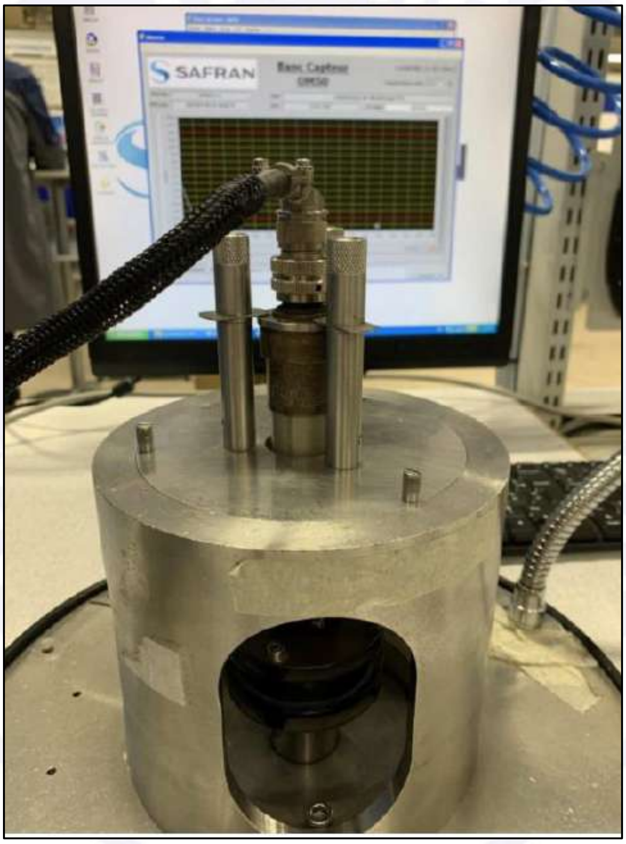


Figure 97 – Synchro Transmitter mounted on a test bench for functional testing.

The electrical tests, including continuity, insulation, and resistance tests, yielded results within the specified limits.

Therefore, it can be stated that the component remained functional, even after the accident, with overall satisfactory performance in the tests to which it was subjected. Despite the positive test results, they were not sufficient to explain the inconsistency observed in the left elevator position recorded by the FDR.

In view of this, a second round of tests was conducted at the aircraft manufacturer's electronics laboratory, with the aim of further investigating the origin of the inconsistencies.

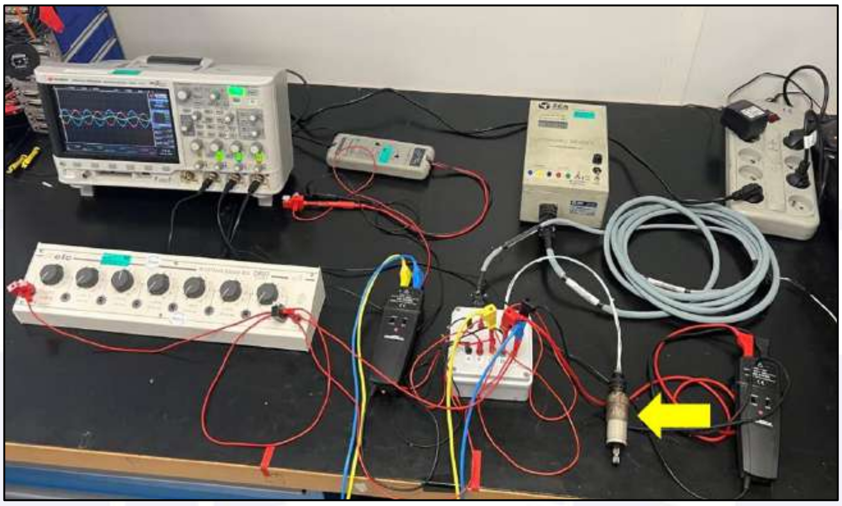


Figure 98 – Second round of tests at the aircraft manufacturer's facilities.
The yellow arrow indicates the synchro transmitter connected to the test equipment.

Even with the additional tests, it was not possible to reproduce or explain the anomaly observed in the data recorded by the FDR.

The Commission then proceeded to install the component in an aircraft of the same model belonging to the manufacturer, whose recording of elevator position data by the FDR was fully compliant. The objective was to reproduce the observed recording condition and isolate the source of the inconsistency between the sensor and the platform.

The aim was to determine whether the anomaly was related to the synchro transmitter under examination or to the accident aircraft, for example due to a possible fault in the wiring responsible for transmitting the sensor signal to the FDR.

When the original synchro transmitter of that aircraft was replaced with the accident component, satisfactory recordings were obtained. The elevator data was consistent, without presenting the discrepancies found in the data from the accident aircraft, and were correctly captured and stored.

However, during the process of removal and reinstallation of the component on the test aircraft, the possibility of an installation error was identified.

Based on this hypothesis, the Commission deliberately installed the component incorrectly, simulating an erroneous installation scenario, and conducted a new round of functional tests with analysis of the data recorded by the FDR.

With this intentionally incorrect installation, the results reproduced the condition observed in the PS-VPB aircraft. The data were being captured normally but showed inconsistencies resulting from the incorrect installation of the Synchro Transmitter and its linkage rods to the elevator.

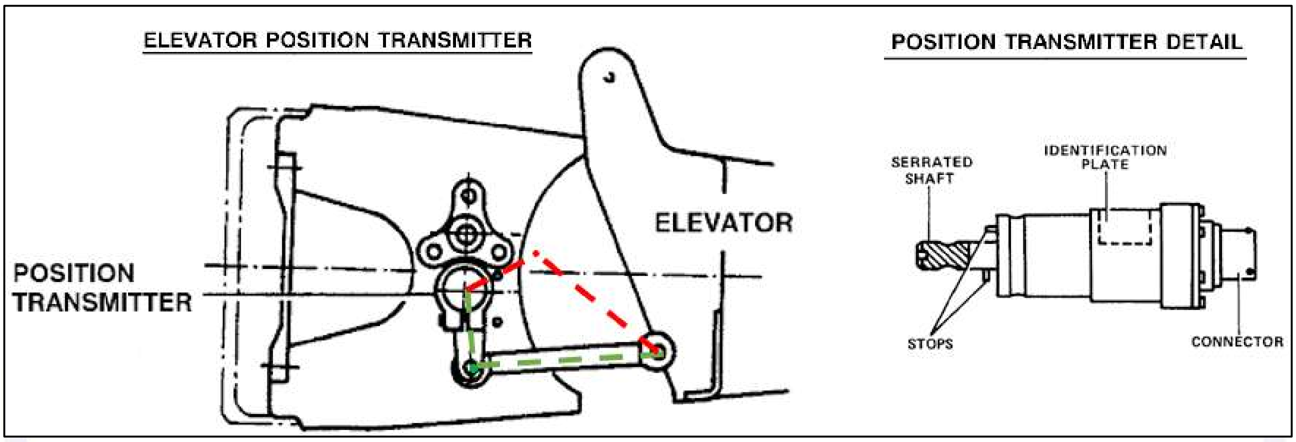


Figure 99 – On the left, front view. The green dashed line indicates the correct installation of the linkage rods between the elevator and the synchro transmitter. The red dashed line indicates the incorrect installation. On the right, side view of the component.
Source: Adapted from the AMM.

After confirming that the component had been incorrectly installed on the aircraft, the SIPAER Investigation Commission developed an algorithm to correct the reading of the data recorded in the FDR and to present corrected data regarding the position of the left elevator. Thus, the data related to the elevator position presented in this report were considered reliable and with the correct sign convention.

Maintenance records indicated that the synchro transmitter of the PS-VPB aircraft was manufactured in April 2017 and, since then, had not undergone an overhaul.

The commission was not able to locate specific maintenance records that evidenced the occurrence of the installation error.

The absence of an overhaul history and the inability to trace the intervention that resulted in the incorrect installation prevented the determination of the exact moment when the error was introduced.

It was also verified that the functional test to check the data recorded in the FDR was prescribed both in the Maintenance Planning Document (MPD) and in the operator’s maintenance program, both approved for the fleet of ATR-72 aircraft.

This test was capable of identifying inconsistencies in the elevator data, and its performance was scheduled in C-type inspections, with an interval of 8,000 flight hours. Records indicated that the last execution of this functional test took place on 29SEP2017, when the aircraft had a TSN of 10,908 hours and 20 minutes of flight time.

It is important to note that this incorrect assembly did not interfere with the normal movement of the aircraft's elevators, which functioned normally throughout the flight and had no relation to the contributing factors of the accident. Accordingly, the incorrect assembly of the synchro transmitter only affected the recording of the left elevator position parameter in the FDR, which was able to be corrected for use in the investigation process.

1.16.6. Angle of Attack (AOA) sensors

The SIPAER Investigation Commission recovered both AOA sensors from the aircraft wreckage. The sensors were properly secured to the fuselage by their attachment bolts. However, the sensor vanes were missing, having fractured upon the aircraft’s impact with the ground.

The left sensor was manufactured in JUN2008 and had already undergone an overhaul at the manufacturer’s facilities after an unscheduled removal. Several tests were conducted on this component, and no discrepancies were found. The results obtained were consistent with normal operation of the equipment during the accident flight.

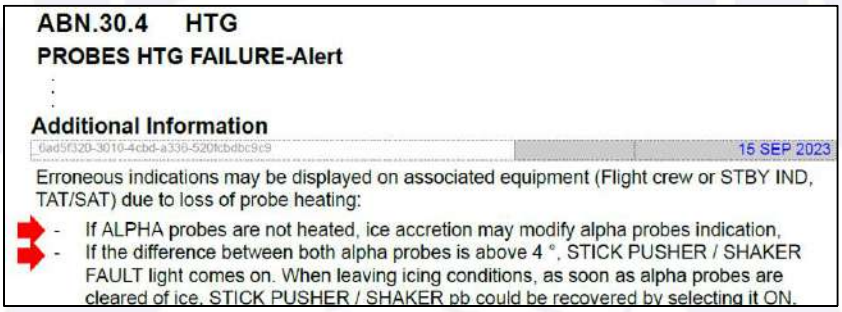
The right sensor was manufactured in December 1985 and had already undergone overhauls at the manufacturer, following unscheduled removals in 2012 and 2013.

During the initial cross-check of data, the SIPAER Investigation Commission identified that, on “flight -1” —corresponding to the outbound leg between SBGR and SBCA—fault messages related to the heating of the right AOA sensor were recorded in the MPC memory.

The F/O ALPHA PROBE HEAT message was recorded 16 times during this flight, indicating that no alternating current (AC) was detected for the heating system of the right-side AOA probes (F/O – First Officer). This failure resulted in illumination of the ALPHA light on the PROBES HTG F/O panel, accompanied by the ANTI-ICING light on the CAP, a MASTER CAUTION alert, and a single chime aural warning.

No records of discrepancies entered in the aircraft Technical Logbook (TLB) associated with these events were found.

The FCOM emphasized, in the 30.4 Additional Information section of Abnormal Procedure ABN – PROBES HTG FAILURE Alert, that if the AOA probes were not properly heated, ice accretion could occur, potentially altering their indications.



ABN.30.4 HTG

PROBES HTG FAILURE-Alert

:

Additional Information

6ad5f320-3010-4cbd-a336-520fcbdbc9c9 15 SEP 2023

Erroneous indications may be displayed on associated equipment (Flight crew or STBY IND, TAT/SAT) due to loss of probe heating:

- If ALPHA probes are not heated, ice accretion may modify alpha probes indication,
- If the difference between both alpha probes is above 4 °, STICK PUSHER / SHAKER FAULT light comes on. When leaving icing conditions, as soon as alpha probes are cleared of ice, STICK PUSHER / SHAKER pb could be recovered by selecting it ON.

Figure 100 –Arrows indicating additional information contained in the ABN 30.4 of the aircraft FCOM.

It was also identified that, during the same “flight -1”, STICK PUSHER FAULT messages were recorded in the MPC. Cross-checking these faults with the FDR data indicated temporary discrepancies greater than 4° between the information provided by the two AOA sensors simultaneously, as detailed in the following figure 101. Jumps in the values of the right AOA sensor (AOA2) were observed.

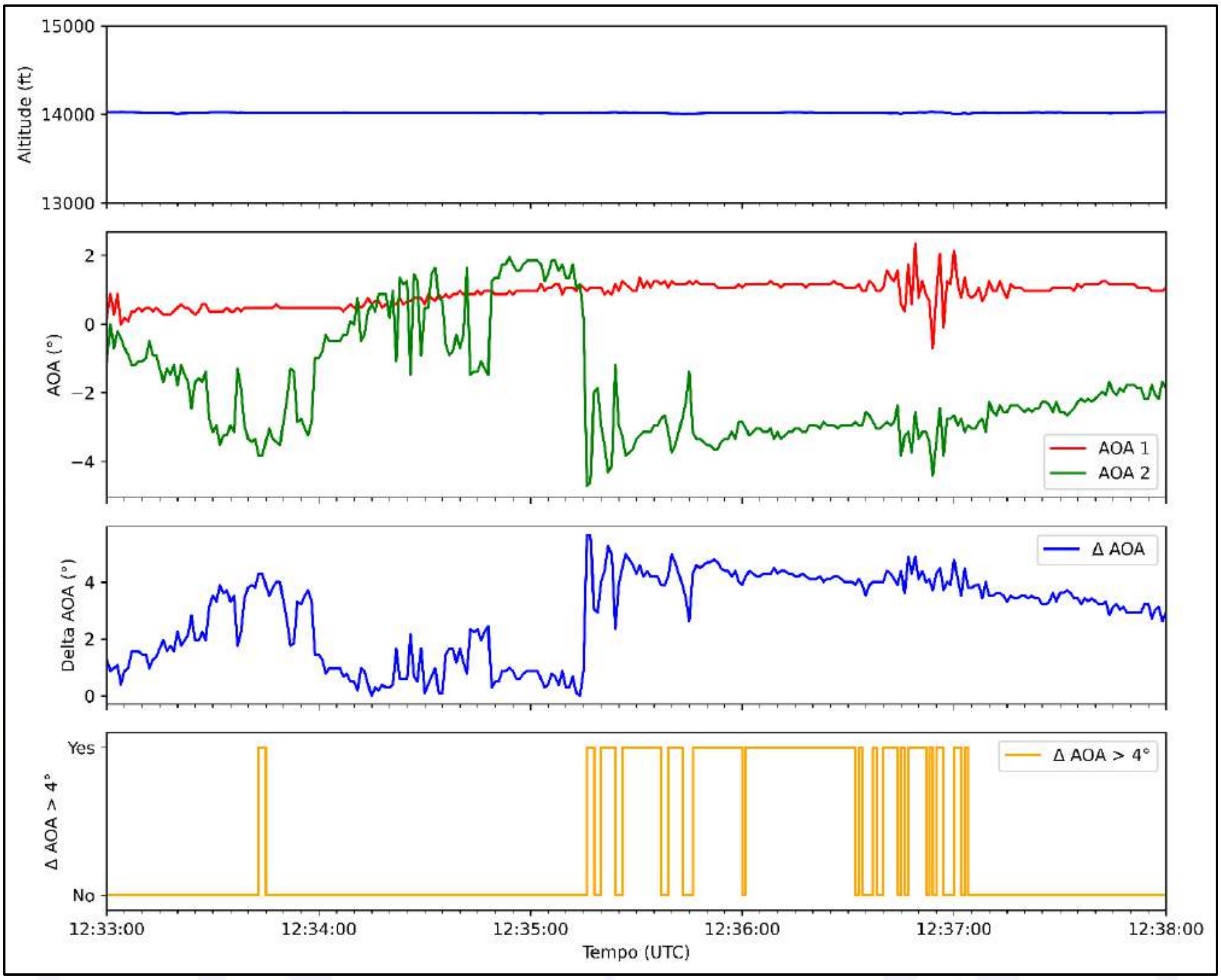


Figure 101 –Excerpt from “flight -1” showing a discrepancy greater than 4° between the AOA sensor indications.

Due to the discrepancies identified, examinations and tests were carried out, including an evaluation of the electrical and mechanical condition of the right AOA sensor at the component manufacturer’s facilities.

During the examinations, it was verified that both power wires for the heating elements were electrically connected to their respective pins in the connector, and that both the sensor housing and its connector were in good condition.

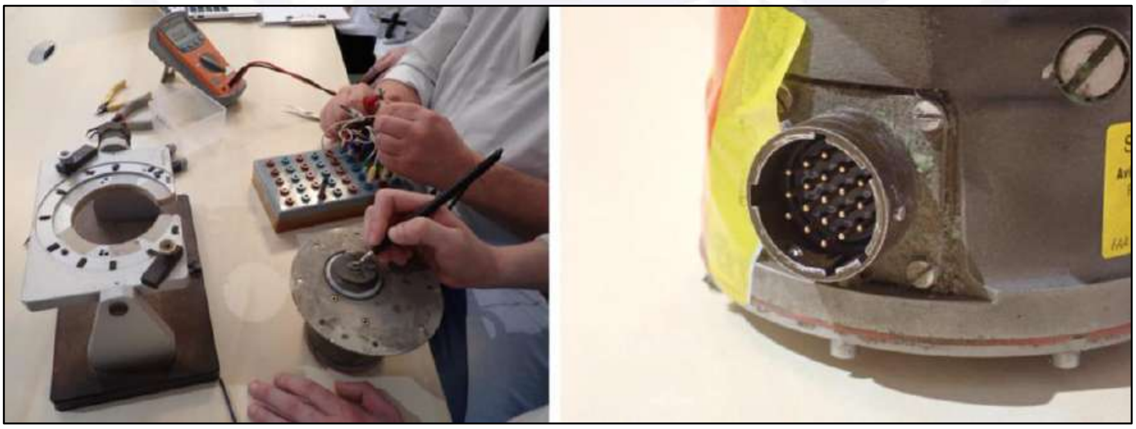


Figure 102 – Images recorded during the examinations and tests performed on the right AOA sensor. On the left, execution of electrical tests on the heating wiring; on the right, the good condition of the connector pins.

The examinations and tests performed on the right AOA sensor showed that it was in good overall condition, with most quantitative measurement parameters within the specified ranges.

The bench tests performed did not reproduce the condition observed on flight minus one (“flight -1”), which is consistent with a scenario of intermittent failures in the heating of the right AOA sensor.

These failures reduced the effectiveness of its ice protection system, resulting in ice accretion during a specific phase of flight -1. Consequently, a discrepancy occurred between the AOA values of the left (AOA1) and right (AOA2) sensors, with temporary activation of the Fault light on the Stick Pusher/Shaker button.

No record of this malfunction was found entered in the aircraft’s Technical Logbook (TLB), nor was there any record of dispatch under specific conditions as provided for in the MEL.

Despite the records on flight −1, this failure related to the heating of the right AOA sensor was not reproduced on the accident flight. Therefore, the absence of fault records related to AOA2 on flight 0 indicated a scenario consistent with the normal operation of this component during the accident flight.

1.16.7. Dual Distributor Valves (DDV)

During the activities carried out by the SIPAER Investigation Commission at the wreckage site, two of the seven DDVs were located and subsequently subjected to examinations and tests.

After tracing its history through the component control sheet tracking report records obtained from the operator, the SIPAER Investigation Commission concluded that it was the valve installed at position FIN 11DM (Figures 103 and 104), responsible for the actuation of the horizontal stabilizer boots.

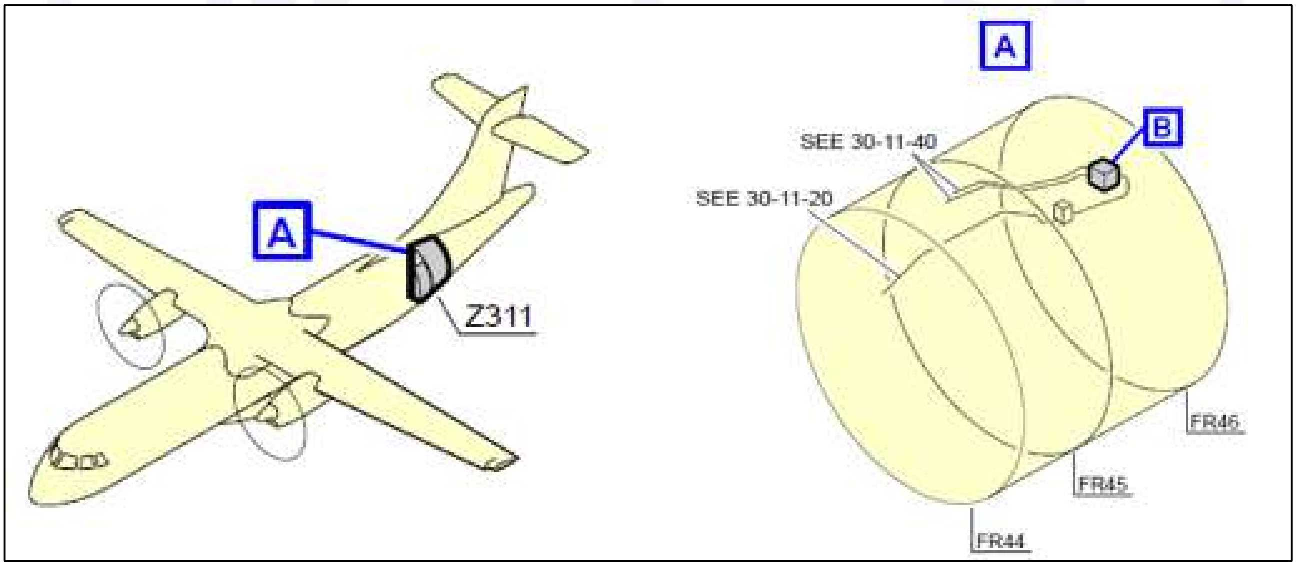


Figure 103 – Illustration showing the FIN 11DM location of the DDV with PN B03AA1040 and SN 00468.
Source: Maintenance Manual ATR-A-30-11-30-0400A-94AA-A-*VALVE INSTL-DUAL DISTR*, FR45-FR46.

Figure 104 – DDV, FIN 11DM, Identification Plate.

The records indicated that the valve had a TSN of 59,903 hours and 36 minutes. They also showed that the valve had been in service since 1999, having been installed on six different aircraft before being incorporated into the PS-VPB aircraft on 19JUN2024 (Figure 105).

COMPONENT CONTROL SHEET - TRACKING REPORT

PN: B03AA1040 **Nomenclature:** DUAL DISTRIBUTOR VALVE

ATA: 30 **SN:** 00468

INSTALLATION INFORMATION								REMOVAL INFORMATION							
COMPONENT						AIRCRAFT		COMPONENT					AIRCRAFT		
Installation Date	Document	TSN/ CSN	TSO/ CSO	Registration	Position	TAT	TAC	Removal Date	Document	TSI/ CSI	TSN/ CSN	TSO/ CSO	TAT	TAC	Removal Reason
01/10/1999	AIR MSN 572	0,0 0	0,0 0	PR-PDH	10DM	0,0	0	19/02/2015	NRC 5867	40002,7 33563	40002,7 33563	40002,7 33563	40002,7	33563	MNT CONVENIENCE
19/02/2015	NRC 5869	40002,7 33563	40002,7 33563	PR-PDE	10DM	32653,9	37790	28/07/2016	WO 28055/16	4646,0 3212	44648,7 36775	44648,7 36775	37299,8	41002	MNT CONVENIENCE
27/03/2018	NRC 103493	44648,7 36775	44648,7 36775	PP-PTQ	11DM	25508,1	21713	28/03/2018	NRC 103493	0,0 0	44648,7 36775	44648,7 36775	25508,1	21713	T/S - SWAP PTP
28/03/2018	NRC 103492	44648,7 36775	44648,7 36775	PP-PTP	11DM	25950,1	21513	05/10/2022	WO 54273/22	11082,3 8775	55730,9 45550	55730,9 45550	37032,4	30288	MNT CONVENIENCE
05/10/2022	WO 27639/22	55730,9 45550	55730,9 45550	PR-PDY	11DM	24295,5	28295	27/10/2023	WO 62499/23	2432,3 1868	58163,2 47418	58163,2 47418	26727,8	30163	MNT CONVENIENCE
27/10/2023	WO 61994/23	58163,2 47418	58163,2 47418	PP-PTM	11DM	38081,1	31693	19/06/2024	WO 70009/24	1740,4 1439	59903,6 48857	59903,6 48857	39821,5	33132	MNT CONVENIENCE
19/06/2024	69869/24	59903,6 48857	59903,6 48857	PS-VPB	11DM	17170,8	11065								

Figure 105 – Image of the *Component Control Sheet Tracking Report* for DDV PN B03AA1040 and SN 00468, highlighting its installation on aircraft PS-VPB. Source: Operator's Technical Center of Maintenance.

The component was sent for examination at the manufacturer's facilities, where it was subjected to inspections. During the initial inspection, the presence of the original warranty seal was noted, indicating that the component had not undergone repairs after its delivery by the manufacturer. However, the damage caused by the impact prevented the performance of complete bench tests.

Electrical tests of continuity, impedance, and insulation were performed, with results showing minimal variations outside the specified tolerances, without functional impairment. Subsequently, functional tests were carried out on the valve's two solenoids, both yielding results within specifications and with no discrepancies recorded.

Finally, the component was fully disassembled for inspection of the two pressure sensors (pressure switches). The tests indicated that the sensor in channel B was operating within specifications, while the sensor in channel A showed damage due to impact and thermal deformation resulting from the post-impact fire.

Figure 106 – DDV responsible for actuating the horizontal stabilizer boots subjected to examination.

The second DDV located could not be identified due to degradation resulting from the post-impact fire, which also precluded any functional testing.

Considering the position in which it was found, near the tip of the right wing, the SIPAER Investigation Commission inferred that it corresponded to the DDV associated with FIN 10DM, responsible for actuating the right-wing outboard boots. (Figure 107).

Figure 107 – Image of the FIN 10DM DDV at the crash site.

The DDV was subjected to a 3D X-ray computed tomography scan in order to obtain a three-dimensional reconstruction of the valve for information extraction. However, it was not possible to obtain elements that would allow the operational condition prior to the impact and fire exposure to be inferred.

Figure 108 – Photograph of the DDV responsible for actuating the outer boots of the right wing on the test bench for analysis.

Despite the impossibility of confirming the identification of the DDV, the history of all seven DDVs installed on the aircraft was reviewed.

The component control records showed that the DDV at position FIN 10DM had PN B03AA1040, SN 00545, and unknown TSN and TSO. According to the records, this DDV had been in operation since 2016 and had been installed on five different aircraft before being incorporated into the aircraft PS-VPB on 20JUN2024.

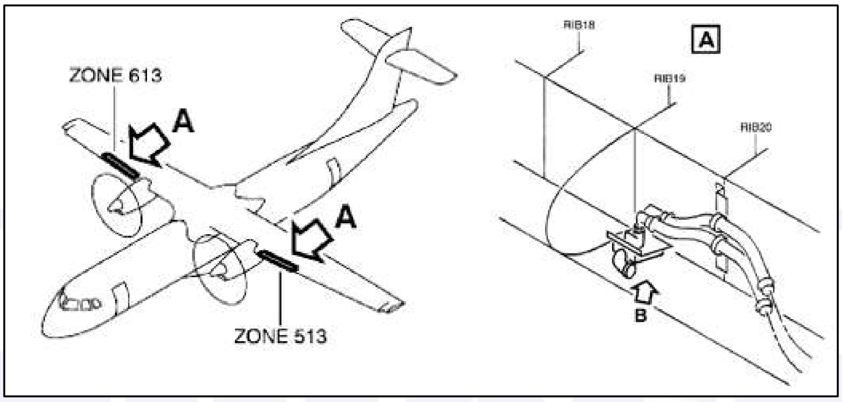


Figure 109 – Illustration showing the FIN 10DM location for the DDV of PN B03AA1040 and SN 00545.
Source: Maintenance Manual ATR-A-30-11-70-0800C-94AA-A-VALVE INSTL-DUAL DISTR, RIB 19-20.

COMPONENT CONTROL SHEET - TRACKING REPORT

PN: B03AA1040 Nomenclature: DUAL DISTRIBUTOR VALVE
ATA: 30 SN: 00545

INSTALLATION INFORMATION								REMOVAL INFORMATION							
COMPONENT						AIRCRAFT		COMPONENT					AIRCRAFT		
Installation Date	Document	TSN/ CSN	TSO/ CSO	Registration	Position	TAT	TAC	Removal Date	Document	TSI/ CSI	TSN/ CSN	TSO/ CSO	TAT	TAC	Removal Reason
10/12/2016	-	UNK UNK	UNK UNK	PP-PTO	10DM	20673,6	17707	11/12/2016	NRC 14198	0,0 0	UNK UNK	UNK UNK	20873,6	17707	MNT CONVENIENCE
11/12/2016	NRC 14199	UNK UNK	UNK UNK	PR-PDI	10DM	15113,9	11153	10/11/2017	TLB 45987	3361,0 2486	UNK UNK	UNK UNK	18475,0	13639	MNT CONVENIENCE
12/11/2017	TLB 45987	UNK UNK	UNK UNK	PP-PTP	84DM	24486,0	20325	26/10/2023	WO 62500/23	12546,4 9963	UNK UNK	UNK UNK	37032,4	30288	PHYSICAL CHECK
26/10/2023	WO 62500/23	UNK UNK	UNK UNK	PR-PDY	84DM	26727,8	30163	26/10/2023	WO 62500/23	0,0 0	UNK UNK	UNK UNK	26727,8	30163	MNT CONVENIENCE
27/10/2023	WO 61995/23	UNK UNK	UNK UNK	PP-PTM	84DM	38081,1	31693	20/06/2024	WO 70445/24	1740,4 1439	UNK UNK	UNK UNK	39821,5	33132	MNT CONVENIENCE
20/06/2024	WO 70446/24	UNK UNK	UNK UNK	PS-VPB	10DM	17170,8	11065								

Figure 110 – Image of the Component Control Sheet – Tracking Report for the DDV PN B03AA1040 and SN 00545, highlighting its installation on aircraft PS-VPB.

It was not possible to identify the remaining valves in the aircraft wreckage due to the severe thermal damage caused by the post-impact fire.

The operator's control records regarding the five DDVs that were not located contained incomplete or unknown TSN and TSO data.

1.16.8. Engines

Both engines were exposed to a post-impact fire. As a result, the rotors of the Low Pressure Compressor (LPC) were left completely exposed.

The LPC rotors of both engines showed signs of Foreign Object Damage (FOD) on the leading edges of their blades. Some LPC blades also exhibited deformation in the direction opposite the rotation of the rotor shaft (Figures 111 and 112).

Figure 111 – Image of the LPC rotor of engine No. 1. Red arrow indicating blade deformations in the direction opposite to the rotation of the rotor shaft.

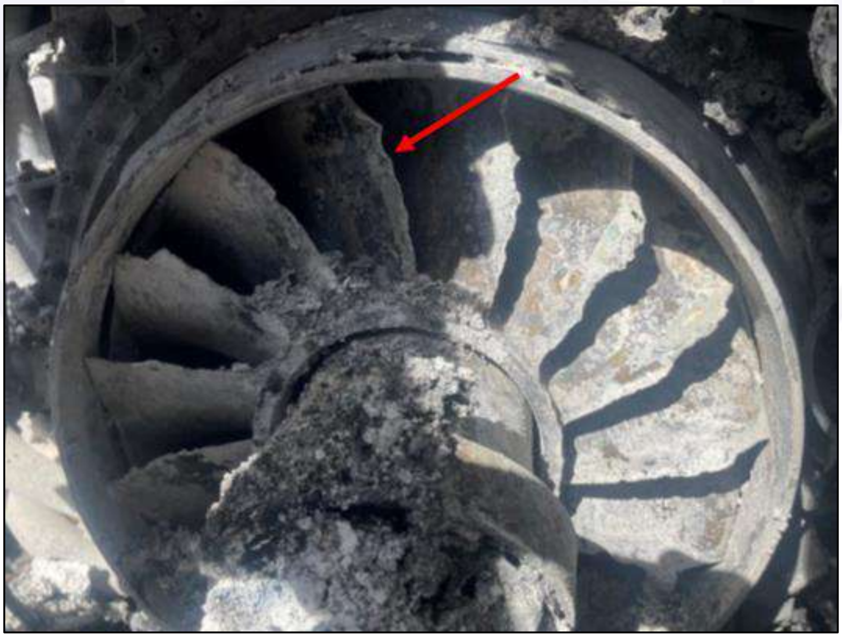


Figure 112 – Image of the LPC rotor of engine No. 2. Red arrow indicating blade deformation in the direction opposite to the rotation of the rotor shaft.

The components of the Reduction Gear Boxes (RGB) of both engines were also exposed, showing damage resulting from both the impact with the ground and the post-impact fire (Figures 113 and 114).

Figure 113 – Image of the RGB of engine No. 1.

Figure 114 – Image of RGB of the engine No. 2.

The turbine support casings of both engines exhibited severe plastic deformation resulting from the impact with the ground. However, the second stages of the power turbines of both engines, visible through the exhaust duct and the casing surrounding the turbines (at the rear of the engines) were with no indications of fractured blades that could suggest blade liberation (fracture or loss of blades in flight).

Figure 115 – Rear view of engine No. 1, showing deformations in the turbine support casing and the blades of the 2nd stage of the power turbine.

One of the aircraft's avionics system logics determined that average values of certain engine parameters were recorded in the MPC during the cruise phase of each flight.

The recognition of entry into cruise was performed automatically by the system, based on the stabilization of previously defined operational parameters. The purpose of this recording was to enable monitoring of engine operation and performance over time, from a medium- and long-term perspective.

The average values of these parameters were stored on the MPC PCMCIA memory card, which was recovered at the accident site and analyzed as described in item 1.16.2 – Multi-Purpose Computer. These data are documented in the R02 reports, with identification codes R0202886, R0202887 and R0202888, and recorded, among other parameters, the following:

- The average cruise value of the TAT parameter recorded on the accident flight was -1°C, while on the outbound flight to SBCA and the preceding flight, it was 4°C and 3°C, respectively;
- The average cruise value of the Indicated Airspeed (IAS) parameter on the accident flight was 196 kt, while on the outbound flight to SBCA and the preceding flight it was 204 kt and 207 kt, respectively.
- On the three flights conducted on the day of the accident, engine No. 1 operated with a higher average torque value than engine No. 2. This difference was provided for in MOP 21.50-01P of the aircraft's MEL for operation under the condition of pack No. 1 inoperative;
- The average cruise values of the NP parameter for both engines remained equivalent and stable across the three flights of the day, with an average of

82% NP, consistent with the propeller blade angle in cruise and normal thrust delivery by the engines to the aircraft;

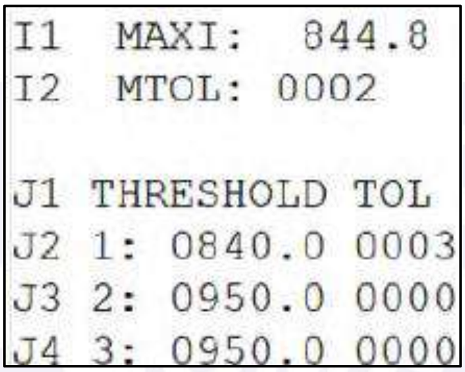
- The average cruise values of the NL, NH, ITT, and FF parameters remained stable, with the values recorded for engine No. 1 being slightly higher than those for engine No. 2;
- On the accident flight, an average value of 2 amperes of electrical current was recorded in the starter generator of engine No. 1 and 74 amperes for engine No. 2;
- The binary parameter for detection of bleed air flow to pack No. 1 was recorded as absent on all three flights of the day; and
- The binary parameter for detection of bleed air flow to pack No. 2 was recorded as present on all three flights of the day.

Data name	Data additional description	R0202886 file data	R0202887 file data	R0202888 file data
GMT reference		09:45	12:39	15:30
Pressure altitude	Unit in ft	15016	14015	17015
Total Air Temperature	Unit in Celsius	3	4	-1
IAS	Unit in kts	207	204	196
Eng1 / Eng2 Torque	Unit in %	78.2 / 71.1	79.3 / 74.9	78.5 / 73.0
Eng1 / Eng2 NP	Unit in %	82.0 / 81.9	81.9 / 81.9	81.9 / 81.9
Eng1 / Eng2 NL	Unit in %	96.2 / 94.5	96.2 / 95.4	97.9 / 96.2
Eng1 / Eng2 NH	Unit in %	96.2 /95.8	96.1 / 95.2	97.0 / 95.7
Eng1 / Eng2 ITT	Unit in Celsius	680 / 655	681 / 641	704 / 657
Fuel flow	Unit in kg per hour	374 / 361	382 / 369	373 / 353
Current from engine generator	Unit in Amp	00 / 80	04 / 64	02 / 74
Left HP valve position	0 = OPEN, 1 = CLOSED	1	1	1
Right HP valve position	0 = OPEN, 1 = CLOSED	1	1	1
Normal / High flow control	0 = HIGH, 1 = NORMAL	0	1	1
Pack air flow left	0 = ON, 1 = OFF	1	1	1
Pack air flow right	0 = ON, 1 = OFF	0	0	0

Figure 116 – Data from the R02 reports of the three flights conducted on the day of the accident.

The MPC was also capable of storing certain engine data in the event of exceedance of previously established limits, recording an excerpt of these parameters at the time of occurrence in report R03, with identification code R030057

The report R030057 was generated approximately 8 seconds before the end of the recordings, at the moment of impact. The data were recorded due to a transient exceedance, lasting three seconds, of the ITT parameter of engine No. 1, which surpassed the temperature limit established for normal operation. The excerpt stored in the R03 report indicated that the ITT of engine No. 1 exceeded the limit of 840°C for three seconds, without exceeding other limits (950 °C), with a maximum recorded value of 844.8 °C (Figure 117).



```
I1  MAXI:  844.8
I2  MTOL: 0002

J1 THRESHOLD TOL
J2 1: 0840.0 0003
J3 2: 0950.0 0000
J4 3: 0950.0 0000
```

Figure 117 – Excerpt from report R03 showing the ITT exceedance.

The FDR also recorded an increase in the rotational parameters (NL, NH, and NP), along with the onset of loss of control of the aircraft, suggesting that the pilots were commanding the power levers.

The data showed an engine response to the pilots' power lever inputs consistent with normal operation.

Although an exceedance of the No. 1 engine ITT occurred during engine acceleration by the pilots, all data collected was consistent with normal operation of the powerplants, which exhibited parameters within expected limits and responded appropriately to the flight crew's inputs up to the moment of impact.

1.16.9. DC BUS 1 electrical bus

From the taxi phase of the aircraft during the accident flight, an intermittent and inconsistent behavior was observed in the status of the DC Bus 1 parameter, as illustrated by the blue trace in Figure 118.

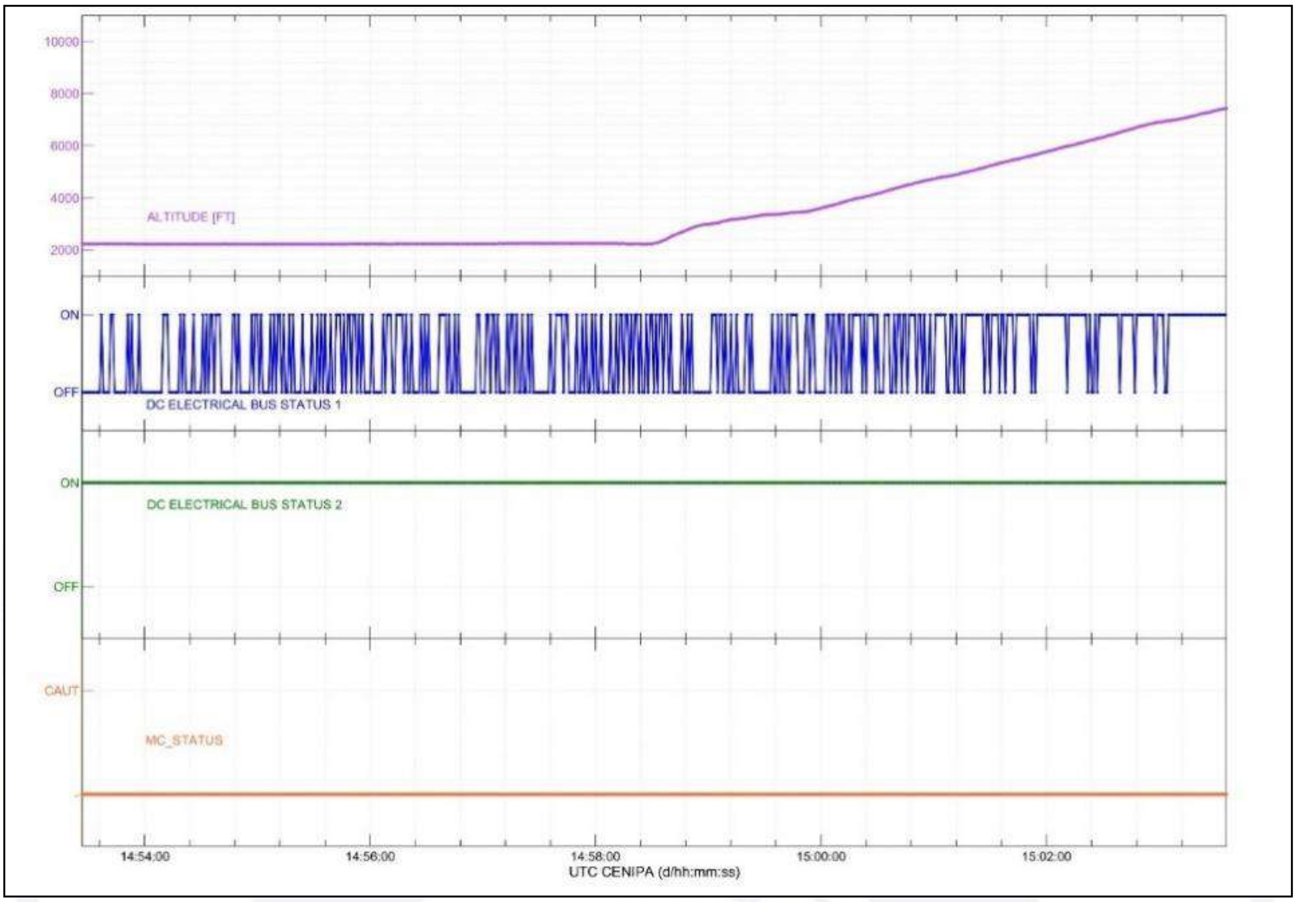


Figure 118 – DC Bus 1 status graph based on FDR and MPC data.

The records showed that the status of the DC Bus 1 electrical bus (blue trace in the figure 118) fluctuated continuously from the beginning of taxi, a behavior that contrasted with DC Bus 2 (green trace in the figure 118), whose operation remained stable and continuously energized throughout the analyzed period.

The status of DC Bus 1 was recorded as OFF whenever the MFC1 detected a low-voltage condition in the bus. This condition was indicated in the cockpit by illumination of the DC BUS OFF light on the left side of the electrical panel, located on the overhead panel, in addition to triggering a MASTER CAUTION alert, a single chime aural warning, and illumination of the ELEC indication on the CAP.

However, throughout the analysis of the flight data and FDR records, no activation of the MASTER CAUTION alert was identified that could be associated with a failure or malfunction of DC Bus 1.

The absence of MASTER CAUTION alerts was consistent with a scenario in which the DC Bus 1 was effectively energized throughout the entire flight, and the fluctuations recorded by the FDR in the status of this parameter occurred spuriously, not correlated with actual system failures, being consistent with an intermittent contact in the electrical grounding of the DC Bus 1 indicator light.

1.16.10. Pitch uncoupling mechanism

In order to ensure that the entire pitch control chain functioned correctly, the SIPAER Investigation Commission evaluated the Pitch Uncoupling Mechanism at the wreckage site during the initial on-site action. The component was visually identified in the uncoupled position (Figure 119), consistent with the in-flight activation of the pitch uncoupling mechanism.

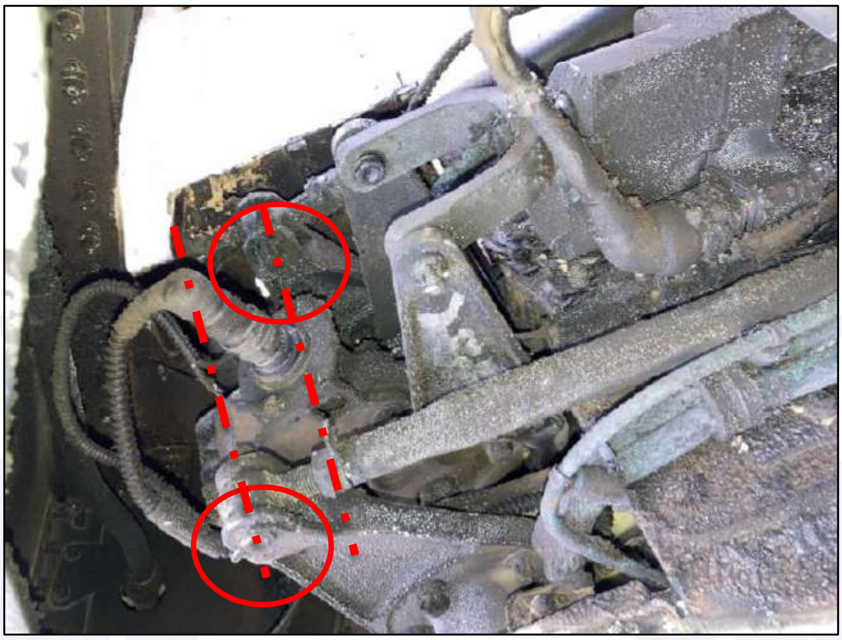


Figure 119 – Pitch uncoupling mechanism found in the disengaged position.

1.16.11. Flight simulator

Members of the SIPAER Investigation Commission conducted a flight simulator session at the aircraft manufacturer's facilities.

A Full Flight Simulator (FFS) representative of the accident aircraft model – ATR-72-212A (500) – was used, qualified at Level D in accordance with the European Union Aviation Safety Agency (EASA) CS-FSTD(A) requirements and Title 14 of the Code of Federal Regulations (14 CFR), Part 60, representing the highest level of fidelity available for simulators of this category.

For the simulation of severe icing conditions, the Severe Icing package available in the system was used, intended for the reproduction of specific ice accretion scenarios.

During the simulator session, particular attention was given to aspects related to cockpit ergonomics and human-machine interaction (discussed in Section 1.13.2 of this report).

The objective was to demonstrate the application of the procedures for operating the aircraft in severe icing conditions leading to degraded aircraft performance.

It is important to emphasize that the simulator model was not fully representative of the actual conditions of the accident flight. Nevertheless, it was observed that both the rate of airspeed decay and the timing of the advisory and alert messages occurred at moments similar to those recorded during the accident flight.

1.16.12. Demonstration Flight

In order to identify characteristics related to the flight qualities of the ATR-72 212A (500), particularly with regard to aerodynamic aspects and stability in conditions close to stall, the SIPAER Investigation Commission participated in a demonstration flight in Toulouse, France.

For this purpose, an ATR aircraft (SN 1157, model ATR-72-212A, equipped with PW127M engines, same model of aircraft PS-VPB) was used. The activities were conducted by a mixed team consisting of two test pilots and one flight test engineer from the manufacturer, as well as two members of the SIPAER Investigation Commission.

The flight was conducted under visual meteorological conditions in a calm atmosphere, conducive to the safe execution of the planned maneuvers and encompassed a wide range of operational conditions, including different flight configurations and scenarios:

- Flaps: at F0° and F30°;
- Landing gear: retracted and extended;
- Power Management (PWR MGT) knob: set to Cruise (CRZ) and Maximum Continuous Thrust (MCT);
- Engine power levers: adjusted according to each test profile;
- Deceleration rates: of -1 kt/s and -3 kt/s;
- Flight condition: with wings level and in 30° bank turns; and
- Autopilot: engaged and disengaged.

The flight evaluation matrix (Figure 120) presents the numbering and the conditions associated with each demonstrated point.

Test Point	Configuration	Trim Speed	Deceleration Rate	Power Management	Power Levers	AP	Flight Conditions
1	F0°/GU	N/A	N/A	CRZ	Flight Idle	ON	Turn
2	F0°/GU	1.3VSR	–1 kt/s	MCT	Flight Idle	OFF	Wings leveled
3	F30°/GD	1.3VSR	–1 kt/s	MCT	Flight Idle	OFF	Wings leveled
4	F0°/GU	1.3VSR	–1 kt/s	MCT	Power For Level	OFF	Wings leveled
5	F0°/GU	1.3VSR	–1 kt/s	MCT	Power For Level Flight	OFF	Turn at 30° bank angle left
6	F0°/GU	1.3VSR	–1 kt/s	MCT	Power For Level Flight	OFF	Turn at 30° bank angle right
7	F0°/GU	1.3VSR	–3 kt/s	MCT	MCT	OFF	Wings leveled
8	F0°/GU	1.3VSR	–3 kt/s	MCT	Power For Level Flight	OFF	Turn at 30° bank angle left
9	F0°/GU	1.3VSR	–3 kt/s	MCT	MCT	OFF	Turn at 30° bank angle right
10	F30°/GD	1.3VSR	–3 kt/s	MCT	MCT	OFF	Wings leveled
11	F30°/GD	1.3VSR	–3 kt/s	MCT	Power For Glide Slope	OFF	Turn at 30° bank angle left
12	F30°/GD	1.3VSR	–3 kt/s	MCT	MCT	OFF	Turn at 30° bank angle right

Figure 120 – Flight evaluation matrix.

In general, all tests demonstrated that the ATR-72-212A aircraft exhibited controllable and predictable behavior during stall approach conditions, with adequate recovery in all configurations, including wings level and 30° bank turns, deceleration rates of -1 and -3 kt/s, and tested power settings. No tendency for pitch-up or significant oscillations in any axis was observed for the configurations established in the demonstration flights.

It is worth noting that the application of rudder was not required in any of the tests and that the STALL procedure provided in the AFM included a warning stating that the rudder should be “used with caution” (RUDDER: USE WITH CARE).

Therefore, for the conditions tested by the Commission together with the ATR manufacturer, the absence of a requirement for rudder input reinforced the presence of lateral–directional stability during the approach to stall and the effectiveness of the stall protection devices, namely the stall warning and stick pusher.

It is emphasized that the results of the flight presented herein cannot be considered representative of the condition observed during the accident flight, since the conditions under which the PS-VPB aircraft was operating—under severe icing—resulted in an aerodynamic configuration different from that evaluated.

Accordingly, the observations described herein were intended to characterize the aircraft's behavior under normal operating conditions, with a view to providing the SIPAER Investigation Commission with a better understanding of the performance of the high-AOA protection systems and the aircraft's stability characteristics.

1.17. Organizational and management information

This section describes the structural, administrative, and managerial aspects related to the operator and the regulatory authority, bringing together elements concerning the company's internal organization, its decision-making processes, management practices, Safety Management System (SMS), and its maintenance, training, and dispatch policies.

The objective was to analyze the institutional environment in which the crew members and other parties were operating, assessing whether organizational factors—such as safety culture, supervision, risk management, and resource allocation and work-group culture—may have influenced the context of the accident.

The data collection combined visits to the company's operational and administrative facilities, including its headquarters at Ribeirão Preto (SBRP) and bases at other locations, with semi-structured interviews conducted with personnel from various areas, including pilots, flight attendants, mechanics, managers, and administrative staff.

Data from documents—such as organizational charts, training plans, audit reports, and inspection records—were used and analyzed for regulatory compliance and technical consistency, as well as informal inputs regarding employees' perceptions of the organizational climate and the practices shared within the company.

This approach made it possible to identify not only the formally established processes, but also the practices tolerated in day-to-day operations with potential impact on the organization's safety culture.

1.17.1. Theoretical Model of the Organizational Accident

The Theoretical Model of the Organizational Accident developed by James Reason (1990)[4] has become one of the most relevant frameworks for explaining the occurrence of accidents in complex systems, such as the aviation sector.

This model provides a comprehensive and realistic view of how different failures interact within complex systems. It is based on the premise that all human beings are prone to error and emphasizes that operational safety depends on the continuous monitoring of vulnerabilities—both at the operational and organizational levels—on strengthening defenses, and on the development of a culture that recognizes, addresses, and learns from failures.

1.17.2. Situational Awareness Model in Dynamic Environments

The Situational Awareness Model in Dynamic Environments, developed by Mica Endsley in 1995[5], is a framework used to understand how professionals operating in highly complex contexts, such as pilots, perceive, interpret, and anticipate what is happening around them.

In scenarios where information changes rapidly, decisions must be made dynamically, with multiple variables interacting simultaneously. In such contexts, situational awareness becomes a key element for operational safety.

---

[4] *REASON, James. Human error. Cambridge: Cambridge University Press*, 1990.

[5] *ENDSLEY, Mica R. Toward a theory of situation awareness in dynamic systems. Human Factors*, v. 37, n. 1, p. 32-64, 1995.

Endsley defines situational awareness as the perception of elements in the environment within a given time and space, the comprehension of their meaning, and the projection of their future status. This definition emphasizes that it is not sufficient to identify what is occurring; it is necessary to understand the implications of what has been perceived and, moreover, to anticipate its developments.

The relevance of Mica Endsley's model lies in demonstrating that erroneous decisions can occur even among experienced professionals. Many failures are not the result of ignorance or negligence, but rather of gaps in the development of situational awareness.

Several factors influence the quality of situational awareness, including individual characteristics (knowledge, training, fatigue, cognitive workload, emotional state), the complexity and urgency of tasks, the reliability of supporting tools (interfaces, alerts, displays), the presence of distractions in the work environment, and the clarity and effectiveness of team communication.

Studies indicate that deficiencies in situational awareness are present in a large proportion of accidents in complex systems, whether due to the failure to perceive critical cues, the misinterpretation of what was perceived, or the inability to anticipate the evolution of the scenario.

1.17.3. Complacency, normalization of deviance, and managerial oversight

The relationship between complacency, normalization of deviance, and managerial oversight constitutes a decisive element in preserving operational safety and aviation efficiency.

Complacency, in this context, may be understood as a mental state characterized by overconfidence, reduced vigilance, and relaxation in relation to established standards and procedures, which may result from an exaggerated belief in one's own abilities and an underestimation of task complexity.

It frequently arises in highly repetitive environments, in which operators, accustomed to routines with little variation, tend to underestimate risks and normalize failures. This phenomenon directly impacts operational safety, leading to reduced attention, omission of critical steps, and acceptance of deviations as though they were normal.

On the other hand, managerial oversight plays an essential role in mitigating this risk. Proactive, technically competent management that remains closely engaged with operational teams is capable of promptly identifying signs of complacency, intervening through constructive feedback, and continuously reinforcing the importance of adherence to operational procedures.

Effective oversight not only corrects failures, but also strengthens the safety culture by fostering among professionals the perception that they are, at the same time, both valued and accountable for their actions.

On the other hand, the absence of active oversight or the adoption of overly permissive models creates fertile ground for complacent behaviors. Minor errors cease to be corrected and begin to be regarded as acceptable, conveying to teams the notion that deviations from established conduct do not entail consequences.

Over time, these deviations become normalized, creating a false sense of safety and increasing the vulnerability of the system's defenses. This process is known as normalization of deviance, in which behaviors contrary to safety gradually become routine and acceptable (VAUGHAN[6], 1996)

---

[6] *VAUGHAN, Diane. The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA. Chicago: University of Chicago Press, 1996.*

Normalization of deviance occurs when an incorrect, non-standardized, and unforeseen practice becomes an informal norm experienced by the members of an organization. Among its causes are the existence of a permissive organizational culture, routinization, and the absence of immediate negative consequences.

Skipping checklists, ignoring warnings, and exceeding operational limits are examples of such erroneous behaviors, which create a false sense of safety justified by previous experience in which no consequences were perceived to be associated with those actions. Such conduct may be prevented through the establishment of a just culture, in which unintentional deviations are reported without retaliation, while intentional acts are subject to disciplinary measures.

It is also important to consider that excessively rigid and punitive oversight may produce contrary effects: professionals may refrain from reporting errors out of fear of sanctions, thereby reducing organizational learning and weakening the operational safety culture.

When properly structured, however, oversight acts as a natural counterbalance to complacency and the resulting normalization of deviance. In highly routine environments marked by automatism, the active presence of management is crucial for detecting signs of professional relaxation and implementing measures aimed at maintaining vigilance at elevated levels.

On the other hand, deficiencies in managerial oversight may reinforce complacency and the normalization of deviance, whether by minimizing recurrent errors or by failing to enforce an adequate accountability system. Environments in which deviations are ignored or treated with indifference ultimately create the perception that risks are acceptable. This dynamic increases the likelihood of an accumulation of latent vulnerabilities that only become evident in the presence of a critical failure.

1.17.4. Company Background

1.17.4.1. History

Passaredo Transportes Aéreos began operations in 1995, headquartered in *Ribeirão Preto*, State of *São Paulo*. Its initial fleet consisted of Embraer EMB-120 *Brasília* aircraft, operating short-haul routes between inland cities and major state capitals.

In 2002, the company suspended its operations due to financial difficulties, remaining inactive for two years. Operations resumed in 2004 under the name *Passaredo Linhas Aéreas*, following an internal restructuring that included fleet adjustments and route realignment.

In October 2012, the company filed for judicial reorganization. The process sought to restructure its obligations with creditors while maintaining active operations. In 2014, the reorganization plan was approved, allowing *Passaredo* to continue operating with significant adjustments to its organizational structure. The judicial proceedings extended until 2017, when they were officially concluded.

Beginning in 2014, the company entered into commercial agreements with other operators, approved by ANAC and by CADE (*Conselho Administrativo de Defesa Econômica*), allowing passengers to purchase integrated tickets and access regional destinations.

In 2019, *Passaredo* announced a corporate and operational integration agreement with *MAP Linhas Aéreas*, headquartered in *Manaus*, State of *Amazonas*. During the same period, the company underwent a brand renewal process and adopted the trade name *VoePass Linhas Aéreas*.

According to reports, in the months preceding the accident, the company anticipated short-term growth and had announced plans to expand its operations. Discussions involved additional hiring and the arrival of more aircraft to increase the fleet.

This trajectory was interrupted by the accident involving PS-VPB on 09AUG2024. The repercussions resulted in the suspension of routes, as well as the cancellation of interline agreements and partnerships. Finally, in 2025, the National Civil Aviation Agency decided to permanently revoke the company's Air Operator Certificate (COA).

1.17.4.2. Company Identification and Structure.

The company was a national scheduled air carrier operating under the requirements of RBAC 121 — Operating Requirements: Domestic, Flag, and Supplemental Operations — and RBAC 145 — Certified Maintenance Organizations, headquartered in *Ribeirão Preto*, State of *São Paulo*. At the time of the occurrence, it operated a total of 15 ATR-72 and ATR-42 aircraft.

The operator's organizational structure consisted, at its highest level, of Senior Management and the Board of Directors, which were responsible for defining strategic guidelines and overseeing the company as a whole. The Presidency or General Management exercised executive leadership, with responsibilities encompassing institutional and regulatory relations, as well as coordination of the operational areas.

The Operations Directorate was responsible for route network planning, crew allocation, and coordination between the Operational Control Center (CCO) and the other operational sectors.

According to the company's General Operations Manual (MGO), the CCO was responsible for the coordination and operational control of all flights, as well as for the preparation of aircraft flight plans, taking into account the forecast meteorological and operational conditions, and for transmitting such information to the flight crew.

As for the Flight Dispatcher (DOV), this professional was responsible for providing the PIC with all available meteorological information relevant to the flight.

The responsibilities of the CCO and of the DOV will be presented in detail in item 1.19.2, Requirements Related to Flight Operations, Training, Dispatch, and Flight Release.

The company did not outsource its flight operational functions.

The duties assigned to the flight crew were established in the company's General Operations Manual (MGO), in accordance with National Civil Aviation Agency regulations.

The MGO established that the Pilot in Command was responsible for flight planning and flight operations. Among the assigned duties, the PIC was required to verify the airworthiness status of the aircraft and refuse it for flight if it was not in an airworthy condition, as well as ensure that any failure or malfunction affecting its airworthiness was recorded in the TLB.

The Second in Command (SIC), in turn, was qualified to assume aircraft operation and the responsibilities of the PIC in the event of incapacitation. The assigned duties included alerting the PIC to any discrepancies observed in the aircraft and performing the tasks delegated to the SIC.

The flight attendants, in turn, were responsible for maintaining cabin safety and passenger comfort.

The Maintenance Directorate was responsible for overseeing aircraft maintenance, ensuring regulatory compliance, and planning scheduled and corrective inspections.

In addition to these areas, there was the Operational Safety Directorate, which was responsible for implementing and monitoring the SMS, conducting internal audits, and overseeing the investigation of incidents and operational safety occurrences.

In the commercial field, the Sales and Marketing Directorate was responsible for the interface with strategic partners, on whose distribution network the operator depended for most of its revenue.

The Quality Control and Internal Audit sector was responsible for ensuring the compliance of operational and maintenance processes with regulatory requirements.

Complementing the organizational structure, there were also administrative and support areas, such as Human Resources, Finance, and Information Technology, whose roles were to ensure the company's systemic functioning by providing direct support to the other areas.

1.17.4.3. Organizational Climate and Culture

Regarding the company's organizational climate, the interviewees presented different perceptions. In general, employees expressed satisfaction with the fact that the company was relatively small, which favored closer interpersonal relationships among personnel and minimized hierarchical barriers.

With regard to administrative processes, several positive remarks about the company were reported. From the perspective of the flight crews, satisfaction was identified regarding the workload, which, according to reports, was lower than that of other companies within the sector and allowed for longer periods with their families.

Reports from individuals who felt grateful to the company for the growth opportunities provided and for the support offered in advancing their careers were frequent. On the other hand, there were also sources of dissatisfaction, namely: delays in the payment of benefits such as meal vouchers; delinquency regarding payments to the Severance Indemnity Fund (FGTS); and the instability of the secondary bases, which, due to the frequent deactivation and reactivation of their operations, required constant adaptation on the part of employees, generating insecurity among them.

Informality predominated in the interactions among company personnel, permeating different hierarchical levels and sectors. According to reports, while this proximity and informality contributed to a friendly organizational climate, they also created room for improvisation and permissiveness, potentially impacting the flexibilization of rules and the degradation of the flight safety culture.

With regard to organizational culture, it was reported that, as a consequence of fluctuations in the company's economic condition, it became necessary to adopt resource-saving practices, leading to the acceptance of working conditions that did not necessarily violate regulations, but consistently operated close to the prescribed limits.

1.17.4.4. Recruitment and Selection

The company's recruitment and selection process was conducted by three psychology professionals, including one intern. This sector operated based on demands submitted by managers from the other areas, who identified the vacancies to be filled and specified the desired profile for the prospective employee.

Due to the shortage of aircraft maintenance technicians in the labor market and the high turnover rate among these professionals, the highest qualification levels were often not required during the selection process. This scenario led to the hiring of mechanics with limited experience and knowledge, and difficulties were at times observed in the performance of their duties, particularly with regard to the use of maintenance manuals, since they were written in English.

1.17.4.5. *Training and Qualification*

The company's training programs were divided between flight crew members and maintenance personnel. Flight crew training was conducted periodically, in accordance with regulatory requirements, and included theoretical modules, simulator training, and practical evaluations.

As for the maintenance sector, training was predominantly outsourced and offered through distance learning (E-learning) programs. Although this arrangement was not inconsistent with the regulations in force at the time of the occurrence, reports indicated that it was insufficient to develop the motor skills and technical proficiency required for the safe execution of specialized tasks.

1.17.4.6. *Maintenance Bases*

Document code L-MNT-MNT-03-14-01, entitled List of Maintenance Bases, established the conditions applicable to the certified maintenance organization for providing maintenance services to the operator's fleet aircraft.

It was a controlled document prepared by the operator's Maintenance Engineering department and submitted for approval to ANAC. On the date of the accident, the document was in force under revision V.11, dated 02JUL2024, with validity until 02JUL2026. The document established the authorized maintenance services, the maintenance complexity classification, the list of the operator's maintenance bases, and the authorized maintenance service providers.

With regard to the authorized maintenance services, the document presented a total of eleven different types of interventions, coded from "A" to "L", with the exception of the letter "I" (Figure 121).

Código	Estrutura Local	Mecânico a Bordo	Nível de Manutenção
A	X	-	Manutenção programada
B	X	-	Manutenção não programada de baixa complexidade
C	X	-	Inspeção 48 Horas
D	X	-	Inspeção de Rotina
E	X	-	Inspeções até, e inclusive, Check 1A
F	X	-	Daily Check
G	X	-	Line Check
H	X	-	Weekly Check
I	X	-	DELETADA
J	X	-	Check de 1500FH, exceto inspeção boroscópica do motor
K	X	-	Inspeções até 4000FH, 4000FC e 1YE
L	-	X	Mecânico a bordo

Figure 121. Authorized maintenance services. Source: L-MNT-MNT-03-14-01, List of Maintenance Bases, V.11, dated 02JUL2024.

With regard to maintenance complexity, the services were classified into levels 1 through 4, in ascending order (Figure 122).

Código	Nível de Manutenção
1	Atendimento com mecânico a bordo e flight kit.
2	Preflight, Transit, Daily, Weekly, servicing e tarefas de lubrificação ou tarefas programadas simples de intervalo inferior a uma semana.
3	Tarefas programadas com intervalo superior a semanal (calendáricas, FH e FC) simples com, por exemplo, testes operacionais, tarefas com a utilização de ferramentas simples com ou sem controle de calibração.
4	Tarefas calendáricas, FH e FC mais complexas com, por exemplo, inspeção visual detalhada, testes funcionais, tarefas com utilização de ferramentas especiais que exijam controle de calibração.

Figure 122. Maintenance complexity classification.
Source: L-MNT-MNT-03-14-01, List of Maintenance Bases, V.11, dated 02JUL2024.

The list of the operator's maintenance bases, in turn, identified the types of authorized services and the respective assigned complexity levels (Figure 123).

According to the document, only the maintenance bases located at SBRP and at SBSV (*Deputado Luís Eduardo Magalhães* Airport, *Salvador*, State of *Bahia*) held maintenance complexity level 4, being qualified to perform more complex tasks, such as detailed visual inspections and tasks involving the use of special tools requiring calibration control.

According to the document, no provision was identified for outsourced companies participating in maintenance activities.

Aeródromo	Tipo OACI	Operação Regular	Manutenção Própria	Manutenção Terceirizada	Classificação de Complexidade (ANAC)
SBAC (ARX)	AT72	X	L		1
SBBR (BSB)	AT72	X	E		3
SBCX (CXJ)	AT72	X	L		1
SBDN (PPB)	AT72	X	E, F, G, H		3
SBFN (FEN)	AT72	X	L		1
SBFZ (FOR)	AT72	X	L		1
SBGR (GRU)	AT72	X	F, G, H		2
SBIP (IPN)	AT72	X	E, F, G, H		3
SBJV (JOI)	AT72	X	B		2
SBKG (CPV)	AT72	X	L		1
SBMS (MVF)	AT72	X	L		1
SBNM (GEL)	AT72	X	L		1
SBPA (POA)	AT72	X	F, G, H		2
SBPK (PET)	AT72	X	L		1
SBRF (REC)	AT72	X	E, F, G, H		3
SBRJ (SDU)	AT72	X	B		2
SBRP (RAO)	AT72	X	E, F, G, H, K		4
SBSG (NAT)	AT72	X	E, F, G		3
SBSP (CGH)	AT72	X	F, G, H		2
SBSV (SSA)	AT72	X	E, F, G, H, K		4
SBSM (RIA)	AT72	X	L		1
SBUG (URG)	AT72	X	L		1
SBZM (IZA)	AT72	X	E, F, G, H		3
SNBR (BRA)	AT72	X	L		1
SNGI (GNM)	AT72	X	L		1
SNTF (TXF)	AT72	X	L		1
SWLC (RVD)	AT72	X	L		1

Figure 123- List of the operator's maintenance bases.
Source: L-MNT-MNT-003-14-01, List of Maintenance Bases, V.11, dated 02JUL2024

With regard to the corrective maintenance actions performed on the Airframe De-Icing system boots, the records demonstrated that repair and replacement activities were conducted exclusively at the SBRP maintenance base.

1.17.4.7. Maintenance Organization and Working Conditions

The SIPAER Investigation Commission identified limitations within the company's maintenance sector. According to reports, there were instances in which working hours exceeded the prescribed limits, particularly during periods when the fleet was operating under high demand, at times exposing personnel to fatigue.

Human fatigue is a condition resulting from stressful stimuli of various natures that, due to their accumulation or intensity, lead to a decline in work quality. As such, it may contribute to errors, since it reduces the professional's state of alertness and concentration on the task being performed.

Particularly during nighttime periods, there was pressure to expedite aircraft release, which often conflicted with the lack of time available for troubleshooting, performing procedures, and resolving discrepancies reported in the TLB.

According to reports, the shortage of qualified technical personnel led to the delegation of critical activities to assistant mechanics, frequently without proper supervision. On several occasions, shift changes took place without a formal briefing.

These practices led to the performance of aircraft part and component removal or installation tasks without the completion of the documentation required at the time the service was carried out, resulting in failures in item traceability and reflecting an organizational characteristic of accepting such risk as operationally normal.

It was also reported that communication between the secondary maintenance bases and the administrative sectors, such as Human Resources, Information Technology, and Finance, was limited, with complaints regarding the lack of responses to basic demands and deficiencies in organizational support.

At some secondary bases, the SIPAER Investigation Commission identified situations such as limited resources for the maintenance area, absence of institutional uniforms for employees, and even restrictions on access to the airport apron due to the lack of airport credentials, which had been denied as a result of outstanding debts with the terminal administration.

1.17.4.8. TLB Records and Aircraft Dispatch Based on the MEL

According to data collected during interviews, the number of aircraft in the fleet, combined with the company's operational demand, contributed to situations in which no spare aircraft were available for replacement in the event of an aircraft becoming unavailable, thereby increasing pressure on the maintenance and operational dispatch sectors to ensure service continuity.

The secondary bases distributed throughout Brazil operated with a low degree of autonomy, with the SBRP base, through the Maintenance Control Center (MCC), directing the maintenance tasks to be performed by the mechanics assigned to the secondary bases.

In addition to the practices involving the performance of operational tests on systems for the purpose of renewing the MEL time limit for fault correction, identified through the surveillance actions carried out by the ANAC (described in item 1.17.6, ANAC Surveillance Actions), other irregular practices were highlighted by employees interviewed during the investigation process.

Different interviewees reported that, in some cases, mechanics signed off services performed by assistant mechanics even without having directly supervised the execution of those services. There were also reports of recurrent TLB entries indicating fault rectification without the corresponding corrective action having been effectively carried out, thereby allowing the aircraft to be released for operation.

Additionally, the interviewed mechanics reported the existence of a practice whereby an inoperative aircraft component was replaced with another component known to be faulty. After the replacement, the aircraft was released, and during the subsequent flight the same discrepancy would reappear. This conduct allowed the successive renewal of the MEL item without the discrepancy having been effectively corrected.

Several flight crew members reported that technical anomalies were handled verbally with maintenance personnel without being officially recorded, with the purpose of avoiding aircraft unavailability, and that, even after repeated reports, the problems persisted.

1.17.5. ANAC's Specific Operational Safety Program

The Brazilian Civil Aviation Operational Safety Program (PSO-BR) was the document that consolidated the joint proposal of the two Brazilian authorities related to the operational safety management of Brazilian civil aviation, namely the National Civil Aviation Agency and the Brazilian Air Force Command, in pursuit of compliance with the provisions established in the amendments to Annexes 1, 6, 11, and 14 to the Convention on International Civil Aviation.

The PSO-BR was signed by the two Brazilian authorities on 08JAN2009. Based on the PSO-BR, ANAC and the Brazilian Air Force Command began to have specific guidance for the development of their respective Specific Operational Safety Programs (PSOE). The PSOE-ANAC was approved on 11MAY2009 and currently constitutes an integral part of the PSO-BR.

With regard to operational safety oversight, the PSOE-ANAC established the following:

> Article 27. The operational safety oversight exercised by ANAC shall be capable of identifying the degradation of the technical and financial conditions, as applicable, required to ensure operational safety in the activities conducted by regulated entities.

Regarding operational safety risk management, the PSOE-ANAC established the following:

> Article 56. Risk management shall be adopted by ANAC as a tool to support the strategic decision-making processes necessary for the mitigation and control of risks directed toward the operational environment regulated and overseen by the Agency, as well as toward its own capacity to act as a regulatory authority.
>
> § 1. With regard to the operational environment regulated and overseen by ANAC, the following risks shall be evaluated and treated as priorities:
>
> I. evidence of degradation of the conditions required for the maintenance of certification or authorization of the activities of civil aviation service providers (PSAC) and other regulated entities;
>
> II. recurrence of nonconformities and violations in the activities of PSACs and other regulated entities; and
>
> III. identification of operational behaviors or practices whose results negatively impact operational safety.
>
> § 2. With regard to ANAC's own operational capability, the following risks shall be evaluated and treated as priorities:
>
> I. failures in the capability to detect nonconformities and violations related to aircraft operations, aircraft maintenance, as well as the qualification of operational personnel;
>
> II. deficiencies in the performance of individuals or organizations accredited by ANAC;
>
> III. ineffective or incorrect application of regulations; and
>
> IV. failure in complying with legal and regulatory responsibilities.

Article 57. The operational safety risk management process adopted by ANAC is composed of the following phases:

I. hazard identification;

II. analysis of the causes and consequences of the hazards;

III. assessment of the risks associated with the consequences of the hazards;

IV. proposal of actions for risk mitigation, elimination, and control; and

V. evaluation of the effectiveness of the implemented actions.

Article 60. For the operational implementation of the operational safety risk management process, ANAC shall establish means capable of recording, processing, and monitoring data and information related to hazards and risks, as well as generating management reports that enable the evaluation of the effectiveness of said process.

Sole paragraph. The following shall be recorded, processed, and monitored:

I. hazards and latent conditions identified within the operational environment, together with the respective corrective and preventive measures adopted by ANAC for risk mitigation and control;

II. operational safety reports classified as mandatory, voluntary, anonymous, or identified; and

III. data or information originating from other sources deemed relevant to the risk management process.

1.17.6. ANAC Surveillance Actions

The National Civil Aviation Agency (ANAC), as the authority responsible for the regulation and oversight of civil aviation, carried out continuous surveillance actions aimed at the systematic monitoring of the performance of operators, aircraft, processes, services, and certified personnel in a planned and recurring manner.

An annual plan was prepared to define the quantity and types of continuous surveillance actions to which each operator would be subjected during the following year. Whenever necessary, additional activities outside the annual plan could be established in order to monitor areas considered to be priorities.

A simplified overview of the annual continuous surveillance planning process, taking into account the operator’s profile, may be seen in Figure 124.

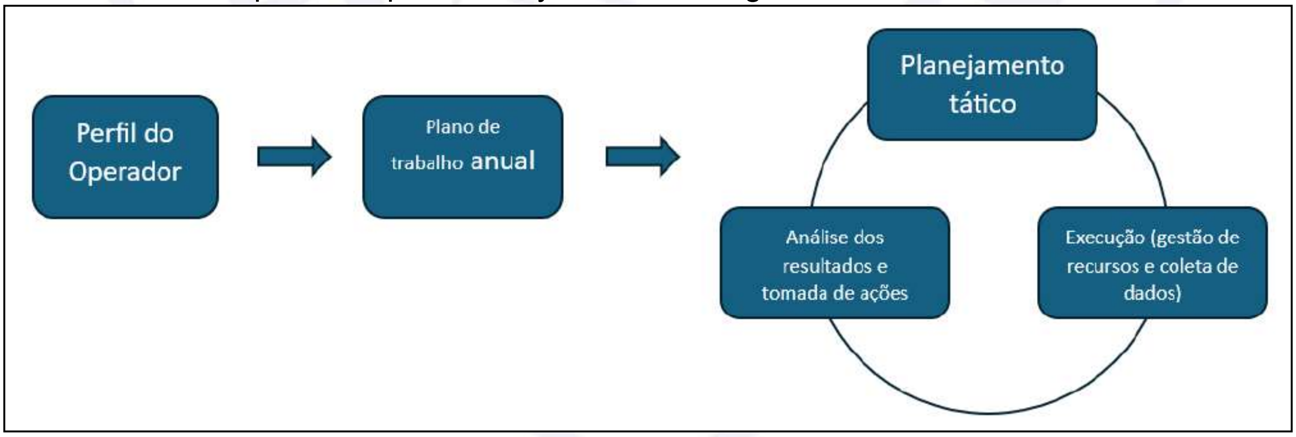


Figure 124 — Definition process for the quantity and types of surveillance activities.
Source: National Civil Aviation Agency (ANAC).

Following the execution of the surveillance actions, based on the collected data and evidence, ANAC could adopt the following administrative instruments, with progressively increasing levels of severity and impact:

- Preventive measures: correction of nonconformities and identification and treatment of the root causes identified during surveillance activities;

- Specific precautionary measures: suspension of aircraft from the fleet and/or of COA privileges until the nonconformity had been corrected;
- Personnel removal: removal of technical personnel and managers from the administrative staff;
- Operational restrictions: imposition of reductions in the operational network and the requirement to make reserve aircraft available; and
- COA suspension: precautionary suspension of all operations.

The SIPAER Investigation Commission requested data regarding the number of surveillance actions carried out on RBAC 121 airline operators in operation in Brazil. From the data provided, it was verified that ANAC used a metric based on the ratio between the number of queries identified during surveillance actions and every 1,000 takeoffs performed by each operator. The results may be seen in Figure 125.

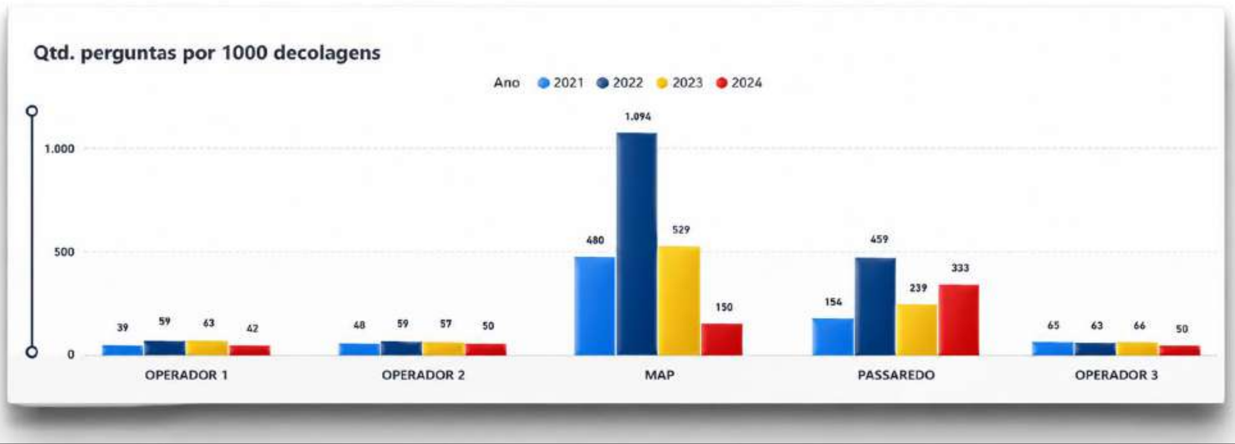


Figure 125 – Number of queries per 1,000 takeoffs among ANAC's principal regulated operators.
Source: ANAC.

As a result, a total of 768 queries were identified in 2023 and 483 queries in 2024, considering the *VoePass*, *Passaredo*, and *MAP* group. It is worth emphasizing that, at the time, the operator represented approximately 0.6% of the Brazilian scheduled aviation network volume.

Records of surveillance actions carried out prior to the accident were obtained from ANAC within the scope of the following regulatory activities:

- Ramp inspections: operational inspections conducted before departure or after engine shutdown, focusing on compliance with applicable technical requirements and procedures;
- Reduced-scope inspections: actions aimed at the surveillance of secondary operational or maintenance bases, focusing on facilities, personnel, resources, and regulatory compliance;
- Follow-up flight surveillance inspections: on-site evaluations of compliance with operational specifications and the maintenance of continuing airworthiness during flight operations; and
- Follow-up audits at maintenance bases: assessments of compliance with the processes established in the General Maintenance Manual, including evaluations of personnel, facilities, documentation, tools, maintenance

programs, and control systems, such as the Continuous Analysis and Surveillance System (SASC).

Table 3 presents some of the surveillance actions carried out between January 2022 and August 2024.

Regulated entity	Activity description	Execution
PASSAREDO 121	Ramp inspection	Monthly from JAN2022 to AUG2024
MAP 121	Ramp inspection	Monthly from JAN2022 to APR2024
PASSAREDO 121	Audit at Main Base	Two in 2022 and two in 2023
MAP 121	Audit at Main Base	One in 2022 and two in 2023
PASSAREDO 121	Follow-up Flight Surveillance Inspection	Two in 2022 and two in 2024
MAP 121	Follow-up Flight Surveillance Inspection	Two in 2022, one in 2023, and one in 2024
PASSAREDO 121	Audit at Secondary Base	Five in 2024
PASSAREDO 121	Reduced-Scope Inspection	One in 2024
MAP 121	Reduced-Scope Inspection	One in 2024
PASSAREDO 145	Continued Surveillance – RBAC 145 Audit	One in 2023

Table 3 – Surveillance actions carried out by ANAC between January 2022 and August 2024.

The actions conducted by ANAC between 2022 and 2024, particularly ramp inspections and follow-up flight surveillance inspections, revealed several technical, procedural, and systemic nonconformities, ranging from line maintenance to document and operational management. The occurrences were recorded at several maintenance bases, both primary and secondary, and involved different aircraft from the fleet. Some findings may be highlighted:

- Maintenance Control Weaknesses

  ANAC reports indicated that mechanics were performing activities without consulting technical manuals. At secondary bases, it was observed that, on certain occasions, maintenance personnel carried out maintenance tasks based on informal communications with more experienced mechanics from the SBRP base. Surveillance actions established that the secondary bases did not have direct access to the technical documentation required for the proper execution of maintenance activities.

  There were also reports of maintenance services being performed without the supervision of an inspector mechanic, both at the SBRP base and at secondary bases. Surveillance actions additionally identified cases involving the lack of basic tooling required for certain maintenance interventions at some secondary bases, resulting in compromised quality of the procedures performed and fostering improvised practices.

- Irregular Technical Release of Aircraft

  In the specific case of failures related to the Airframe De-Icing system, aircraft dispatch was authorized for up to three days under MEL Category B, provided that no flight into icing conditions was forecast. However, it should be emphasized that, once the three-day period had elapsed, corrective maintenance action was mandatorily required in order to restore the airworthiness condition of the system.

ANAC identified records indicating that the expiration of the time limit established by the MEL occurred while aircraft were positioned at secondary bases. In some of these cases, records indicated that operational tests had been performed on the Airframe De-Icing system without the execution of corrective maintenance actions. Such tests declared the system functional and, consequently, the aircraft eligible for dispatch. On certain occasions, it was verified that the failure reappeared on flights subsequent to the performance of the operational tests.

This practice resulted in the reopening of the MEL-conditioned dispatch, repeatedly renewing the three-day period for corrective action and extending the aircraft's operational period with the unresolved discrepancy.

- Pressurization Problems

ANAC reports also identified that, on some aircraft within the fleet, the pressurization seals of the passenger door exhibited damage exceeding the limits established in the maintenance manual. Seven notifications of irregular condition were issued during the period between 2022 and 2024.

- Damage to Airframe De-Icing System Boots

Recurring failures involving the Airframe De-Icing systems of different aircraft within the fleet were identified by ANAC. Repetitive records were found regarding the identification of bubbles, tears, and irregular repairs on wing and engine air intake boots installed on aircraft in operation, frequently without records describing the failure conditions or dispatch restrictions through the MEL.

- The Agency verified that many existing boot damages were not being identified during the visual inspections prescribed in the Daily/Weekly Checks, nor through the Scheduled Maintenance Program (PMAC), given the existence of the damage and the absence of corresponding entries in the applicable TLB.

The operator did not maintain adequate control of the service life of most of the boots installed on the aircraft within its fleet. There were also deficiencies in the traceability of installations and repairs performed.

Repairs performed on the boots that diverged from the aircraft maintenance manual were also identified, including overlapping repairs and/or repairs exceeding the maximum permitted size and quantity limits.

The absence of consistent records and the lack of traceability compromised the technical control necessary to ensure the proper condition of these components.

Between 2022 and 2024, ANAC issued ten notifications of irregular condition related to the Airframe De-Icing system. In response, throughout the first half of 2024, the company carried out the progressive replacement of all Airframe De-Icing system boots throughout its fleet.

- Tires Operated Beyond Wear Limits

ANAC verified that the operator considered the absence of tread grooves on a tire to constitute normal wear, replacing the tire only when the cord layer became visible. However, this practice was contrary to the manufacturer's manual. This condition was recorded by the agency on four occasions between 2022 and 2024.

According to ANAC, the operator employed practices considered unacceptable with regard to operational safety, and its Continuous Analysis and Surveillance System (SASC) was not functioning adequately. Surveillance reports contained remarks referring to deficiencies in maintenance oversight and even to the possible absence of such oversight, representing an imminent risk to operational safety.

In addition to the notifications of irregular condition, ANAC adopted administrative enforcement measures associated with each identified situation.

Among the enforcement measures, several precautionary aircraft suspensions were identified between 2022 and 2024. The peak number of suspensions occurred in 2023, when aircraft were prevented from being operated on 24 occasions.

In 2024, a reduction in aircraft groundings was observed, with this condition being identified on five occasions through the month of August. Figure 126 presents the precautionary aircraft suspensions imposed by the Agency between 2022 and 2024. It is important to highlight that no groundings were observed involving the PS-VPB aircraft.

Figure 126. Number of precautionary suspensions between 2022 and 2024.
Source: ANAC.

As a rule, the nonconformities identified during surveillance actions were communicated to the operator through preventive and enforcement administrative measures. The operator, in turn, presented its considerations and implemented the actions determined by ANAC.

The progress of these processes depended on the complexity of the nonconformities identified during the surveillance actions. It was possible to verify that there were processes initiated from an RBAC 121 technical audit that began on 27OCT2023 and remained under processing until 19AUG2024. The nonconformities identified during this audit were considered closed, with the exception of one, for which the proposed mitigating action was accepted, subject to the condition that it would be reassessed during the next audit.

Within this same timeframe, it was also possible to identify processes initiated from an inspection for verification of RBAC 121 requirements conducted on 13 and 14MAR2024, which remained under processing until 19DEC2024, when the recorded nonconformities were considered closed and resolved.

There were also processes initiated from an Inspection for Verification of RBAC 121 Requirements conducted on 17 and 18JUN2024, which remained under processing until 19AUG2024, when one of the recorded nonconformities was considered closed, while the remaining findings remained open. The nonconformities that remained open were related to maintenance services performed on the aircraft of registration marks PR-PDS, PR-PDP, and PR-PDT.

1.17.7. Safety Management System

1.17.7.1. Operator's SMS

The company's SMS was structured through the Safety Management Manual (SMM) and had been accepted by ANAC. The MGSO was based on four components: safety policy and objectives; risk management; safety assurance; and safety promotion.

With regard to risk management, the company's SMM (MGSO) established that formal, documented, and traceable processes should be maintained for the continuous monitoring of safety, including procedures aimed at the identification and systematic recording of hazards associated with scheduled passenger air transport.

It was the company's responsibility to ensure that the risks associated with hazards identified in ongoing operations remained under control and complied with the previously established safety targets. This process, referred to as Safety Risk Management (SRM/GRSO), involved the following phases:

- hazard identification;
- risk assessment;
- risk classification;
- definition and implementation of mitigation actions; and
- risk monitoring and control.

Risk management should be applied whenever the presence of a hazard was identified, regardless of the means by which it was detected.

With regard to hazard identification, the company was required to establish and maintain clear, consistent, and effective procedures and processes to collect, record, analyze, and provide feedback on hazards observed during operations. Such identification would employ both reactive methods, through the analysis of events that had already occurred, and proactive methods, through the monitoring and management of risks.

The sources for hazard identification, whether internal or external, were to be handled in accordance with standardized procedures established in a specific internal regulation. Among the main sources, mandatory and voluntary reports stood out.

The company had clear rules regarding the mandatory reporting of operational occurrences, technical anomalies, and systemic failures that could impact flight safety.

The company also had provisions for the voluntary reporting of situations that could compromise operational safety, ensuring that personnel would not be subject to disciplinary action, except in cases involving illegal acts or intentional noncompliance with regulations.

The company had dedicated software and a specific department to analyze voluntary reports in order to assess their impacts on operational safety and subsequently forward them to the sector to which they were related.

As part of its commitment to the continuous improvement of the SMS, the company's MGSO established formal procedures aimed at identifying deviations and hazards related to aviation activities, assessing the impact of such deviations on operations, and correcting situations that resulted in performance levels below the established standards.

Among the actions established within this process, the following stood out:

- systematic monitoring of occurrences, errors, infractions, and/or violations of regulations, based on reports submitted by crew members; and

- performance of trend analyses based on indicators extracted from the Flight Data Monitoring and Analysis Program (PAADV), aimed at anticipating risks and implementing preventive measures.

Based on the survey conducted by the Investigation Commission, no analyses related to the collected data were presented to demonstrate that the PAADV was being effectively applied in a continuous and comprehensive manner.

It was only verified that the FDM data extracted from the aircraft were stored on a computer, with no evidence that the analyses were being conducted in a systematic fashion.

1.17.7.2. Oversight of the Operator's SMS by ANAC

In October 2009, ANAC approved RBAC 119 — Certification: Public Air Transport Operators. The regulation introduced new requirements for the certification of scheduled and non-scheduled operators, establishing the need to incorporate an SMS into the certification process, as well as defining the requirements and phases for its implementation.

RBAC 119 established that holders and/or applicants of a certificate regulated under RBAC 121 were required to submit an MGSO by 30APR2011.

According to Supplementary Instruction 119-002 — Guide for the Development of an SMS for Airline Companies Certified under RBAC 119, Revision D, in force at the time of the accident, operators were required to have their MGSOs accepted by ANAC, implemented, and fully operational by December 2014.

ANAC approved the Guidelines for SMS Assessment, whose purpose was to provide detailed guidance to personnel in order to harmonize SMS evaluations during the certification and continued surveillance activities of civil aviation service providers (PSAC).

During SMS audits, an assessment tool composed of 23 topics distributed among the four components was used, seeking to address specific subjects within each component through a maturity scale known as PAOE, which considered the initials of the terms describing the levels: "Present," "Adequate," "Operational," and "Effective."

The levels were progressive, such that "Present" represented the lowest level and "Effective" the highest. If a given item was found to be "Adequate," it was implicitly considered "Present." If it was found to be "Operational," it was implicitly considered "Present" and "Adequate," and so forth.

The documentation contained the following definitions and guidance for each of the aforementioned levels:

> Present: There is evidence that the process is documented in the organization's Safety Management Manual and/or in the SMS documentation.
>
> Adequate: The process is adequate based on the size, nature, complexity of the organization, and the inherent risk of the activity. The assessment of adequacy is organization-specific.
>
> Operational: There is evidence that the process is in use and is producing results for the organization.
>
> Effective: There is evidence that the process is achieving the desired outcome and has a positive impact on safety.

The maturity scale was applied in accordance with the guidelines, and a checklist indicated which level of the scale needed to be demonstrated for the item to be considered compliant with the requirements.

The SIPAER Investigation Commission reviewed the records of continued surveillance conducted by ANAC on the operator that could clarify the Agency's actions and the effectiveness of its oversight mechanisms.

Between the days 9 and 11APR2024, ANAC conducted an on-site audit at the main base in SBRP, during which the operations sector and the air operator's risk management were assessed using the evaluation tool established in the Agency's guidelines.

In that audit, two items within the component "Safety Policy and Objectives" were assessed at the "Present" maturity level, and one item within the component "Risk Management" was assessed at the "Adequate" maturity level, both, therefore, below the "Operational" level.

In the nonconformity notification form forwarded by ANAC to the operator, the following aspects were listed:

> - the company did not demonstrate that the hazard identification process is adequate[7]; and
>
> - the company did not demonstrate that the means used to evaluate its SMS processes in order to continuously improve the effectiveness of the SMS are adequate[7].

At the time of the occurrence, ANAC used the SMS Index as a reference for monitoring the operational safety of operators regulated under RBAC 121. This index essentially consisted of a weighted sum of all topics included in the SMS assessment tool and ranged from 0 (zero), representing the lowest maturity level, to 1 (one), representing the highest.

The SMS Index achieved by the operator during the audit conducted in April 2024 was 0.71, whereas during the same period the average index for operators regulated under RBAC 121 was 0.78.

1.17.8. Flight Data Monitoring FDM

The Supplementary Instruction (IS) No. 119-008, Revision A, dated 22FEB2022, in force at the time of the accident and issued by ANAC, addressed the topic "Procedure for the Implementation of a Flight Data Monitoring and Analysis Program" (PAADV). The PAADV was the formal designation of a structured flight data analysis program used as a systematic tool for the proactive identification of hazards in operations.

Terms such as Flight Data Monitoring (FDM), Flight Data Analysis (FDA), and Flight Operations Quality Assurance (FOQA) refer to data analysis activities carried out within a PAADV.

The FDM was one of the primary tools supporting data-driven safety management, enabling the monitoring of events that did not necessarily result in incidents, but that indicated operational, behavioral, technical, or systemic trends requiring managerial attention.

In this Report, the term FDM was adopted specifically to designate the flight data analyses conducted by the SIPAER Investigation Commission.

The PAADV, in turn, as a comprehensive program, encompassed additional aspects, including basic principles, functions and responsibilities within the organization, workflow, required equipment and infrastructure, program management structure, data retention and protection policies, as well as usage restrictions.

IS 119-008A established, in item 5.3.2, Purpose of the PAADV, the following:

> 5.3.2.1 The primary purpose of a PAADV is to ensure that operations achieve an adequate level of operational safety. The PAADV shall be integrated into the Safety Management System (SMS), with the following objectives.
>
> a) identify areas of operational risk and quantify safety margins;

[7] the appropriate term used by the auditor in the descriptions of the nonconformities does not refer to the 'Adequate' maturity level of the PAOE scale.

> b) identify and quantify risks associated with deviations from standards defined by the operator/manufacturer or with atypical/unsafe events during operations;
>
> c) assess the risk of specific occurrences and identify which risks may become unacceptable if certain trends persist;
>
> d) implement procedures to mitigate unacceptable risks, whether arising from current hazards or those anticipated through trend analysis;
>
> e) analyze the effectiveness of corrective actions through continuous monitoring of operations.
>
> 5.3.2.2 In addition to its use as an operational safety tool, the PAADV may be used by the air operator for other purposes, such as:
>
> a) analysis of events and operational trends aimed at the continuous improvement of performance, procedures, and training;
>
> b) statistical collection and analysis of events;
>
> c) specific flight analysis upon request by the involved flight crew members, for educational purposes;
>
> d) provision of data for cost-benefit analyses;
>
> e) support for preventive engineering and maintenance actions
>
> f) assessment of the condition of engines, systems, and other aircraft components;
>
> g) support for corrective maintenance actions (troubleshooting);
>
> h) other purposes, provided that the conditions and restrictions on data use are respected.

The Supplementary Instruction (IS) 119-008A was applicable to Air Operator Certificate (COA) holders operating under RBAC 121 or 135 and using airplanes with a maximum takeoff weight (MTOW) greater than 27,000 kg. The IS also provided that its guidelines could be adopted by operators that voluntarily wished to implement a PAADV within their fleet, even if the aircraft had an MTOW equal to or less than 27,000 kg.

The AFM for the ATR-72-212A-500 model, S/N 908, stipulated, in its Limitations section, an MTOW of 22,800 kg. Therefore, the implementation of a PAADV for the aircraft PS-VPB was optional for the operator.

The operator maintained a manual titled Flight Operations Quality Assurance (FOQA), whose version in effect on the date of the accident was V.08, which was in accordance with the provisions of IS 119-008A and had been accepted by ANAC, encompassing the aspects related to that operator's PAADV. Accordingly, the operator committed to maintaining the PAADV in operation.

The aforementioned manual provided important definitions, among which the following stood out:

> <u>Exceedance or event</u>: a situation in which the operational safety limits established by the aircraft manufacturer and/or operator are exceeded and whose risk assessment classifies it as intolerable;
>
> <u>Trigger</u>: a programmed logic created for the automatic detection of a specific event within a flight analysis software application, taking into consideration pre-established rules and limits defined in the programming logic according to its intended purpose, and which may be classified according to severity;
>
> <u>Flight parameters</u>: indicators that reflect the operation and activation of aircraft equipment, components, and systems.

Triggers and Events were established within the PAADV based on the aircraft manuals and the operator's SOPs.

The ATR-72-212A family aircraft recorded, on average, approximately 180 flight parameters. A typical flight data analysis program for ATR aircraft could use approximately

100 of these parameters, with triggers programmed to detect around 130 distinct types of operational events.

Still within the scope of the PAADV, the IS established the following definition for safety culture, in accordance with the provisions set forth in Annex 19 to the ICAO's Convention on International Civil Aviation:

> 5.4.4 Safety Culture
>
> 5.4.4.1 A safety culture is a natural consequence of having humans within the aviation system. It may be described as "how people behave in relation to safety and risk when no one is watching". It is also an expression of how safety is perceived, valued, and prioritized by an organization's senior management and employees, and is reflected in the extent to which individuals and groups:
>
> a) are aware of the known risks and hazards faced by the organization;
>
> b) consistently behave in ways that preserve and enhance safety;
>
> c) have access to the resources necessary to carry out/implement safe operations;
>
> d) are willing and able to adapt in response to safety issues;
>
> e) are willing to report safety-related issues; and
>
> f) consistently assess safety-related behaviors throughout the organization.
>
> 5.4.4.2 Annex 19 to the International Civil Aviation Organization recommends that States and service providers promote a positive safety culture.
>
> 5.4.4.3 When an air operator has a positive safety culture, supported by the company's senior management and immediate supervisors, frontline employees tend to have a sense of shared responsibility for achieving the organization's safety objectives.
>
> 5.4.4.4 A positive safety culture requires a high degree of trust and respect between employees and management. Time and effort are needed to build an environment conducive to the exchange of information. Conversely, poor decisions or a lack of action on the part of company management can easily undermine this bond.
>
> 5.4.4.5 Establishing a just culture is an important component of safety culture. The air operator shall therefore establish internal processes to support analyses so that, through clear procedures, flight crews involved in PAADV events receive fair treatment and proportional corrective measures aimed at preventing recurrence.

In this context, it is worth highlighting the provisions set forth in item 5.4.4.6 of the aforementioned IS:

> 5.4.4.6 A PAADV implemented by an air operator will only achieve its full potential if it is embedded in an environment where a positive safety culture exists.

In summary, in this type of program, there were no absolute analytical truths; rather, there was the possibility of interpreting operational deviations, identifying hazards, and generating actions to mitigate the risks associated with the company's flight operations.

According to the IS, the analysis process was carried out through events automatically generated by software, which classified operational deviations by severity, each with limits and tolerances appropriate to the desired levels of operational safety.

Item 10.7.3.1, Analysis Systematics, of the company's PAADV Manual established the following:

> To define which types of events are relevant to safety, an analysis of operational patterns and the variables that may contribute to increased risk is required. From this analysis, the types of events relevant for monitoring are established, along with their severity classes.
>
> The AGS software performs the systematic detection of events in accordance with the defined risk tolerance criteria. Once the monitoring context for data tracking is defined, event detection becomes automatic.

According to IS 119-008A, event classification was as follows:

- Class 0: Event not relevant to operational safety, but monitored for operational quality;
- Class 1: Event providing an early warning without requiring immediate corrective action;
- Class 2: Event in which a flight parameter limit was nearly reached or slightly exceeded;
- Class 3: Event in which an operational limit defined by the aircraft manufacturer or an operational standard defined by the operator was exceeded, potentially placing the operation at risk; and
- Critical Event: A Class 3 event that significantly exceeded the operational safety limits established by the aircraft manufacturer and the operator, for which the risk assessment demonstrated intolerance. This type of event would be classified after Gate Keeper analysis.

The role of the Gate Keeper, as established in the applicable IS and in the operator's manual, was to act as a mediating agent in the process of monitoring and handling operational events identified through FDM, being responsible for the technical analysis, operational contextualization, risk assessment, and the definition of subsequent actions, including interaction with the flight crew when necessary.

According to the operator's PAADV, the levels of risk tolerance were established as follows:

- Class 1: Acceptable Risk;
- Class 2: Acceptable Risk with restrictions; and
- Class 3: Unacceptable Risk.

Classe 1	Classe 2	Classe 3
Risco Aceitável	Risco Aceitável com Restrições	Risco Inaceitável

Figure 127 – Risk tolerance classes established in the operator's PAADV.

1.17.8.1. FDM of aircraft PS-VPB

Considering the characteristics observed in the flights immediately preceding the accident flight, the SIPAER Investigation Commission conducted a history review of the operation of aircraft PS-VPB since August 2023, analyzing 1,206 flights performed by the aircraft up to the day of the accident.

Overall, the information regarding the monthly number and location of the flights performed are presented in Figure 128.

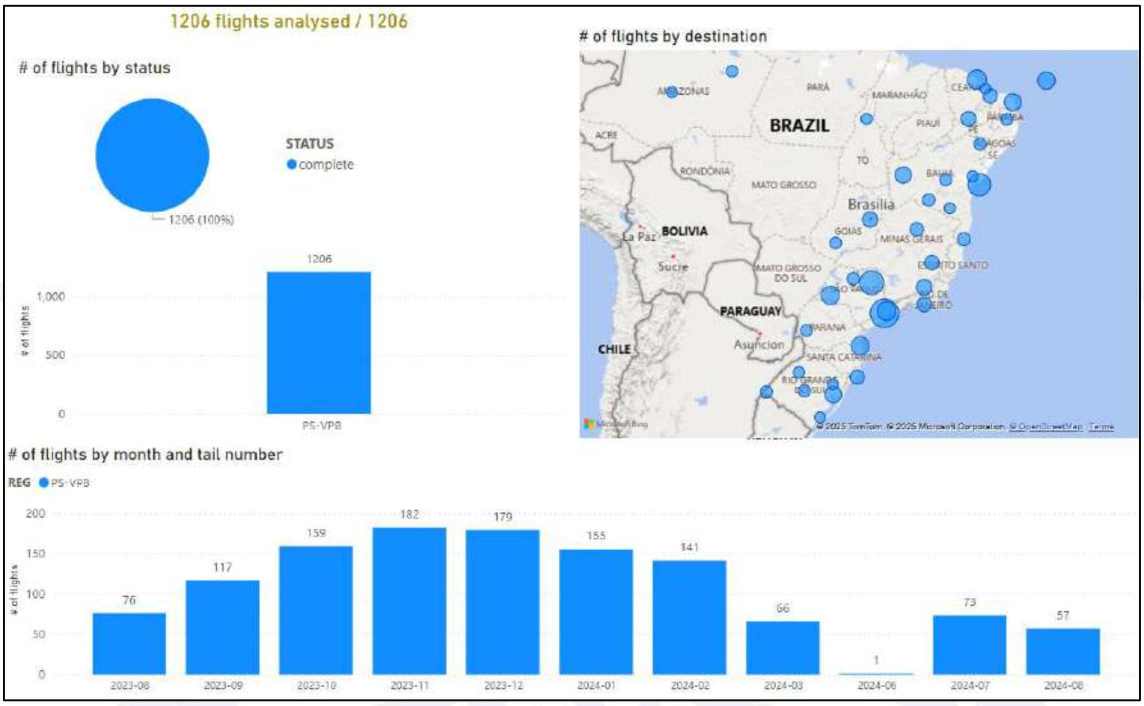


Figure 128 – Flights performed by aircraft PS-VPB, distributed by location and monthly frequency.

The data obtained revealed several relevant events associated with different triggers generated, which contributed to the understanding of the operating conditions of this aircraft throughout its operational life within the company.

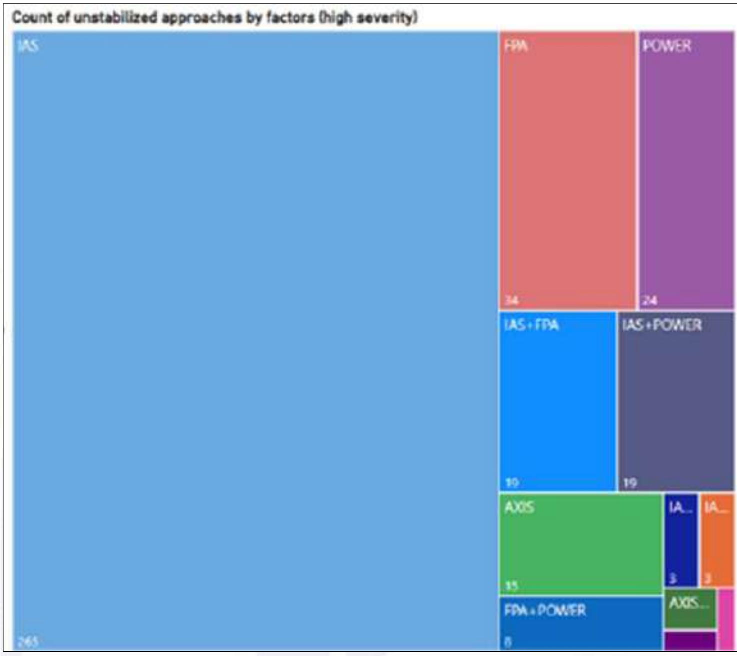
Such events were related to:

- unstable approaches for landing – events generated from various triggers (such as IAS outside the expected stabilization parameters below 1,000 ft and below 500 ft), as well as runway threshold crossing outside the expected parameters;
- premature application of reverse thrust after touchdown;
- performance degradation under icing conditions; and
- other conditions associated with safety culture, such as the conduct of flights without the performance of the Automatic Takeoff Power Control System (ATPCS) test.

<u>Unstable Approaches for Landing</u>

With regard to unstable approach events, the graph in Figure 129 presents the triggers defined for the identification of these conditions, classified by the SIPAER Investigation Commission in terms of severity as LOW, MEDIUM, and HIGH.

Out of the total of 1,206 flights analyzed, 394 (32.67%) were categorized as HIGH by the SIPAER Investigation Commission for failing to meet one or more stabilization criteria below 500 feet AGL. The most frequent criterion was related to elevated IAS values during the final approach.



Above 1000 ft	Between 1000 and 500 ft	Below 500 ft
50.00	17.33	32.67
50.00	**17.33**	**32.67**

Unstab. app. factor(s)	High sev. (count)	Med sev. (count)
IAS	265	109
FPA	34	15
POWER	24	23
IAS+FPA	19	4
IAS+POWER	19	16
AXIS	15	6
FPA+POWER	8	5
IAS+AXIS	3	4
IAS+FPA+POWER	3	3
AXIS+POWER	2	2
CONF	1	0
IAS+AXIS+POWER	1	1
FPA+AXIS	0	10
FPA+AXIS+POWER	0	3
IAS+FPA+AXIS	0	6
IAS+FPA+AXIS+POWER	0	2
Total	**394**	**209**

Figure 129 – Graphical representation of the parameters contributing most significantly to unstable approach triggers. The majority of these cases were associated with elevated IAS values.

In this context, it is worth noting that, on 12MAR2024, aircraft PS-VPB departed from SBRF (*Guararapes – Gilberto Freyre* – Intl Airport, *Recife*, *Pernambuco*), bound for SBSV, operating Flight 2290. During the landing at SBSV, there was an abnormal runway contact (tail strike).

The manufacturer and the operator acted jointly in the assessment of the damage. Based on the information available at the time, CENIPA classified the occurrence as an aeronautical incident.

The operator ferried the aircraft to the maintenance base at SBRP to perform maintenance and repair activities. Upon completion of the required work, the aircraft received its Approval for Return to Service (APRS), issued by ANAC on 26JUN2024.

During the course of the investigation of the accident under analysis, the SIPAER Investigation Commission had access to engineering reports concerning the extent of the damage and the repairs carried out on the aircraft following the incident at SBSV. These reports indicated that the damage resulting from the tail strike was more severe than initially estimated, requiring technically more complex interventions. CENIPA was not informed of the extent of the severe damage identified.

Within the scope of the present investigation, a possible relationship between the damage resulting from the tail strike on 12MAR2024, and the accident that occurred on 09AUG2024, was analyzed, and no connection between the events was identified.

Premature application of reverse thrust after touchdown during landing

A total of 371 flights (30.8% of the total analyzed) were identified by the SIPAER Investigation Commission as involving premature application of reverse thrust during landing (in relation to SOP provisions after touchdown) .

This type of procedure generated certain MASTER WARNING alerts issued by the CCAS. However, the Commission verified that, out of a total of 30 MASTER WARNING messages recorded, 22 were associated with the PITCH DISCONNECT message. This message could occur on the ground with a combination of crosswind and the immediate application of reverse thrust after touchdown during landing. This phenomenon was already recognized by the aircraft manufacturer, with a description of the event provided in abnormal procedure A27.07 of the FCOM (Figure 130).

■ **If pitch disconnect occurred on ground**

► PITCH RECONNECTION ON GROUND procedure (A27.09) ....APPLY

At landing, Pitch disconnect can occur with the combination of crosswind and:

- *Immediate application of reverse, or*
- *Prompt application of full reverse.*

Figure 130 – Excerpt from abnormal procedure A27.07, indicating the possibility of a PITCH DISCONNECT on the ground during landing and application of reverse thrust.

Dynamic Test of the PS-VPB Automatic Takeoff Power Control System (ATPCS)

The ATPCS was essential to ensure adequate power in the event of an engine failure during the critical takeoff phase.

The dynamic ATPCS test was scheduled to be performed daily, preferably after the last flight of the day. This test was conducted with both engines running, under specific conditions, through adjustments of the power levers and monitoring of parameters by the pilots, as established in the AFM Normal Procedures.

It is worth noting that this requirement was not included in the aircraft's maintenance plan within the scope of Daily Check tasks. In fact, it was a procedure established in the aircraft's operational manuals, to be performed by the flight crew.

The Normal Checklist required the pilots to perform the dynamic ATPCS test as part of the after-landing procedures on the last flight of the day (Figure 131).

AFTER LANDING

RADAR...STBY
FLIGHT CONTROLS ....LOCKED
FLAPS...0°
TRIMS [3 AXES] .... RESET
XPDR...STBY
LANDING LIGHTS .... OFF
ANTI-/DE-ICING................................... OFF
PROBES .... OFF

■ **IF LAST FLIGHT OF DAY**
ATPCS DYNAMIC TEST .... PERFORM

Figure 131 – Dynamic ATPCS test included in the After Landing procedure.
Source: ATR-72-500 Normal Checklist, code L-POR-FST-004-20-01, Version 02.00.

The SIPAER Investigation Commission verified that the number of daily ATPCS tests performed within the scope of the analysis, considering the flights conducted by aircraft PS-VPB, indicated an execution rate of 47.2% (Figure 132).

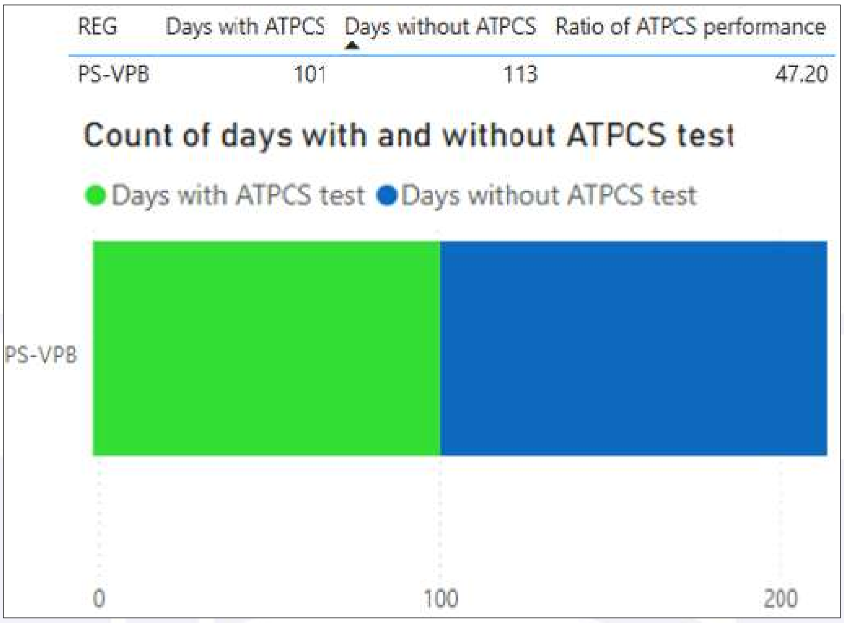


Figure 132 – Graph illustrating the number of days with and without the execution of the aircraft PS-VPB daily ATPCS test.
Source: Aircraft flight data.

Maintenance records and flight data indicated that the dynamic ATPCS test was performed in the early hours of the day of the accident.

Performance degradation under icing conditions

The SIPAER Investigation Commission evaluated flights in which triggers were activated in relation to APM alerts, as well as specific cases in which IAS decreased to values close to, and at times below, VmLB0icing.

Some flights classified as high severity (HIGH) are presented below:

Flight 2242 – probable ice accretion and performance degradation in cruise.

- Date of flight: 15SEP2023
- Departure: SBSP
- Departure runway: 17R
- Destination: SBMK (*Mário Ribeiro* Aerodrome, *Montes Claros*, *Minas Gerais*)
- Landing runway: 12

This was a flight cruising at FL180, with an IAS of approximately 185 kt.

During the flight, there was a reduction in IAS of about 20 kt over a 2-minute interval, in a profile consistent with performance degradation due to ice accretion on the wings (Figure 133).

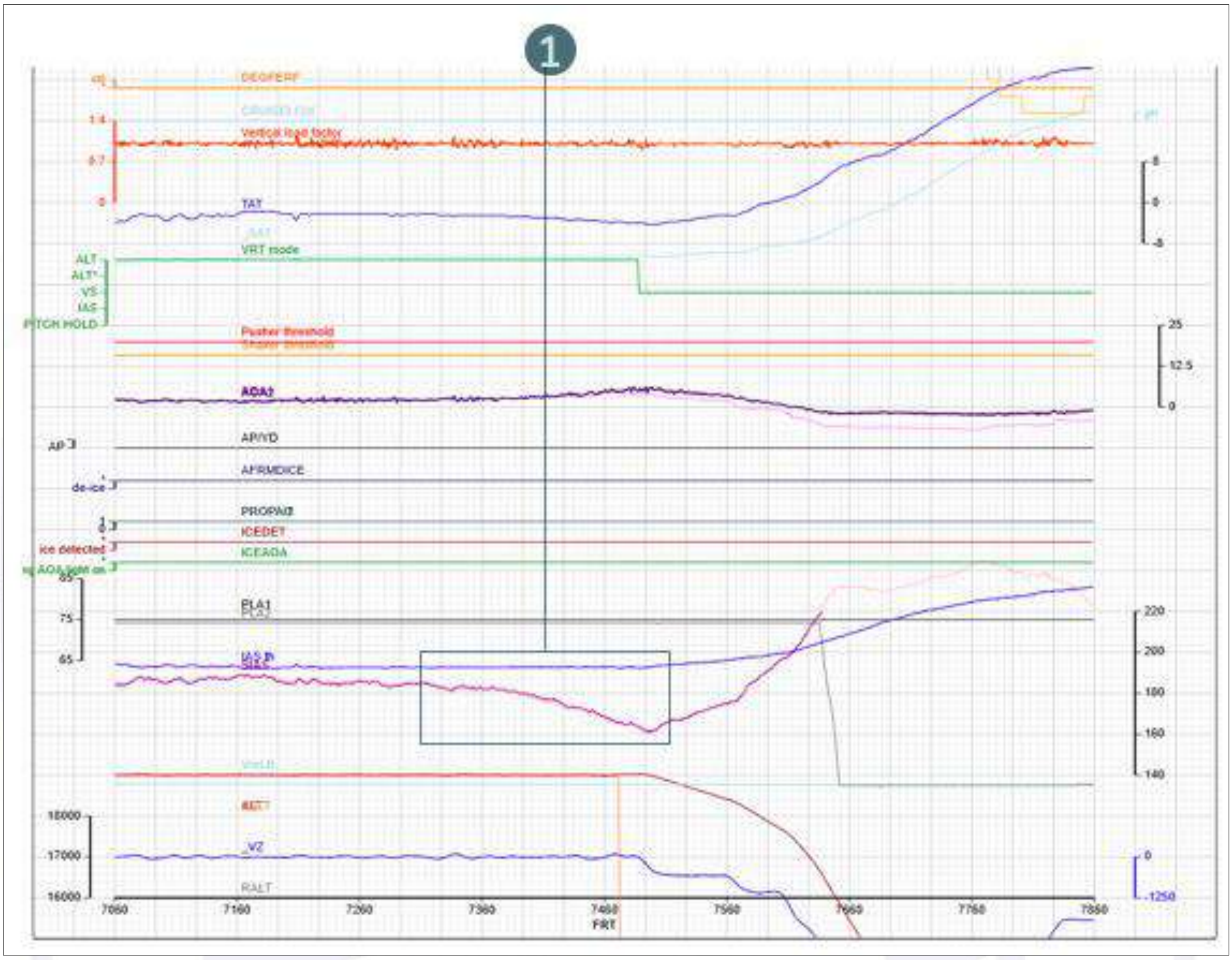


Figure 133 – Graph showing flight data parameters for Flight 2242.

No ice accretion detection was recorded by the Electronic Ice Detector, and the ice protection system (Anti-Icing or De-Icing) was off. The SIPAER Investigation Commission was unable to ascertain with the flight crew of that flight whether there had been any visual perception of ice accretion on the IEP.

As the Anti-Icing System Level 2 was not activated, no APM alerts were recorded.

At the moment when IAS reached its minimum value in the graph above, the APM drag calculation algorithm registered 720 drag counts (dc), compared to a nominal value of 510 dc for that flight, representing a 40% increase in the aircraft's aerodynamic drag.

The increase in IAS occurred after the aircraft initiated its descent for landing.

Flight 2231 – Low IAS at the end of the climb phase.

- Date of flight: 29SEP2023.
- Departure: SBSP
- Departure runway: 17R
- Destination: SBJA (*Regional Sul* Airport, *Jaguaruna*, Santa Catarina
- Landing runway: 05

The aircraft was in the climb phase to FL160, with the AP and YD engaged in IAS vertical mode, with the selected value set at 165 kt. The power levers (PLA1 and PLA2) were set in the Notch position.

Line 1 (Figure 134) highlights the moment at which level 2 of the Anti-Icing systems was activated (parameters PROPAI1 and PROPAI2, referring to Propeller Anti-Icing 1 and

2, and ICEAOA, referring to the illumination of the ICING AOA light). Furthermore, level 3 of the De-Icing systems was also active (Airframe De-Icing parameter). A few seconds later, the Airframe De-Icing system was deactivated and the ICING AOA light (ICEAOA) remained illuminated.

Line 2 indicates the moment at which the IAS selected via the AP (SIAS parameter) was reduced from 165 kt to 160 kt. Consequently, the actual IAS (IAS parameter) began to fall below the VmLB0icing value of 164 kt.

Line 3 highlights the onset of successive reductions in selected IAS, initially to 144 kt and then to 140 kt. The IAS followed these selections, reaching a minimum value of 143 kt (descending arrow), which represented a value 20 kt below VmLB0icing. In response, the AOA increased, although without reaching the stick shaker activation threshold, remaining approximately 2° below that limit.

Line 4 indicates the moment the aircraft leveled off at FL160 and the beginning of the IAS increase (ascending arrow). A brief AP disconnection was also recorded.

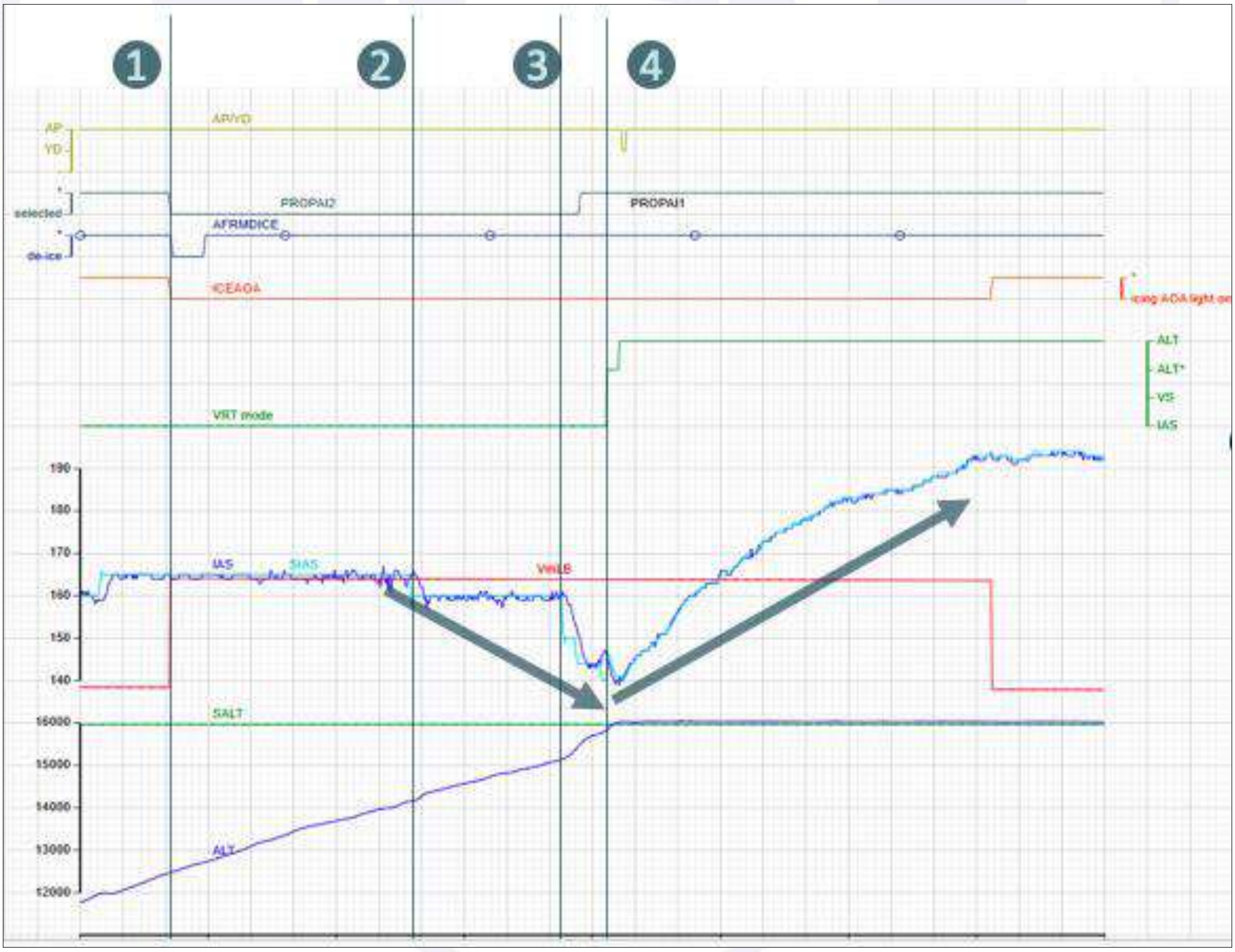


Figure 134 – Graph with flight data parameters of Flight 2231.

Flight 2230 – Icing and performance degradation.

- Date of flight: 01OCT2023
- Departure: SBSP
- Departure runway: 17R
- Destination: SBIP (*Usiminas* Aerodrome, *Santana do Paraíso*, *Minas Gerais*)

- Landing runway: 23

During the cruise flight at FL190, several ice accretion detections were recorded by the Electronic Ice Detector, followed by multiple activations and deactivations (resets) of the Airframe De-Icing system (box 1 in Figure 135).

Following the first ice detection (ICE DETECT parameter), a loss of performance and a reduction in the aircraft's indicated airspeed were identified. APM advisories/alerts for CRUISE SPEED LOW and DEGRADED PERFORMANCE were issued.

Following the third reset, a descent from FL190 to FL170 was recorded, along with the corresponding increase in the aircraft's indicated airspeed.

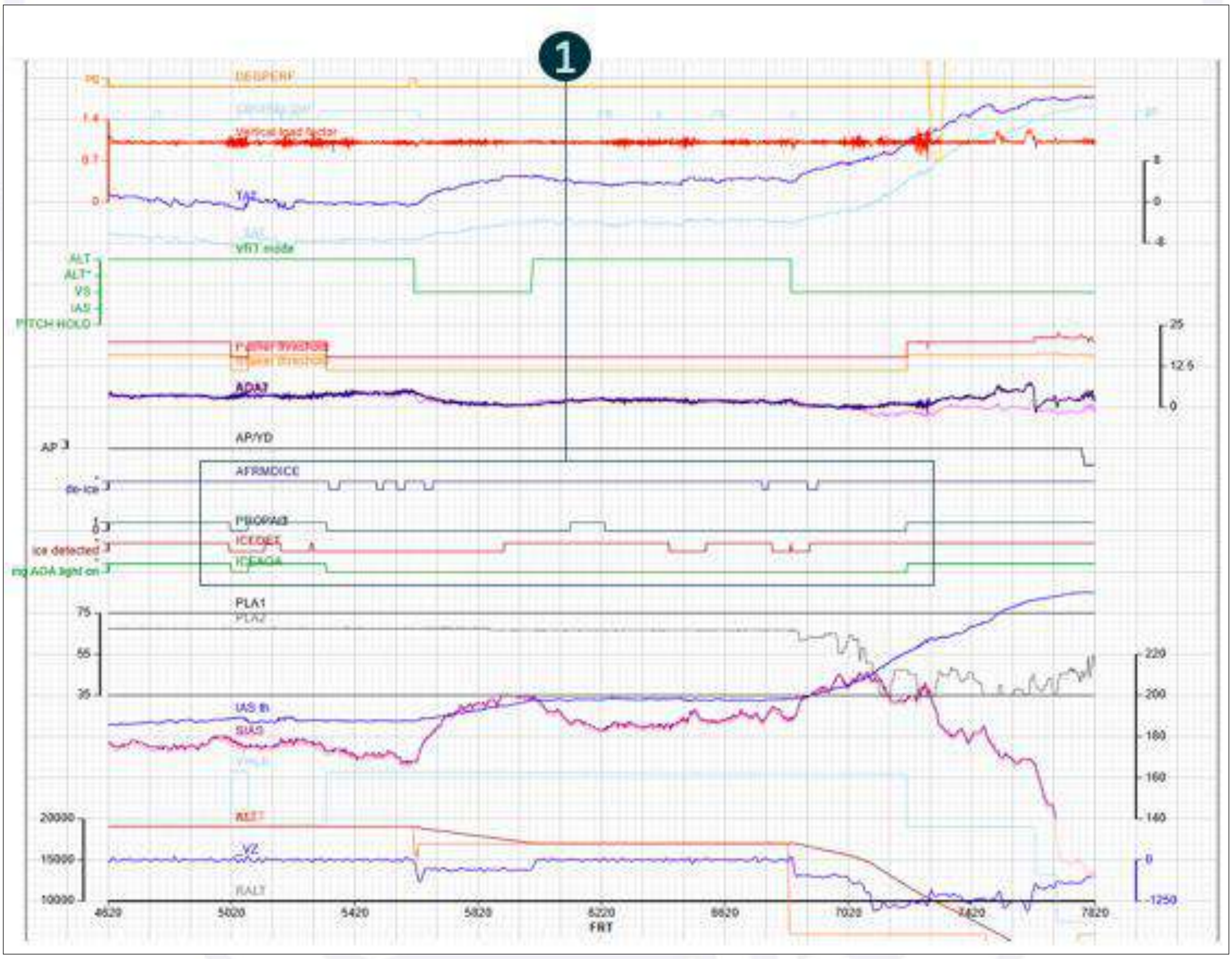


Figure 135 – Graph with flight data parameters related to Flight 2230.

The SIPAER Investigation Commission verified the existence of a fault record in the TLB related to boot 70, with a damaged repair.

BOOT #70 WITH REPAIR DAMAGED.

The corrective action for the fault was recorded as an ACR, and the aircraft was dispatched under restriction 30-11-02, as provided for in the MEL.

Subsequently, the Commission identified the record of the corrective maintenance action performed on 10OCT2023, with the following description:

IT WAS PERFORMED FAULT ISOLATION IAW AFI ATR-A-30-11-XX-04005-421A-A, FOUND BOOT 70 WITH REPAIRS TEARING. PERFORMED REPLACEMENT OF REPAIRS IAW MP ATR-A-30-11-XX-0000-685A-A PERFORMED OPERATIONAL TEST OF DE AIRFOIL DE ICING SYSTEM IAW ATR-A-30-11-XX-00001-320A REVISION: 013 -: 01 JUL-2023- ITEM OK. ACR CLOSED.

The ACR record indicated that the system fault was associated with torn repairs on boot number 70, noting the replacement of the repairs and the operational test of the system.

1.17.8.2. FDM of the ATR-72-500 and ATR-72-600 models.

In light of the diversity of relevant events identified in the flight data records of aircraft PS-VPB, the SIPAER Investigation Commission decided to expand the scope of the study to include the operator's entire fleet, as well as other operators of the ATR-72-500 and ATR-72-600 models. The objective was to obtain a broader view of the operational performance of these aircraft across different operational contexts.

Consequently, the SIPAER Investigation Commission evaluated a total of 15,365 flights from the operator, establishing specific triggers for icing condition events and alerts issued by the APM system, with the aim of enhancing the understanding of operational trends and aspects related to organizational safety culture.

Additionally, data from five other operators of ATR-72-212A aircraft were collected and analyzed using the same triggers. This approach enabled the Commission to conduct a comparative study (Figure 136).

	PTB	1	2	3	4	5
Flights	15365	~10500	~25000	~22000	~30000	~21000
Flights with APM events	1674	69	1269	993	155	1192
Flights with CRZ SPD LO	1305 (**8.5%**)	66 (**0.6%**)	746 (**3%**)	501 (**2.3%**)	126 (**0.4%**)	1046 (**5%**)
Flights with DEG PERF	273 (**1.8%**)	1 (**0.01%**)	427 (**1.7%**)	393 (**1.8%**)	23 (**0.1%**)	119 (**0.6%**)
Flights with INC SPD	96 (**0.6%**)	2 (**0.02%**)	96 (**0.4%**)	99 (**0.5%**)	6 (**0.02%**)	27 (**0.1%**)

Figure 136 – Comparison among ATR-72-212A operators, highlighting events related to the APM system. The acronym PTB refers to the operator of the aircraft involved in this accident.

The analysis of this dataset revealed that the operator presented the highest percentage of occurrences related to APM events (10.9% of total flights), of which 8.5% were associated with the CRUISE SPEED LOW advisory, 1.8% with DEGRADED PERFORMANCE, and 0.6% with INCREASE SPEED, values higher than those observed among the other operators.

The high occurrence rate of the CRUISE SPEED LOW advisory indicated that the company's aircraft were operating in cruise with indicated airspeeds, on average, between 5 and 10 kt below the theoretical IAS.

<u>Some specific cases can be detailed for illustration:</u>

In a flight conducted by the company using another aircraft in the fleet, the theoretical IAS was 195 kt and the VmLB0icing was 160 kt (Figure 137). The Anti-Icing and Airframe De-Icing systems were activated; however, the Airframe De-Icing system presented a fault message.

Throughout the entire cruise phase, the aircraft operated with an indicated airspeed below 180 kt, reaching a minimum speed of 170 kt, that is, 25 kt below the theoretical IAS and 10 kt above the VmLB0icing. The increase in speed occurred only during the descent phase.

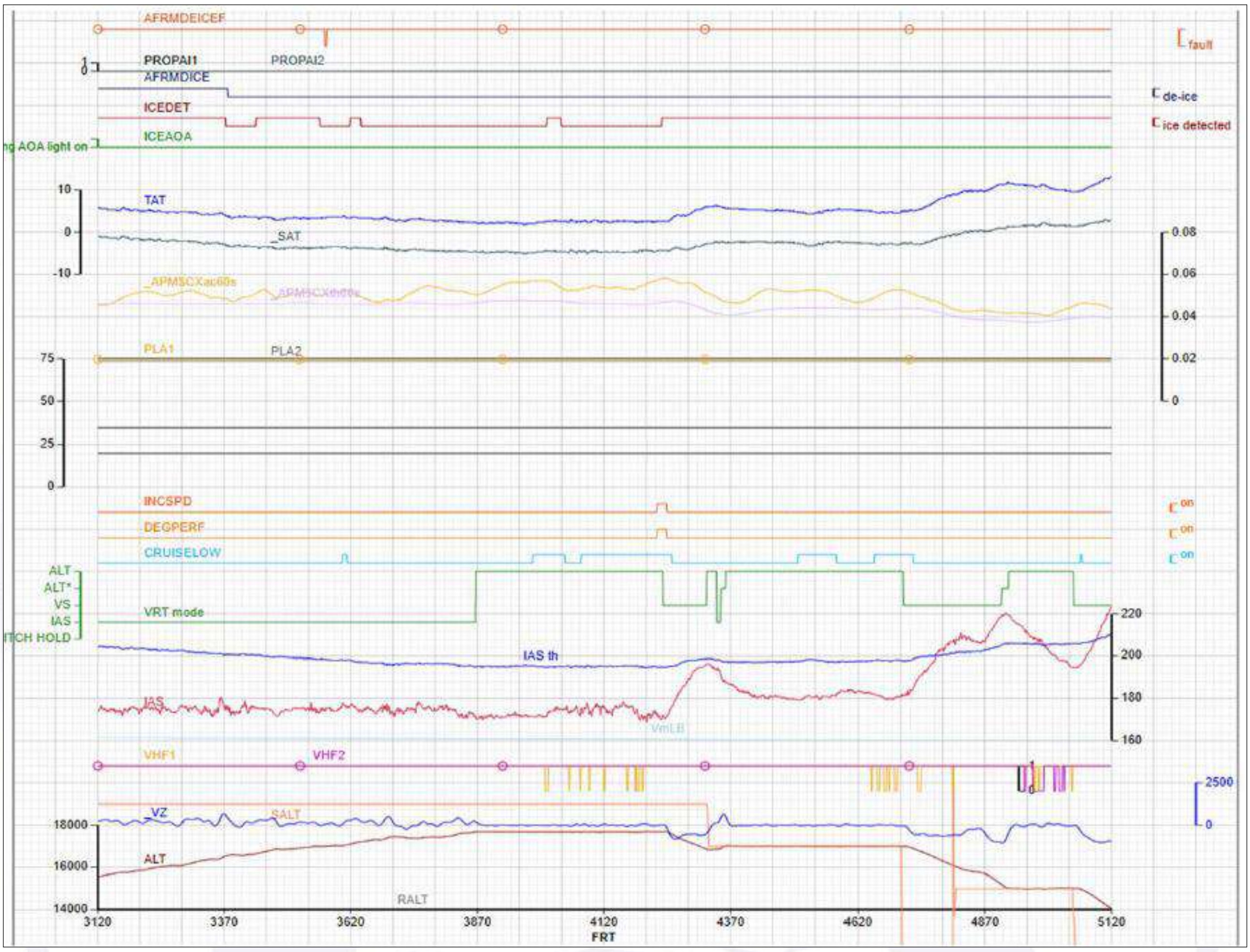


Figure 137 – Graph with flight data parameters from a flight conducted by the operator using an aircraft other than PS-VPB.

In another flight (also conducted by an aircraft other than PS-VPB), the theoretical IAS was 204 kt and the VmLB0icing was 162 kt. The Anti-Icing and Airframe De-Icing systems were properly activated, and no fault in the Airframe De-Icing system was recorded.

During the cruise phase, the aircraft operated with the IAS fluctuating around 180 kt. However, in the final portion of the cruise, prior to the start of the descent, there was a rapid and significant degradation of the IAS consistent with severe icing condition. The IAS reached a minimum value of 163 kt, that is, approximately 41 kt below the theoretical IAS and 1 kt above the VmLB0icing (Figure 138).

During the segment in question, several CRUISE SPEED LOW advisories, three DEGRADED PERFORMANCE alerts, and one INCREASE SPEED alert were recorded. The increase in IAS occurred only with the onset of the descent.

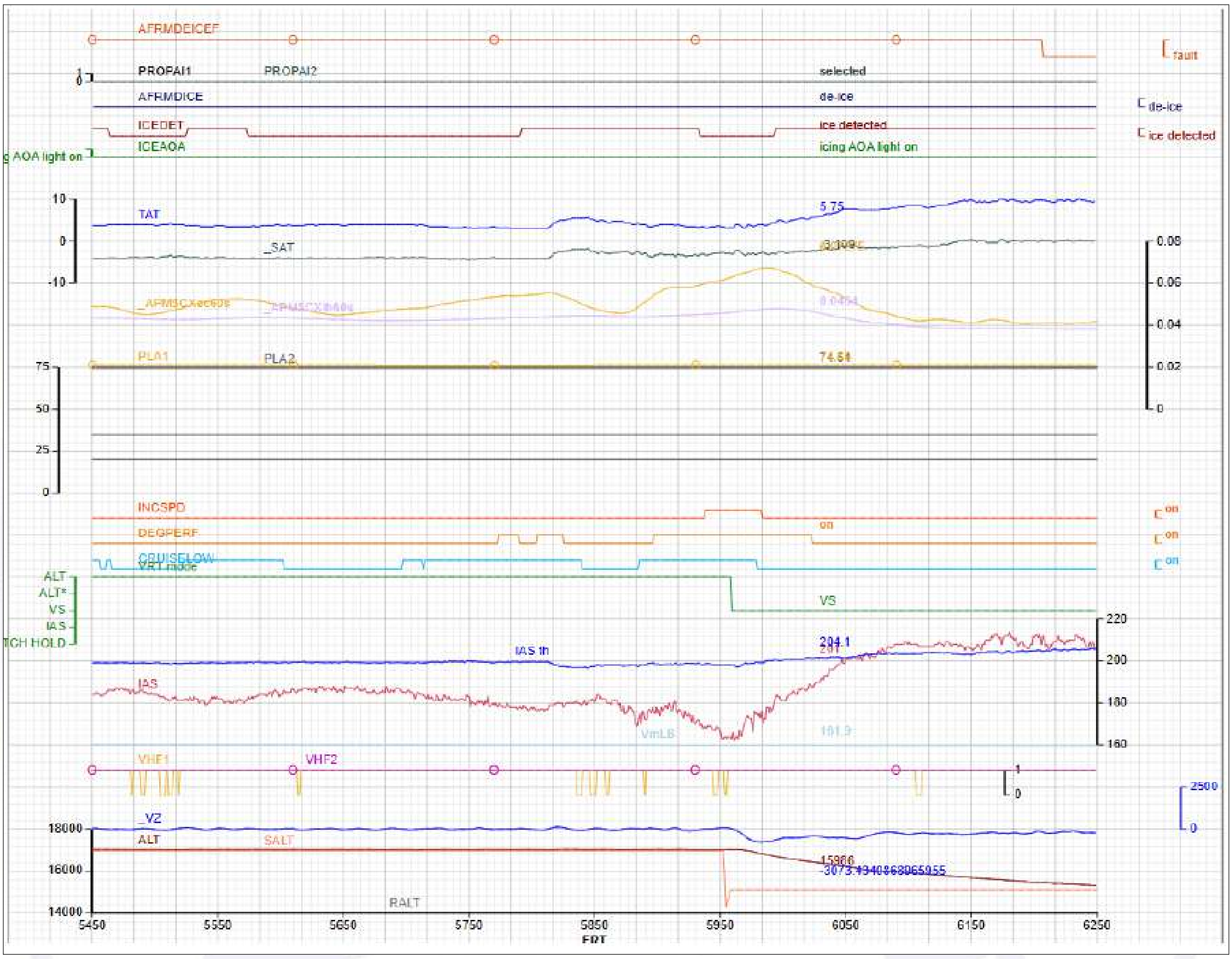


Figure 138 – Graph with flight data parameters from flights conducted by the operator using an aircraft other than PS-VPB.

In another flight conducted by the company using an aircraft other than the one involved in the accident, the theoretical IAS was 190 kt and the VmLB0icing was 156 kt (Figure 139). The Anti-Icing and Airframe De-Icing systems were activated, and multiple fault messages were recorded in the Airframe De-Icing system throughout the flight.

During the cruise phase, the aircraft operated with indicated airspeed oscillating around 180 kt. At a certain point, there was a rapid and significant degradation of IAS, consistent with a severe icing condition, reaching a minimum value of 160 kt, that is, 30 kt below the theoretical IAS and 4 kt above the VmLB0icing.

During the affected segment, several CRUISE SPEED LOW advisories, one DEGRADED PERFORMANCE alert, and one INCREASE SPEED alert were recorded, appearing almost simultaneously. The increase in IAS occurred after the aircraft initiated the descent.

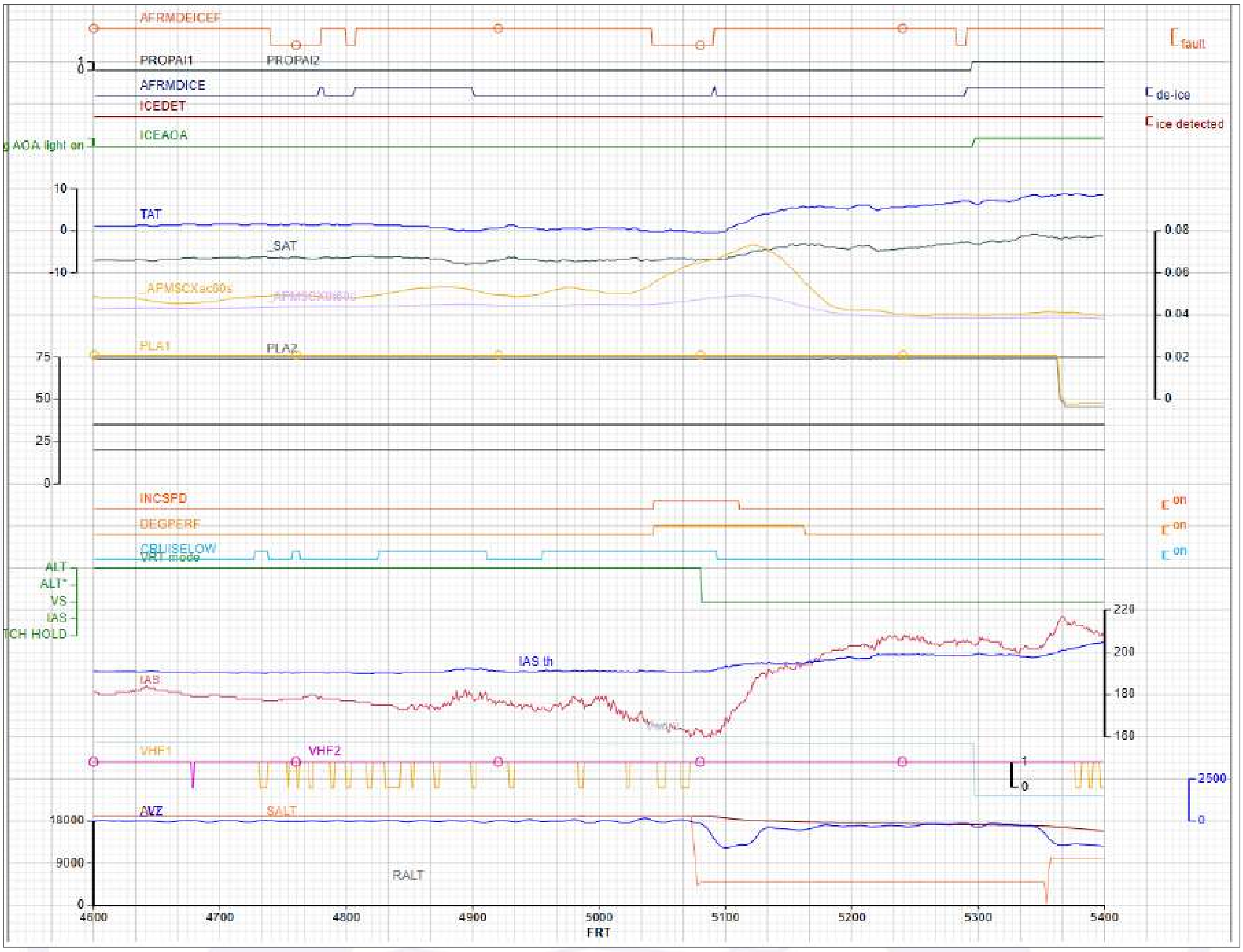


Figure 139 – Graph with flight data parameters from a flight conducted by the operator using an aircraft other than PS-VPB.

Another record of a flight conducted by the operator on an aircraft other than PS-VPB, indicated that the theoretical IAS was 198 kt and the VmLB0icing was 162 kt (Figure 140). The Anti-Icing and Airframe De-Icing systems were activated, and no fault-messages were recorded in the Airframe De-Icing system during the flight.

Throughout the entire cruise phase, the aircraft operated with the IAS around 180 kt. At a certain point, there was a rapid and significant degradation of the IAS, consistent with a severe icing condition, reaching a minimum of 157 kt, that is, 41 kt below the theoretical IAS and 5 kt above the VmLB0icing.

During the affected segment, two CRUISE SPEED LOW advisories, one DEGRADED PERFORMANCE alert, and one INCREASE SPEED alert were recorded, appearing almost simultaneously. The increase in IAS occurred only with the aircraft's descent.

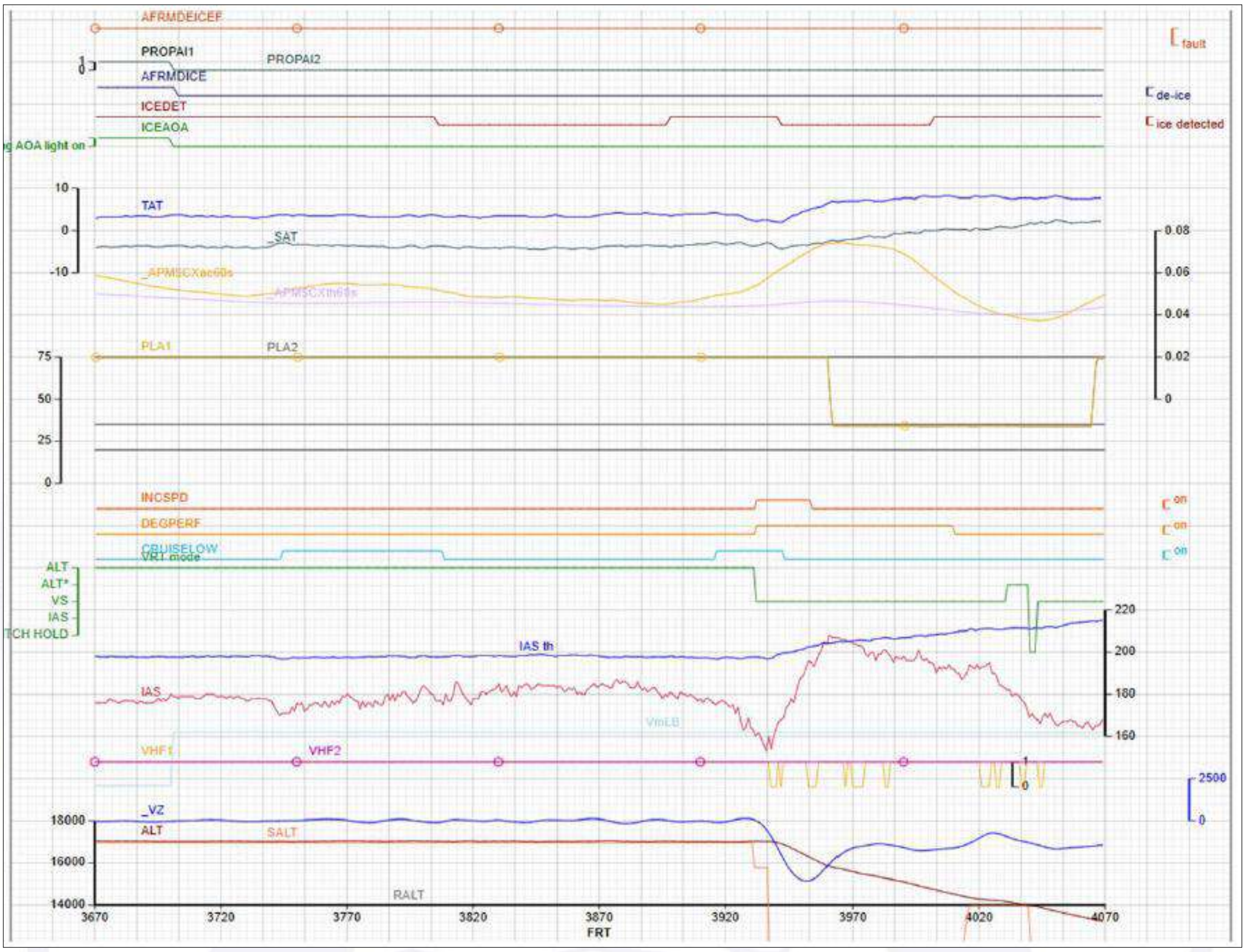
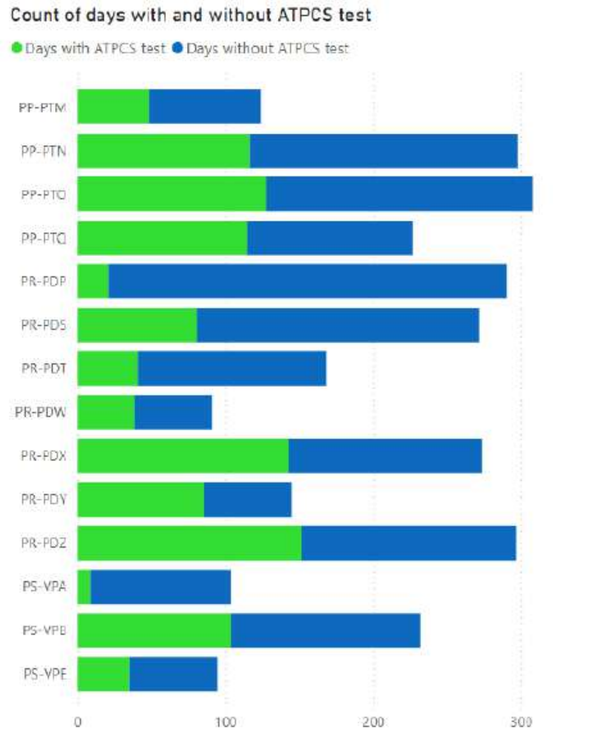


Figure 140 – Graph with flight data parameters from flights conducted by the operator on an aircraft other than PS-VPB.

Dynamic ATPCS Test for the Operator’s Fleet.

With regard to ATPCS execution data for other aircraft in the operator’s fleet, the average execution rate was found to be approximately 37% (Figure 141).

This result highlighted a considerable number of commercial flight operations in which the aircraft took off without performing the dynamic ATPCS test, contrary to what is prescribed in the operational manuals.



REG	Days with ATPCS	Days without ATPCS	Ratio of ATPCS performance
PR-PDW	39	52	42.86
PR-PDY	86	59	59.31
PS-VPE	35	60	36.84
PP-PTM	49	75	39.52
PS-VPA	9	95	8.65
PP-PTQ	115	112	50.66
PR-PDT	41	127	24.40
PS-VPB	104	128	44.83
PR-PDX	143	131	52.19
PR-PDZ	152	145	51.18
PP-PTO	128	180	41.56
PP-PTN	117	181	39.26
PR-PDS	81	191	29.78
PR-PDP	21	269	7.24

Figure 141 – Graph illustrating the number of days with and without the execution of ATPCS tests for the aircraft in the operator’s fleet.
Source: Aircraft flight data.

1.18. Operational information.

The SIPAER Investigation Commission examined technical data from the three flights preceding the accident involving PS-VPB, as well as from the accident flight itself, with the objective of identifying the aircraft’s operational and airworthiness conditions, as well as any recurring patterns or technical abnormalities that might have contributed to the final event.

The Commission used technical data obtained from the FDR, DAR, MPC, Reports, and MFC, considering the flights in which De-Icing system failures were recorded.

The presented graphs include MASTER CAUTION alert activation events recorded by the MFCs to facilitate understanding.

1.18.1. Previous Flights.

The preceding flights were designated as “flight -3”, “flight -2”, and “flight -1”.

1.18.1.1. “Flight -3”

“Flight -3” was conducted on the night prior to the day of the accident. The aircraft departed from SBGR bound for SBRP and was operated by a different crew than that involved in the accident.

During this flight, the Electronic Ice Detector detected ice accumulation, with the illumination of the ICING light. Subsequently, the Airframe De-Icing system was activated. This can be verified in the graph of Figure 142, indicated by the first blue ellipses, one on the ICE DETECTION STATUS parameter and the other on the AIRFRAME DE ICING parameter.

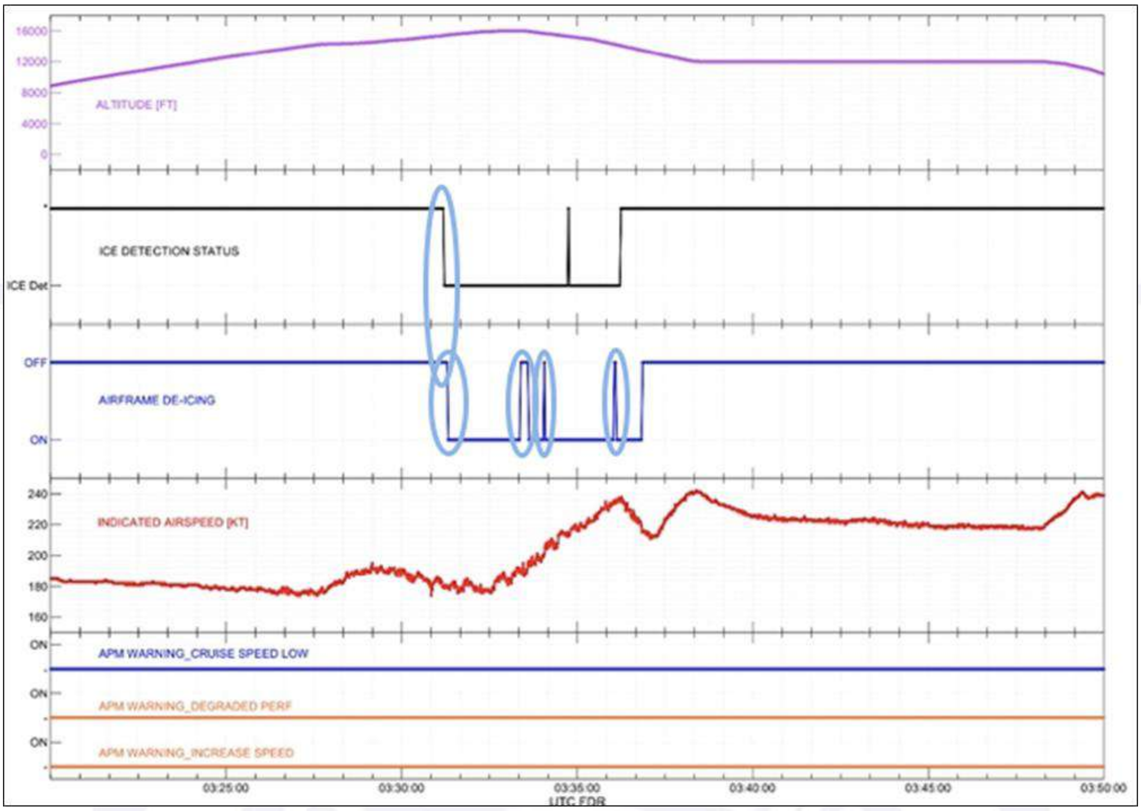


Figure 142 – Graph of flight data parameters for “Flight -3”, highlighting ice accumulation detection, activation of the DE-ICING system, and execution of three system resets.

Upon identification of conditions favorable to ice formation, the aircraft manuals prescribed the execution of specific procedures, to be adopted according to the severity level of the ice formation identified (Figure 143).

_f31f6381-49de-47e4-9a30-6be0d76d9d20 15 JUN 2022

PROCEDURE FOR ICING CONDITIONS

- ► IAS : MAINTAIN AT OR ABOVE ICING BUG
- ► ANTI ICING systems................................ .... ON
- ► ICE ACCRETION : MONITOR
- **● When ice accretion is observed/detected**
  - ► DE ICING systems................................ .... ON
  - **● In FLAPS 0 configuration**
    - ► IAS : MAINTAIN AT OR ABOVE ICING BUG +10 kt
  - ► IAS & V/S : MONITOR

Note

Refer to AFM - SEVERE ICING DETECTION for severe icing indications information.

- **■ If any severe icing indication**
  - ► SEVERE ICING procedure (E99.08) .... APPLY
- **● When leaving icing conditions**
  - ► ANTI ICING & DE ICING systems......... .... TURN OFF AS RQRD
- **● When aircraft is visually verified clear of ice**

  Note

  The aircraft is considered clear of ice when IEP is free of ice.

  - ► ICING AOA pb .... OFF
  - ► NORMAL SPEED : USE

Figure 143 – Procedures for icing conditions.
Source: PS-VPB QRH.

The procedure for operation in icing conditions required that the IAS be maintained equal to or above the speed corresponding to the ICING BUG marking on the airspeed indicator, that the Anti-Icing systems be turned on, and that ice accumulation be monitored.

When ice accumulation was observed or detected, the De-Icing systems were to be activated. In the flaps 0 configuration, the IAS was to be maintained equal to or above the ICING BUG + 10 kt value, and the IAS and vertical speed were to be monitored.

To obtain information on the indications of severe ice formation, the AFM procedure regarding severe icing detection was to be observed.

Should any indication of severe icing be observed, the SEVERE ICING procedure, contained in reference E99.08, was to be applied.

Upon leaving icing conditions, the Anti-Icing and De-Icing systems could be turned off as necessary.

When it was visually verified that the aircraft was free of ice, this condition was only to be considered confirmed when the IEP was also free of ice. In this situation, the ICING AOA button was to be turned off and normal speed was to be resumed.

Approximately two minutes after the activation of the Airframe De-Icing system, the MASTER CAUTION alert was again recorded, associated with the single chime aural warning. The data recorded in the non-volatile memories of the MFCs (Figure 144) indicated that the alert was associated with a fault in the commanding of the B chambers of the right wing boot (Right Wing Boot B Fault) and left wing boot (Left Wing Boot B Fault).

System	Detected failure description	Flight 0	Flight -1	Flight -2	Flight -3	Flight -4	Flight -5	Flight -6	Flight -7	Flight -8	Flights older than "Flight -8" but after last MFC BITE memory erase	Flights older than last MFC BITE memory erase
Boots	Right Wing Boot B Fault	Failure detected	Failure detected	Failure detected	Failure detected						Unknown	Unknown
	Left Wing Boot B Fault				Failure detected						Unknown	Unknown
	Right Engine Boot A Fault											Failure detected
	Right Median Wing Boot A Fault											Failure detected

Figure 144 – Excerpt from the table of external fault history recorded by the MFCs, contained in ATR Technical Reference Report V-339/24.

Following the MASTER CAUTION alert, the Airframe De-Icing system was reset three times (turned off and then on) as indicated by the subsequent blue ellipses in the AIRFRAME DE-ICING parameter in Figure 142.

The aircraft FCOM stated that, at the flight crew's discretion, an attempt could be made to reset a system associated with a MASTER CAUTION alert. This action consisted of selecting the respective push button to the OFF position for 3 seconds and then returning it to the ON position.

If the fault alert disappeared following this procedure, the operation could continue normally, and the event should be recorded in the aircraft's TLB by the flight crew. If the alert persisted, the flight crew was required to apply the corresponding abnormal procedure set forth in the QRH.

ATR 0908 / 75 FCOM	PROCEDURES GENERAL INFORMATION PROCEDURE EXPLANATION	PRO.GEN Page n°07

cont'd... >>>

a) System Reset

At flight crew discretion, one RESET of a failed system associated to an amber caution may be performed by selecting the related pb (push-button) OFF (for 3 s) then ON except for systems listed below. If the failure alert disappears, continue normal operation and record the event in the aircraft maintenance logbook for information. If not, apply the associated abnormal procedure.

Figure 145 – Excerpt from the FCOM outlining the rules for system reset procedures by the flight crew.

It is noteworthy that the procedure established by the aircraft manufacturer was also provided in the SOP, under item 5.4.1.3, addressing the “Reset policy” (Figure 146). However, there was no guidance for recording the failure in the TLB, nor any instructions regarding the procedure to be adopted should the failure alert persist after the reset.

5.4.1.3. Política de reset

A critério do PF (a ser validada a decisão pelo Comandante), um *reset* poderá ser tentado no sistema que apresenta a falha e associado a um alerta âmbar, através da seleção do *push button* em OFF, e após 3 segundos retornando para ON.

Os itens abaixo não devem sofrer *reset* sem que o procedimento de QRH seja executado:

- EEC;	- BAT CHG (EMER & MAIN);
- PEC;	- CAB PRESS MODE SEL

O itens abaixo nunca devem sofrer reset:

- BLEED LEAK através do pb BLEED VALVE associado;
- BUS FAULT através do pb GEN associado;

Figure 146 – SOP item 5.4.1.3 (code M-POR-FST-001-12, version 05.01, Chapter 05), addressing the operator’s “Reset policy”.

The Airframe De-Icing system faults recorded in the non-volatile memories of MFC1 and MFC2 could be reset by the flight crew.

Despite the guidance provided in the FCOM, there was no record of the failure related to the Airframe De-Icing system, nor any record of dispatch under specific MEL conditions in the aircraft’s TLB. The TLB record was the primary source of information for the execution of corrective maintenance actions.

During interviews conducted as part of the investigation, the Commission received reports indicating that members of the night shift maintenance team became aware, through verbal communication with the pilots, of a failure in the Airframe De-Icing system during “Flight -3”.

It should be noted that, in accordance with the FCOM, following the first system reset and the occurrence of a subsequent failure, the flight crew was expected to comply with the corresponding QRH procedure (DE ICING AIRFRAME FAULT), which directed exiting icing conditions, avoiding them, and switching off the Airframe De-Icing system (Figure 147).

DE ICING AIRFRAME FAULT A30.07

- ► ICING CONDITIONS : LEAVE AND AVOID
- ► DE ICING AIRFRAME...OFF

■ **As long as aircraft is not clear of ice**

- OR -

■ **If in icing conditions**

- ► IAS (Refer to QRH - PER.3 - OPSDATA)....NOT LESS THAN icing bug + 15 kt
- ► V_{APP} (Refer to QRH - PER.3 - OPSDATA).... NOT LESS THAN V_{REF} + 15 kt
- ► LDG DIST (Refer to QRH - PER.7.1 - Landing Distance)....MULTIPLY BY 1.25
- ► STEEP SLOPE APPROACH (≥ 4.5 °) : PROHIBITED

Figure 147 – Procedure for Airframe De-Icing system failure in flight.
Source: PS-VPB QRH.

As long as the aircraft was not clear of ice or remained flying in icing conditions, the following procedures were to be adopted:

- IAS should be maintained above ICING BUG + 15 kt;
- the approach speed (V_{APP}) should not be lower than the Reference Landing Speed (V_{REF}) + 15 kt;
- the landing distance should be multiplied by a factor of 1.25; and
- approaches with an angle equal to or greater than 4.5° were prohibited.

In the event of inoperative De-Icing boots, the applicable MEL permitted dispatch of the aircraft, provided that operations were not conducted in known or forecast icing conditions (Figure 148).

May be inoperative provided that aircraft is not operated into known or forecast icing conditions.

30-11-02 Airframe De-icing Boots System

ALL
EASA - APPROVED

RI	NI	NR	PLACARD	O	M
B	1	0	YES	NO	NO

May be inoperative provided that aircraft is not operated into known or forecast icing conditions

Figure 148 – Approved MEL for aircraft PS-VPB, with the red arrow highlighting the dispatch requirement for inoperative Airframe De-Icing boots.
Source: MEL ATR-72 – Revision number 08-20-FEB-2024.

Between “flight -3” and “flight -2”, a Daily Check was performed during the aircraft’s last overnight stay at the SBRP maintenance base. The inspection performed did not include a functional check of the Airframe De-Icing system.

1.18.1.2. “Flight -2”

“Flight -2” departed from SBRP bound for SBGR at approximately 08:20 UTC on the day of the accident, with a crew different from those who operated Flights -3, -1, and the accident flight.

En route, during the cruise phase at FL150, the Electronic Ice Detector detected ice accumulation twice (blue ellipses in Figure 149). These detections were accompanied by MASTER CAUTION alerts and the single chime aural warning.

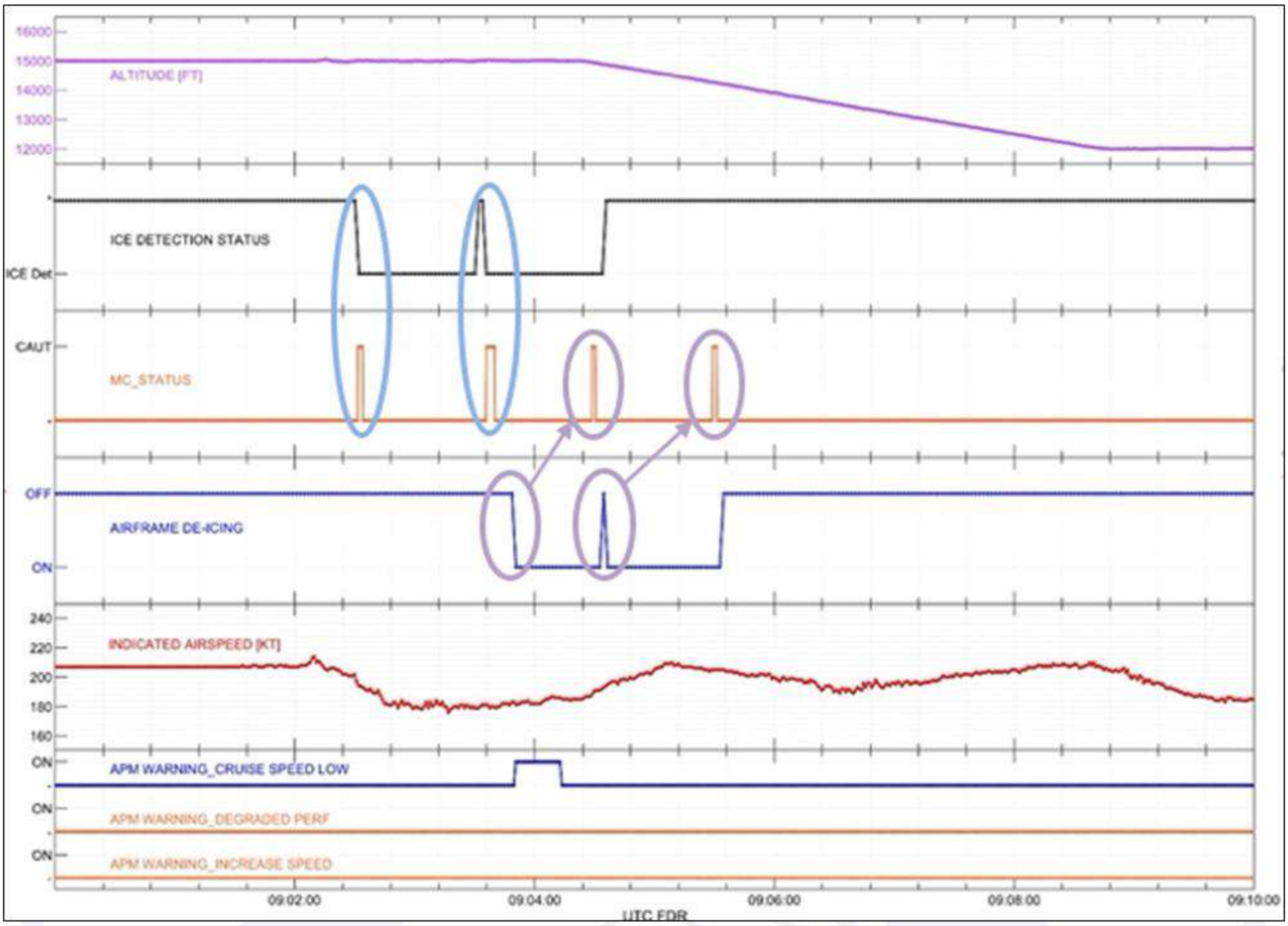


Figure 149 – Graphs of flight data parameters for “flight -2”.

It is worth noting that, as mentioned for 'flight -3', the PROCEDURE FOR ICING CONDITIONS (Figure 143), contained in the QRH, should have been applied as soon as flight in icing conditions was established, with the anti-ice systems being activated.

The illumination of the amber ICING light on the ICE DETECT panel denoted not only icing conditions, but also ice accumulation on the aircraft surface, requiring the activation of the De-Icing system.

It is noteworthy that the MPC recorded, on the PCMCIA card, two occurrences of the messages ICE DETECTED WHILE D/ICE SYSTEM IS OFF, as the Airframe De-Icing system was off following the ice detection events.

At the time of the first ice accumulation detection, the aircraft’s cruise IAS transitioned from a stable condition to an oscillating, decreasing trend, with a reduction of more than 20 kt until the CRUISE SPEED LOW message was triggered, indicating performance degradation due to ice accumulation on the airframe.

The QRH instructed that, upon activation of the CRUISE SPEED LOW, the flight crew should monitor both the icing conditions and the aircraft’s indicated airspeed (Figure 150).

1 Cruise Speed Low

Cruise Speed Low

afeb0a25-4d5c-4e09-aa73-38ec29bdc850 | 15 SEP 2023

CRUISE SPEED LOW

- ► ICING CONDITIONS : MONITOR
- ► SPEED : MONITOR

Figure 150 – QRH procedures for the CRUISE SPEED LOW message.

For the detection of severe icing conditions, section A30.17 of the QRH contained the information set out in the SEVERE ICING DETECTION procedure (Figure 151).

_0542fc4c-6eb7-439a-b570-9935ed5ffbb0 05 JUL 2019

SEVERE ICING DETECTION **A30.17**

SEVERE ICING main indications :

- **Ice covering all/substantial parts of unheated side window (visual cue)**
- **Unable to maintain IAS above ICING BUG +10 kt**
- **Unable to maintain V/S above 100 ft/min AVERAGE at icing bug +10 kt**
- **Abnormal vibrations**

■ **If any severe icing indication :**

► SEVERE ICING procedure (E99.08) .... APPLY

Supplementary indications:

- Water splashing/streaming on the windshield
- Unusual extensive ice accreted on the airframe in areas not normally observed to collect ice
- Accumulation of ice on the lower surface of the wing aft of the protected areas
- Accumulation of ice on propeller spinner farther aft than normally observed

Weather conditions that can result in severe in-flight icing:

- Visible rain at temperatures close to 0 °C (SAT)
- Droplets that splash or splatter on impact at temperature close to 0 °C (SAT).

Figure 151 – SEVERE ICING DETECTION Procedure.
Source: Aircraft QRH.

The severe icing detection procedure presented the following main indications:

- the presence of ice covering all, or a substantial portion, of the unheated side window, serving as a visual reference;
- the inability to maintain IAS above ICING BUG + 10 kt;
- the inability to maintain an average vertical speed above 100 ft/min when flying with IAS ICING BUG + 10 kt; and
- the occurrence of abnormal vibrations.

Upon observation of any indication of severe icing, the SEVERE ICING procedure, contained in reference E99.08, was to be applied.

As supplementary indications, the following were to be considered:

- water splashing/streaming on the windshield;
- unusual extensive ice accreted on the airframe in areas where ice formation is not normally observed to collect ice;
- ice accumulation on the lower surface of the wing, aft of the protected areas; and
- ice accumulation on the propeller spinner in a position further aft than normally observed.

The meteorological conditions conducive to severe icing were identified by:

- visible rain at temperatures close to 0°C Static Air Temperature (SAT); and
- droplets that splash or splatter on impact, with temperatures close to 0°C SAT.

Shortly after the second ice detection by the Electronic Ice Detector, the Airframe De-Icing system was activated, remaining on for approximately 50 seconds, until the appearance of a new MASTER CAUTION alert, associated with the illumination of the FAULT label on the Airframe de-ice pushbutton.

Immediately following this alert, a reset of the system was performed. Shortly thereafter, however, the Electronic Ice Detector no longer detected ice accumulation. Approximately one minute later, a new fault was observed. On this occasion, however, the Airframe De-Icing system was turned off by the crew (purple ellipses in Figure 149).

The MPC recorded, in this context, the AIRFRAME FAULT message, allowing the finding that the two MASTER CAUTION alerts (purple ellipses), which occurred with the Airframe De-Icing system active, resulted from a fault in that system.

It is worth noting, once again, that, in accordance with the FCOM, following the system reset and the recurrence of the fault, the DE ICING AIRFRAME FAULT procedure (Figure 147) should have been applied

Similarly to “flight -3”, no record of Airframe De-Icing system failure was found in the aircraft’s TLB, nor any record of dispatch under specific MEL conditions.

1.18.1.3. “Flight -1”

“Flight -1” departed from SBGR bound for SBCA at 12:06 UTC on the day of the accident. This flight was operated by the same crew that subsequently conducted the accident flight.

The flight was planned for FL160. However, the climb was performed in two stages. Initially, the aircraft leveled off at FL140. It then resumed the climb to FL160, where cruise flight was established.

Ice was detected by the Electronic Ice Detector at the end of the climb phase, near FL140, culminating in the triggering of the MASTER CAUTION alert (blue ellipse positioned in the upper left corner), associated with the single chime aural warning.

The FDR subsequently recorded the activation of the Airframe De-Icing system by the flight crew (Figure 152)

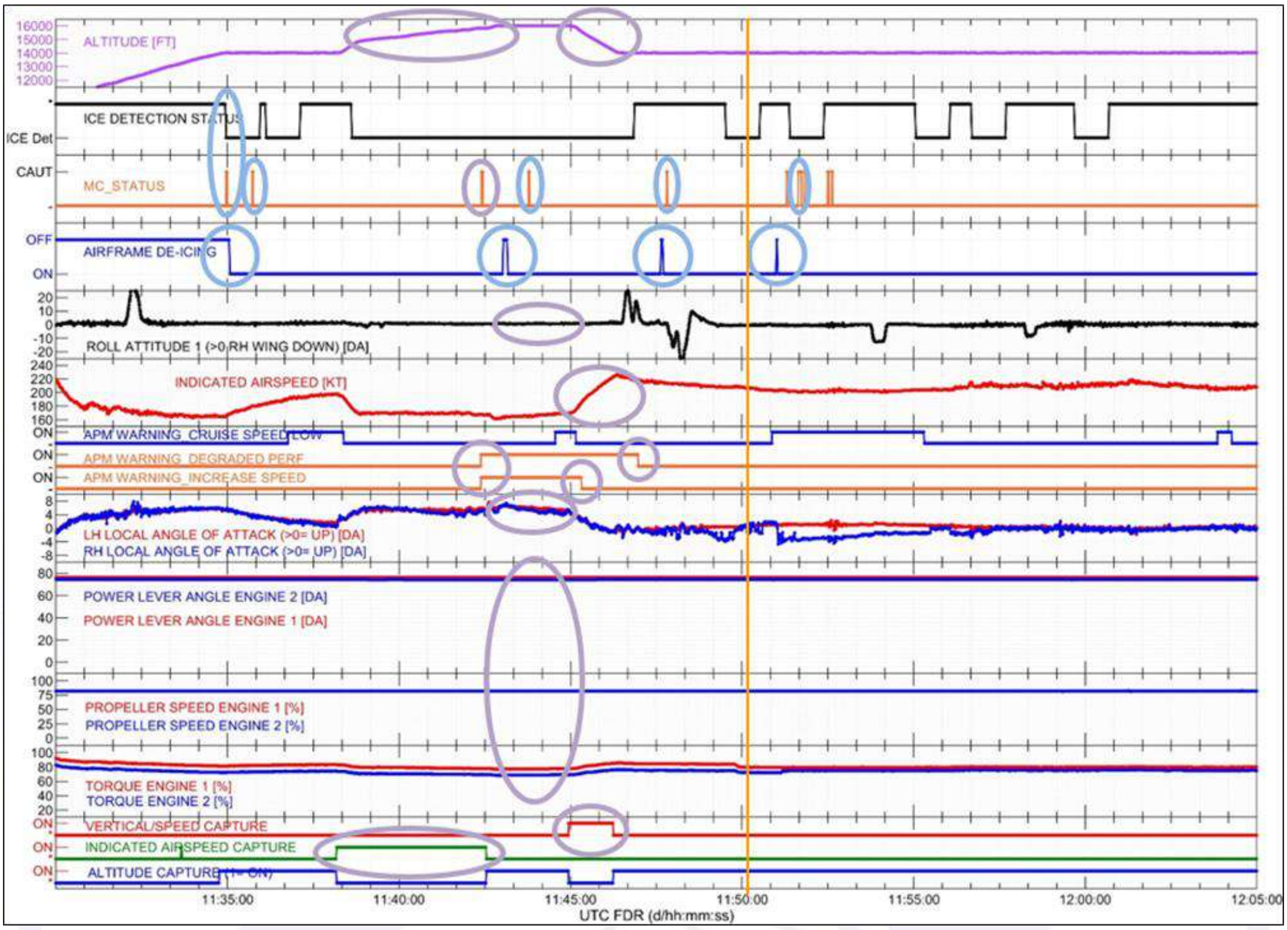


Figure 152 – Graph with flight data parameters related to “flight -1”.

A few seconds later, another MASTER CAUTION alert was issued, accompanied by a single chime aural warning. Data recorded on the MPC memory card indicated that this alert was associated with the AIRFRAME FAULT message. Despite these alerts, the flight crew maintained the AIRFRAME DE-ICING system on, contrary to the DE ICING AIRFRAME FAULT procedure set forth in the QRH (Figure 147).

The aircraft remained at FL140 for slightly more than three minutes while accelerating from 170 kt to 200 kt. During this period, the CRUISE SPEED LOW warning was activated. At that moment, according to the QRH, the flight crew should monitor both icing conditions and the aircraft indicated airspeed.

The crew then selected FL160 as new cruise FL, the aircraft climbed and the airspeed decayed from 200kt to 170kt. When aircraft approached FL160 (preselected cruise level), the DEGRADED PERFORMANCE and INCREASE SPEED alerts were recorded simultaneously, triggering a MASTER CAUTION alert. The flight crew subsequently performed a reset of the Airframe De-Icing system; however, a new MASTER CAUTION alert was generated, accompanied by a single chime aural warning and associated with the AIRFRAME FAULT message, as indicated by data recorded in the MPCs.

The triggering of the DEGRADED PERFORMANCE alert required that the procedures of section A30.15 of the QRH be executed (Figure 153).

A30.15 DEGRADED PERF

- ► IAS : MAINTAIN ABOVE ICING BUG +10 kt
- ► IAS & V/S : MONITOR
- ► FLIGHT PATH : AMEND

Note

- *It is recommended to accelerate above icing bug + 30 kt.*
- *Refer to OPSDATA to determine recommended maximum icing Flight Level.*

■ **If in icing condition**

- ► ANTI ICING systems .... CHECK ON
- ► DE ICING systems .... CHECK ON

■ **If not able to accelerate and maintain IAS above icing bug +30 kt**

- ► AP .... OFF
- ► LOW BANK .... SET

Note

Refer to PRO.NNO.ABN.30.6.ICE.2.A30.17 SEVERE ICING DETECTION for severe icing indications information

■ **If any severe icing indication**

- ► SEVERE ICING procedure (E99.08) .... APPLY

■ **As long as DEGRADED PERF amber light is ON**

- ► TCAS .... TA ONLY

► ICING CONDITIONS : MONITOR

Figure 153 – Procedures following the APM DEGRADED PERFORMANCE alert, as per the aircraft QRH.

The IAS was to be maintained above ICING BUG + 10 kt, the IAS and vertical speed monitored, and the flight path amended as necessary.

The procedure recommended accelerating the aircraft above ICING BUG + 30 kt. The OPSDATA (Operational Data) was to be consulted to determine the maximum recommended flight level in icing conditions.

Once in icing conditions, it was to be verified whether the Anti-Icing and De-Icing systems were turned on. If not able to accelerate and maintain the IAS above ICING BUG + 30 kt, the autopilot was to be disengaged and the LOW BANK mode selected.

For information on the indications of severe icing, the procedure PRO.NNO.ABN.30.6.ICE.2.A30.17-SEVERE ICING DETECTION was to be consulted. Upon observation of any indication of severe icing, the SEVERE ICING procedure, contained in reference E99.08, was to be executed.

While the amber DEGRADED PERF light remained illuminated, the Traffic Collision Avoidance System (TCAS) was to be used only in Traffic Advisory (TA) mode, and icing conditions were to continue to be monitored.

The triggering of the INCREASE SPEED alert required that the procedures of section A30.16 of the QRH be executed (Figure 154)

A30.16 INCREASE SPEED

- ► IAS : ICING BUG +30 kt
- ► SEVERE ICING procedure (E99.08) .... APPLY

Figure 154 - Procedure prescribed following the APM Increase Speed alert, extracted from the aircraft's QRH.

The procedure related to the INCREASE SPEED alert required that the IAS be adjusted to ICING BUG + 30 kt. Additionally, the SEVERE ICING procedure, contained in reference E99.08, was to be applied.

It is important to note that the first item was considered a memory item, as it was highlighted by a box-format line.

The procedures for SEVERE ICING (E99.08), referenced in the PROCEDURE FOR ICING CONDITIONS (Figure 143), in section A30.17 (SEVERE ICING DETECTION – Figure 151), in section A30.15 (DEGRADED PERF – Figure 153), and in section A30.16 (INCREASE SPEED – Figure 154), are shown in Figure 155 below.

_7442ce17-701e-4142-b39e-038dde74f989 01 AUG 2023

SEVERE ICING **E99.08**

► IAS : ICING BUG + 30 kt (or ICING BUG IF FLAPS 15 EXTENDED)
► PWR MGT .... MCT
► PL 1+2 .... ADJUST
► CL 1+2 .... 100 % OVRD
► DESCENT .... INITIATE
► MEA / RECOMMENDED MAXIMUM ICING FLIGHT LEVEL .... CHECK

CAUTION
Firmly hold control column and wheel to avoid non-expected aircraft movements at AP disengagement

► AP .... DISENGAGE

■ **If not able to accelerate and maintain IAS above ICING BUG + 30 kt with flaps 0**

- OR -

■ **If not able to accelerate and maintain IAS above ICING BUG with flaps 15**
► LOW BANK .... SET
► SEVERE ICING CONDITION .... ESCAPE
► ATC .... NOTIFY
■ **If abnormal aircraft roll behavior**
► STALL procedure (E99.09) .... APPLY
● **As long as aircraft is not clear of ice**
► FLAPS : DO NOT RETRACT
► TCAS .... TA ONLY
● **For landing**
► APPROACH CONFIGURATION .... FLAPS 15
HIGH BANK CAN BE SET
► REDUCED FLAPS LANDING procedure (A27.05) .... APPLY

Note
Refer to PRO.NNO.ABN.30.6.ICE.2.A30.17 SEVERE ICING DETECTION for information on severe icing indications.

Figure 155 – Procedures prescribed for the Severe Icing condition, as per the aircraft QRH.

In this case, the QRH prescribed the following procedures:

- maintain the speed corresponding to the ICING BUG + 30 kt (or ICING BUG, if with flaps extended to 15°);

- select maximum continuous power (PWR MGT - MCT);

- adjust the power levers 1 + 2; and

- select the Condition Levers (CL) to 100% Override (OVRD)

It is important to note that the first four items of the checklist, highlighted within a boxed line, were considered memory items and were to be performed prior to consulting the checklist.

Subsequently, the following actions were also prescribed:

- initiate the descent
- checking the minimum en route altitude / recommended maximum icing flight level;
- hold the control column firmly to prevent unexpected movements upon AP disengagement; and
- disengage the AP.

Additionally, if it was not possible to accelerate the aircraft and maintain the IAS above ICING BUG + 30 kt with flaps at 0°, or above ICING BUG with flaps at 15°, the procedure prescribed the following actions:

- set LOW BANK mode;

- escape from the severe icing condition;
- notify Air Traffic Control (ATC);

In the event of abnormal aircraft roll behavior:

- the stall recovery procedure should be applied;

As long as the aircraft was not clear of ice:

- flaps should not be retracted; and
- the TCAS should be selected to TA ONLY.

During the performance degradation and the consequent reduction in speed, the aircraft reached an IAS of 161 kt with an AOA of 6°. It is worth noting that the Weight Rotator Position on the APM panel was set to 22.5 tonnes. For this weight, the VmLB0icing (ICING BUG) speed corresponded to 167 kt, 6 kt above the speed reached by the aircraft during the performance degradation.

According to the communications carried out with the air traffic control units, the flight crew requested a descent from FL160 to FL140 due to icing conditions. The descent was conducted with the AP engaged in VS mode, at a descent rate of 1,500 ft/min, with wings level and no turns performed (with zero bank angle).

Approximately 2 minutes and 30 seconds after the APM alerts were issued, there was an increase in indicated airspeed and a reduction in AOA resulting from the aircraft's descent. This condition led to the cessation of the DEGRADED PERFORMANCE and INCREASE SPEED alerts.

It is worth noting that, after leveling off and establishing cruise flight at FL140, the CRUISE SPEED LOW alert, also generated by the APM, was activated on two additional occasions. During the same period, icing was detected on five additional occasions.

The graphs in Figures 152 and 156 present the same time interval, with the same parameters selected, but with ellipses highlighting different conditions. To facilitate correlation, a vertical orange baseline was marked at the same point, corresponding to the same moment in time, in both graphs, aiding visual orientation.

In Figure 156, the green ellipses highlight moments when the two AOA sensors began to register discrepant values. When this difference exceeded 4° for more than 5 seconds, the MFC inhibited the availability of the stick pusher and stick shaker system. As a result, a MASTER CAUTION alert was generated, accompanied by the single chime aural warning and illumination of the FAULT light on the STICK PUSHER/SHAKER button.

The F/O ALPHA PROBE HEAT message, related to the heating of the right-side AOA sensor, was recorded 16 times by the MPC during this flight.

The STICK PUSHER FLT message was also recorded by the MFC; however, it is important to note that the AOA threshold for stick pusher activation was not reached during this flight.

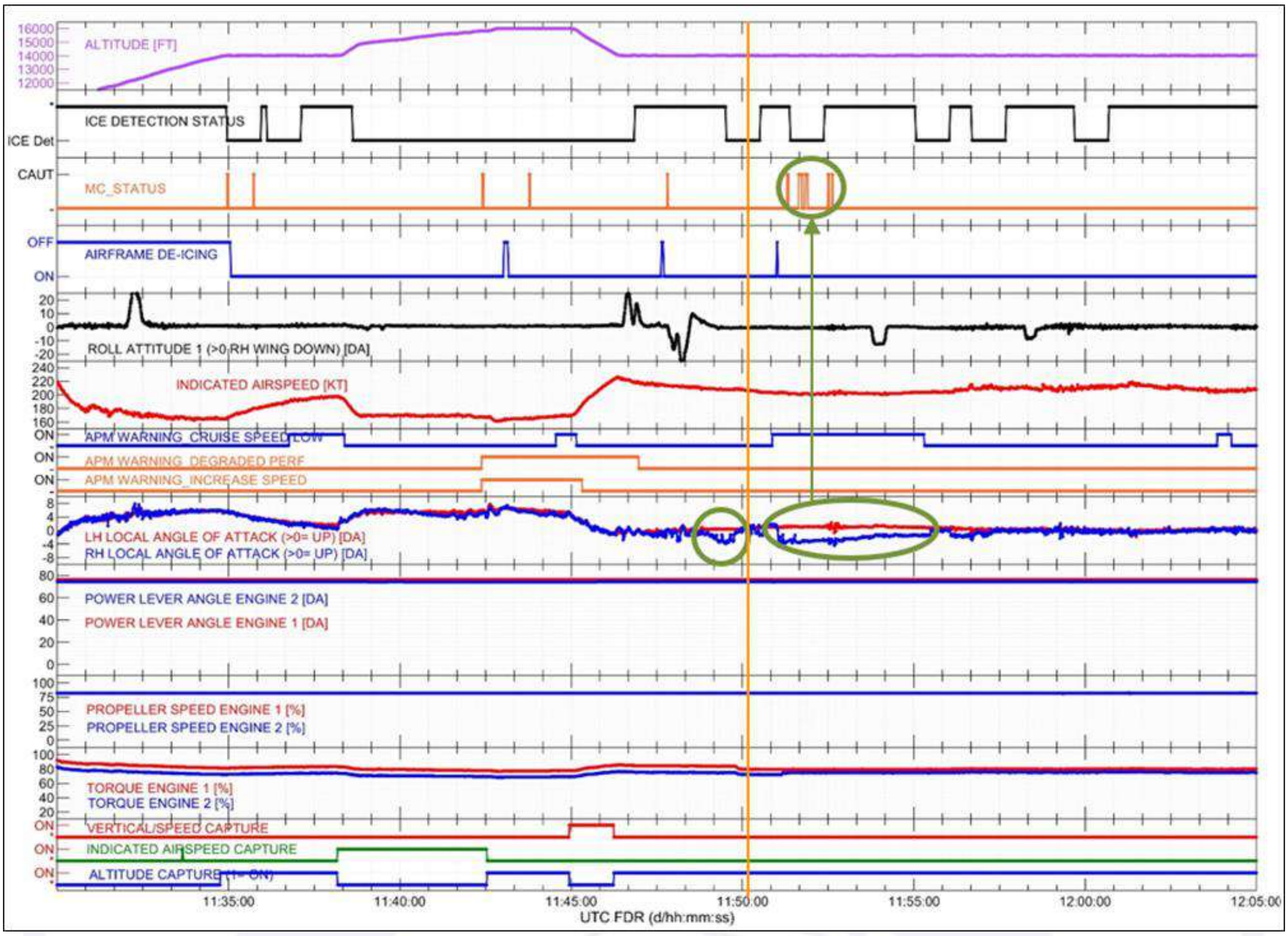


Figure 156 – Graph of flight data parameters, highlighting moments when the two AOA sensors began to register discrepant values, with activation of the MASTER CAUTION alert.

Once the values measured by the two AOA sensors returned to agreement, the alert was suppressed and the stick pusher system resumed its normal functionality. This discrepancy between the values recorded by the AOA sensors did not occur during the accident flight.

Still during this flight, the aircraft climbed to FL160 and subsequently to FL170, before beginning its descent to Cascavel airport.

During the descent, the CVR recorded a comment between the pilots regarding a "noise" associated with ice shedding from the aircraft.

Similarly to what was observed in flights "-3" and "-2", no record of any malfunction in the Airframe De-Icing system was found, nor any record of dispatch under specific MEL conditions in the aircraft's TLB.

1.18.2. Accident Flight

The SIPAER Investigation Commission verified that the DOV (flight operations dispatcher) from *Cascavel* (SBCA) prepared the meteorological data documentation at 10:18:11 UTC.

Such documentation contained, among other data, the 10:00 UTC METAR (Meteorological Aerodrome Report) for SBGR and SBRP (*Leite Lopes* Aerodrome, *Ribeirão Preto*, SP), the 08:45 UTC TAF for SBGR and SBRP, and the SIGMETs 02 and 03 for SBCW, with validity between 07:30 UTC and 11:30 UTC, according to Figure 157.

WX for flight **2283-SBCA-SBGR** (STD 091440)

WX search performed 2024-08-09 10:18:11 UTC for METAR, TAF and SIGMET messages.

TAF and METAR reports are searched for following airport ICAO list:
Departure airport: SBCA.
Destination airport: SBGR.
Alternate airport(s): SBRP.
Adequate airport(s): SBRP.
SIGMET reports are searched for following FIR ICAO list:
SBCW SBBS.

Departure airport SBCA - CAC - CASCAVEL/AEROPORTO REGIONAL DO VAR W18 RWY 15 33
: No METAR or TAF found

Destination airport SBGR - GRU - SAO PAULO/GUARULHOS - GOV.A.F. VAR W22 RWY 10L 10R 28L 28R

```
METAR  091000Z  04005KT CAVOK 19/15 Q1018=
TAF    090845Z  0912/1018 30010KT 8000 BKN030 TX21/0916Z TN11/1011Z PROB30
       0912/0913 4000 RA BR BKN015 BECMG 0914/0916 27007KT RA BKN020 BECMG 0920/0922
       18005KT 6000 RA BKN015 TEMPO 1000/1006 16010KT 4000 RA BR BKN008 PROB30 TEMPO
       1008/1013 2000 DZ BR BKN004 BECMG 1016/1018 16007KT 8000 NSW BKN017 RMK PGH=
```

Alternate airport SBRP - RAO - RIBEIRAO PRETO/LEITE LOPES VAR W22 RWY 18 36

```
METAR  091000Z  00000KT 8000 NSC 19/11 Q1017=
TAF    090845Z  0912/0924 18005KT CAVOK TX28/0917Z TN20/0923Z BECMG 0912/0914
       SCT030 BECMG 0916/0918 25010KT PROB30 0920/0923 VCSH SCT030 FEW040TCU RMK PGH=
```

WX messages for adequate airports previously listed as departure, destination or alternate airport are not repeated.

SIGMET(s) for SBCW FIR

```
WSBZ23 SBGL 090725
SBCW SIGMET 3 VALID 090730/091130 SBCW -
SBCW CURITIBA FIR SEV TURB FCST WI S2511 W05412 - S2605 W05327 - S2659 W05332 - S3109
W04738 - S2930 W04601 - S2818 W04502 - S2758 W04553 - S2302 W05210 - S2511 W05412
FL230/410 STNR NC=

WSBZ23 SBGL 090725
SBCW SIGMET 2 VALID 090730/091130 SBCW -
SBCW CURITIBA FIR SEV ICE FCST WI S2148 W05608 - S2903 W04539 - S2645 W04345 - S2627
W04321 - S1953 W05444 - S2148 W05608 FL120/180 STNR NC=
```

End of WX information

Figure 157 – Excerpt from the dispatch documentation showing the time the document was prepared.

It was further verified that the flight operations dispatcher (DOV) produced another document containing updated meteorological information minutes before the aircraft landed at SBCA, which occurred at 14:15 UTC.

This new documentation contained, among other data, the 14:00 UTC METARs for SBCA and SBRP; the 14:20 UTC SPECI (Aviation Selected Special Weather Report) for SBGR; the 08:45 UTC TAF for SBCA, SBGR and SBRP; the GAMET (General Aviation Meteorological Forecast) for SBCW valid from 12:00 UTC to 18:00 UTC; and SIGMETs 05, 06,and 07 for SBCW with validity from 11:30 UTC to 15:30 UTC, as shown in Figure 158.

Balanceamento | Navegação/Notam

Imprimir

Plano de Voo

Comandante:	[redacted]	ANAC	[redacted]	Ass.	
DOV:	[redacted]				

```
METAR SBCA 091400Z 19010KT 9999 SCT006 BKN100 08/05 Q1023=

SPECI SBGR 091420Z 30012KT 5000 -RA BKN040 OVC070 19/13 Q1021=

METAR SBRP 091400Z 19010KT 8000 NSC 25/12 Q1020=

TAF SBCA 090845Z 0912/0924 20015KT 4000 BR BKN004 TX13/0916Z TN07/0923Z
PROB30 0912/0913 0800 FG OVC001
BECMG 0914/0916 8000 NSW BKN030
BECMG 0918/0920 CAVOK RMK PGH=

TAF SBGR 090845Z 0912/1018 30010KT 8000 BKN030 TX21/0916Z TN11/1011Z
PROB30 0912/0913 4000 RA BR BKN015
BECMG 0914/0916 27007KT RA BKN020
BECMG 0920/0922 18005KT 6000 RA BKN015
TEMPO 1000/1006 16010KT 4000 RA BR BKN008
PROB30 TEMPO 1008/1013 2000 DZ BR BKN004
BECMG 1016/1018 16007KT 8000 NSW BKN017 RMK PGH=

TAF SBRP 090845Z 0912/0924 18005KT CAVOK TX28/0917Z TN20/0923Z
BECMG 0912/0914 SCT030
BECMG 0916/0918 25010KT
PROB30 0920/0923 VCSH SCT030 FEW040TCU RMK PGH=

SBCW GAMET VALID 091200/091800 SBGL- SBCW CURITIBA FIR BLW FL100 SECN I SFC
VIS: N OF S26 4900M RA N OF S26 AND E OF W050 4000M BR
SIGWX: N OF S26 ISOL TS MT
OBSC: SERRA GERAL SIG
CLD: N OF S26 ISOL CB 2500/ABV 10000FT
AGL N OF S26 ISOL TCU 2500/ABV 10000FT
AGL N OF S26 BKN 700/1500FT
AGL 12/16 S OF S29 BKN 900/1500FT
AGL
TURB: MOD ABV FL040 SECN II
PSYS: NIL WIND/
T: 2000FT S OF S26 250/18KT PS04 N OF S26 180/25KT PS18 5000FT S OF S26 240/35KT MS01 N OF S26 180/25KT PS09 10000FT S OF S26 250/35KT MS05 N OF S26 300/40KT PS05
CLD: BKN CU 2000/4000FT
AGL SCT AC 7000/10000FT
AGL BKN SC 1400/5000FT
AGL
FZLVL: S OF S26 ABV 6000FT AGL N OF S26 ABV 10000FT AGL MNM
QNH: 1013HPA
SEA: T20 HGT 2M
VA: NIL=


SBCW SIGMET 5 VALID 091130/091530 SBCW
SBCW CURITIBA FIR SEV TURB FCST WI S2511 W05412
S2605 W05327
S2659 W05332
S3109 W04738
S2930 W04601
S2818 W04502
S2758 W04553
S2302 W05210
S2511 W05412 FL230/410 STNR NC=

SBCW SIGMET 6 VALID 091130/091530 SBCW
SBCW CURITIBA FIR SEV ICE FCST WI S2048 W05721
S2548 W05027
S2900 W04536
S2645 W04345
S2515 W04148
S2234 W04535
S2248 W04546
S2314 W04552
S2338 W04639
S2307 W04734
S2220 W04955
S2020 W05127
S1743 W05350
S1731 W05411
S1826 W05607
S2048 W05721 FL120/210 STNR NC=

SBCW SIGMET 7 VALID 091130/091530 SBCW
SBCW CURITIBA FIR EMBD TS FCST WI S2758 W04549
S2832 W04513
S2646 W04346
S2618 W04438
S2634 W04533
S2758 W04549 TOP FL450 STNR NC=
```

Figure 158 – Excerpt from the dispatch documentation containing updated meteorological information.

It was verified, through the acknowledgment signature on the dispatch documents, that the flight crew received not only the document containing the earlier information, but also a new document with the most updated information, including SBCW SIGMET 06, which contained meteorological information forecasting the occurrence of SEV ICE in the region encompassing the PS-VPB aircraft's route on that flight.

SIGMET 09 for SBCW and SIGMET 02 for SBBS also indicated the presence of SEV ICE along the route and at the aircraft's flight level at the time of the occurrence; however, the pilots did not have access to these messages through the documentation provided by the flight operations dispatcher during the ground time at SBCA aerodrome, as the messages were issued at 15:15 UTC and 15:14 UTC, respectively.

According to the flight plan, the Estimated Off-Block Time (EOBT) was 14:40 UTC, and the aircraft was to follow a route comprising the ROKIR, EDVAK, and BUXUK fixes, thereafter proceeding to the destination, with an estimated flight time of 1 hour and 55 minutes.

The planned cruise level was FL170, which corresponded to the maximum operational ceiling permitted due to the unavailability of the left air conditioning and pressurization unit. In addition to Pack No. 1, there were nine other MEL items recorded in the dispatch documentation.

The aircraft had a basic weight of 13,728 kg. Due to prior knowledge of degraded meteorological conditions along the route, the flight dispatcher (DOV) at SBCA requested that the aircraft be fueled with an additional 311 kg of fuel, resulting in a total of 3,200 kg of fuel on board. The endurance declared in the flight plan was 3 hours and 55 minutes.

Considering the weight of the passengers, the cargo carried, and the fuel consumed on the ground, the takeoff weight was estimated at 21,665 kg, with the CG at 26.9% of the Mean Aerodynamic Chord, within the operational envelope (green point in Figure 159).

Based on the flight time and the average consumption derived from the FDR fuel flow data, it was calculated that, at the time of the accident, the aircraft had approximately 2,189 kg of fuel on board, corresponding to a total weight of 20,654 kg and a CG at 26.3% of the Mean Aerodynamic Chord (red point in Figure 159). Ice accretion was not considered in the weight and balance calculation at the time of the accident.

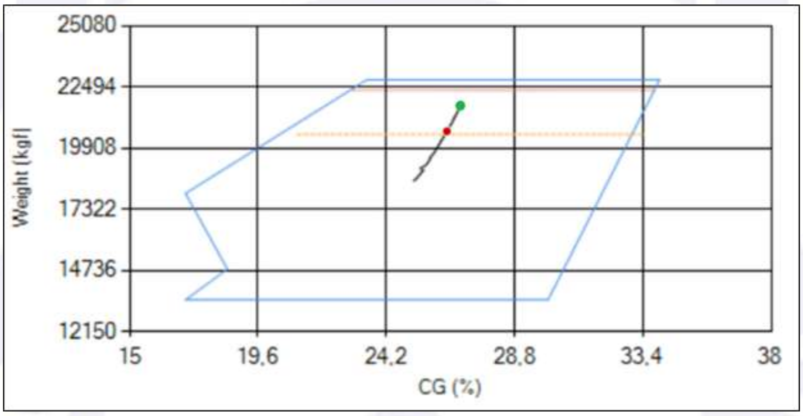


Figure 159 – Aircraft weight and balance envelope showing the estimated weight and CG position, without considering ice accretion.
Source: Adapted from the operator’s WEIGHT & BALANCE AND TAKEOFF COMPUTATION.

Based on the CVR recordings, during the execution of the preflight procedures, the pilots mentioned that the ICING BUG would be set to a speed of 165 kt, corroborating the Investigation Commission’s calculations for a takeoff weight close to 22 tonnes (Figure 160).

TAKE OFF SPEEDS (NON LIMITING RWY)				MIN. ENROUTE		LANDING SPEEDS	
ATOW (KGx1000)	V1=VR	V2	VFTO NORM FLAPS 0	VMLB0 NORM FLAPS 0	VMLB0 ICING FLAPS 0	VMHB30 NORM FLAPS 30	VGA NORM FLAPS 15
15K	104	110	114	114	136	95*	101**
16K	104	110	118	118	141	95*	104**
17K	104	110	122	122	146	96*	107**
18K	104	110	125	126	150	99	110
19K	104	110	129	129	154	101	114
20K	106	110	132	133	158	104	117
21K	108	111	136	136	162	107	120
21.5K	109	113	138	138	164	109	121
22K	111	114	140	139	165	110	124
22.5K	112	115	141	141	167	112	124
23K	113	117	143	143	169	113	127

Figure 160 – Identification of the VmLB0icing for a takeoff weight of 22 tonnes.
Source: OPS Data ATR-72-500, code L-OPR-FST-006-20-02.

According to the CVR audio recordings, the Investigation Commission determined that the PIC was acting as Pilot Flying and the SIC as Pilot Monitoring.

Furthermore, PIC's airspeed indicator (Figure 161) was found at the accident site with the ICING BUG (RED BUG) speed set close to the calculated value, indicating that the pilots did, in fact, set the VmLB0icing speed as reflected in the audio recordings. However, it was not possible to identify the position of the SPEED BUG on the airspeed indicator.

Figure 161 – PIC's airspeed indicator with the RED BUG set to a speed close to 165 kt.

Based on the analysis of the recorded data, it was verified that the takeoff from SBCA occurred at 14:58:05 UTC, with the APM Weight Rotator Position set to 22 tonnes.

After takeoff, the AP was engaged at 14:59:54 UTC, with LNAV (lateral control mode) and IAS mode selected at 173 kt, and ALT SEL set to 17,000 ft.

Figure 162 shows the data recorded from the beginning of the climb of PS-VPB.

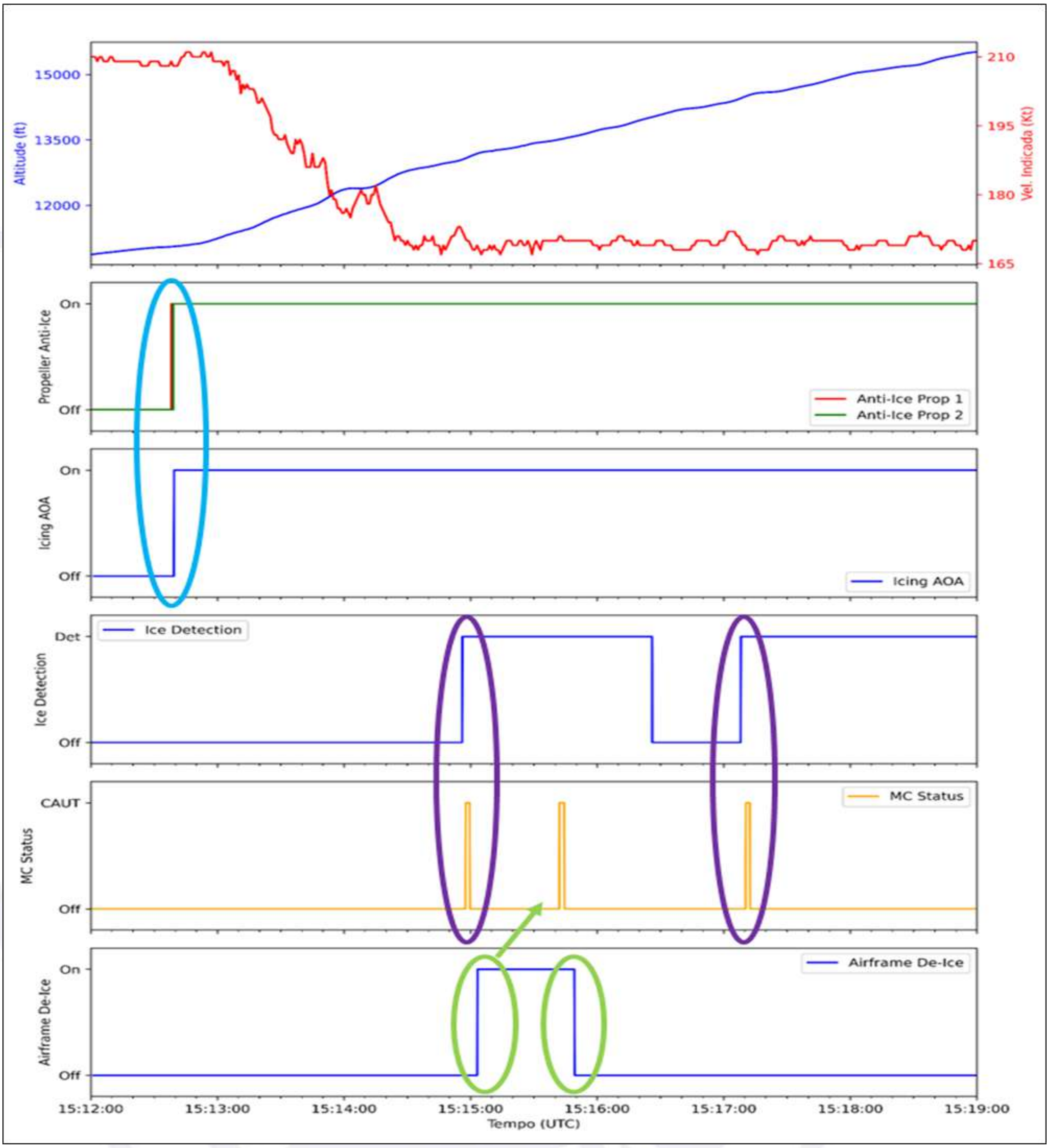


Figure 162 – Graph of flight data parameters highlighting information from systems related to ice detection and Anti-Icing/De-Icing.

The blue ellipse highlights the moment when the level 2 Anti-Icing systems were activated. The purple ellipses indicate the moments when icing was detected by the Electronic Ice Detector, along with the triggering of the MASTER CAUTION alert. The green ellipses refer to the moments of activation and deactivation of the Airframe De-Icing system. The green arrow indicates another instance of MASTER CAUTION alert activation. Data recorded in the non-volatile memories of the MFCs indicated that this alert was associated with the Right Wing Boot B Fault message.

During the climb phase, at 15:12:40 UTC, while passing approximately FL110, the flight crew activated the propeller and probe Anti-Icing systems (level 2), in accordance with the operational procedures prescribed for flight in conditions conducive to icing. From that moment on, the green ICING AOA light remained illuminated, indicating that the stall warning thresholds had been redefined for icing conditions.

At 15:14:56 UTC, while passing approximately FL130, the Electronic Ice Detector detected ice accretion, triggering a MASTER CAUTION alert, accompanied by a single chime aural warning and illumination of the ICING light on the ICE DETECT panel. At that moment, the MPC recorded an ice detection message while the De-Icing system was off (ICE DETECTED WHILE D/ICE SYSTEM IS OFF).

At 15:15:03 UTC, seven seconds after the ICING light was activated, the aircraft's Airframe De-Icing system was turned on. No evidence was found in the CVR recordings of the PROCEDURE FOR ICE CONDITIONS being read.

At 15:15:42 UTC, 39 seconds after activation of the Airframe De-Icing system, a MASTER CAUTION alert, accompanied by a single chime, was triggered in the cockpit. At that moment, the MPC recorded the fault message AIRFRAME FAULT, associated with the operation of the right-wing boots (Right Wing Boot B Fault). The FDR data indicated that no attempt was made by the pilots to reset the Airframe De-Icing system following the failure.

According to the aircraft QRH, given the Airframe De-icing system failure condition, the DE ICING AIRFRAME FAULT procedure should have been executed by the flight crew (Figure 147). The FDR data indicated that the Airframe De-Icing system was manually turned off by the flight crew at 15:15:49 UTC, complying with one of the items prescribed in the QRH. The SIC stated that the Airframe De-Icing system malfunction was not recorded in the TLB, and that, in order to avoid icing, they would have to conduct the flight at FL110. No response from the PIC to the SIC's remark was recorded on the CVR.

At 15:16:26 UTC, 37 seconds after the Airframe De-Icing system was switched off, the ICING alert was deactivated. At 15:17:10 UTC, a new MASTER CAUTION warning was recorded, this time with a renewed detection of icing conditions, as again indicated by the Electronic Ice Detector (ICING light).

Level-off at FL170 occurred at approximately 15:22 UTC through AP operation, capturing the selected flight level (ALT SEL) and subsequently maintaining the assigned altitude of 17,000 ft in ALT HOLD vertical mode.

After the aircraft leveled off at FL170, critical events related to ice accretion and aerodynamic performance degradation were identified, with a consequent reduction in the aircraft's IAS (Figure 163).

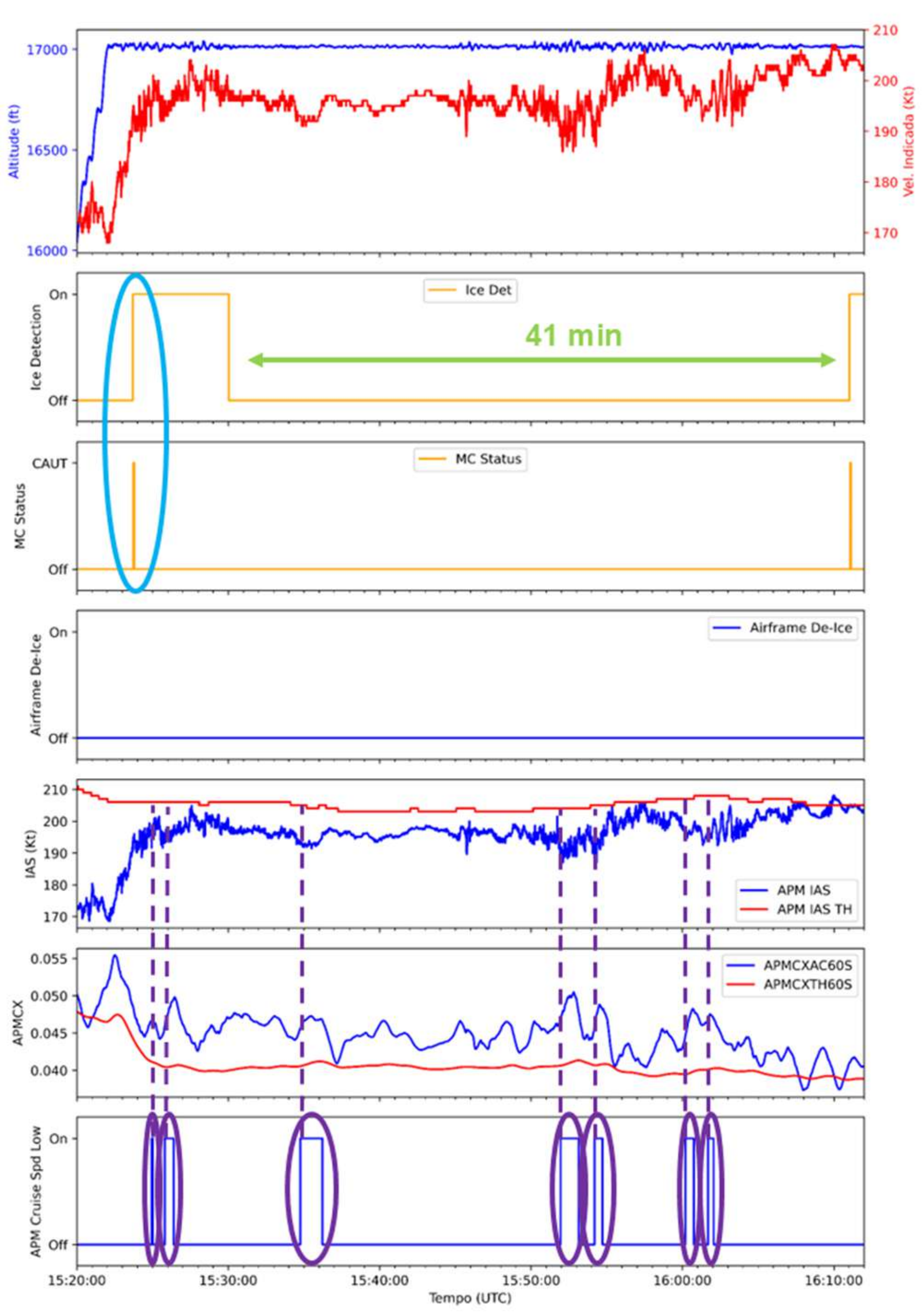


Figure 163 – Graph of flight data parameters highlighting the moments of ice detection and the warnings/alerts issued.

At 15:23:42 UTC, approximately two minutes after the aircraft leveled off at FL170, the Electronic Ice Detector indicated ice accretion, which was accompanied by the issuance of a MASTER CAUTION alert (blue ellipse) and the automatic recording by the MPC of a message related to ice detection while the De-Icing system was not activated (ICE DETECTED WHILE D/ICE SYSTEM IS OFF).

In that phase of the flight, seven additional distinct episodes were also identified (purple ellipses) in which the APM issued the CRUISE SPEED LOW alert, indicating different moments when the aircraft’s indicated airspeed (APM IAS) was at least 10 kt below the theoretical speed computed by the APM (APM IAS TH) with the calculated average drag at least 10% higher than the theoretical drag prescribed by the APM (APMCXTH60s) for cruise flight.

The CRUISE SPEED LOW alerts occurred in two distinct moments: the first two coincided with ice accretion detection by the Electronic Ice Detector. The remaining five were triggered over an interval of approximately 41 minutes (green arrow), during which no ice accretion was detected by the Electronic Ice Detector.

The SIPAER Investigation Commission was unable to identify, based on the CVR recordings, any acknowledgment or processing of these warnings/alerts, nor the execution of the corresponding procedures prescribed in the checklist.

It was also verified that the Airframe De-Icing system remained off during the interval in which the warnings/alerts occurred.

After an interval of approximately 41 minutes without detection, indications of ice accretion were again observed at three distinct moments (blue ellipses in Figure 164). These three detections, identified by the Electronic Ice Detector, were associated with three MASTER CAUTION alerts.

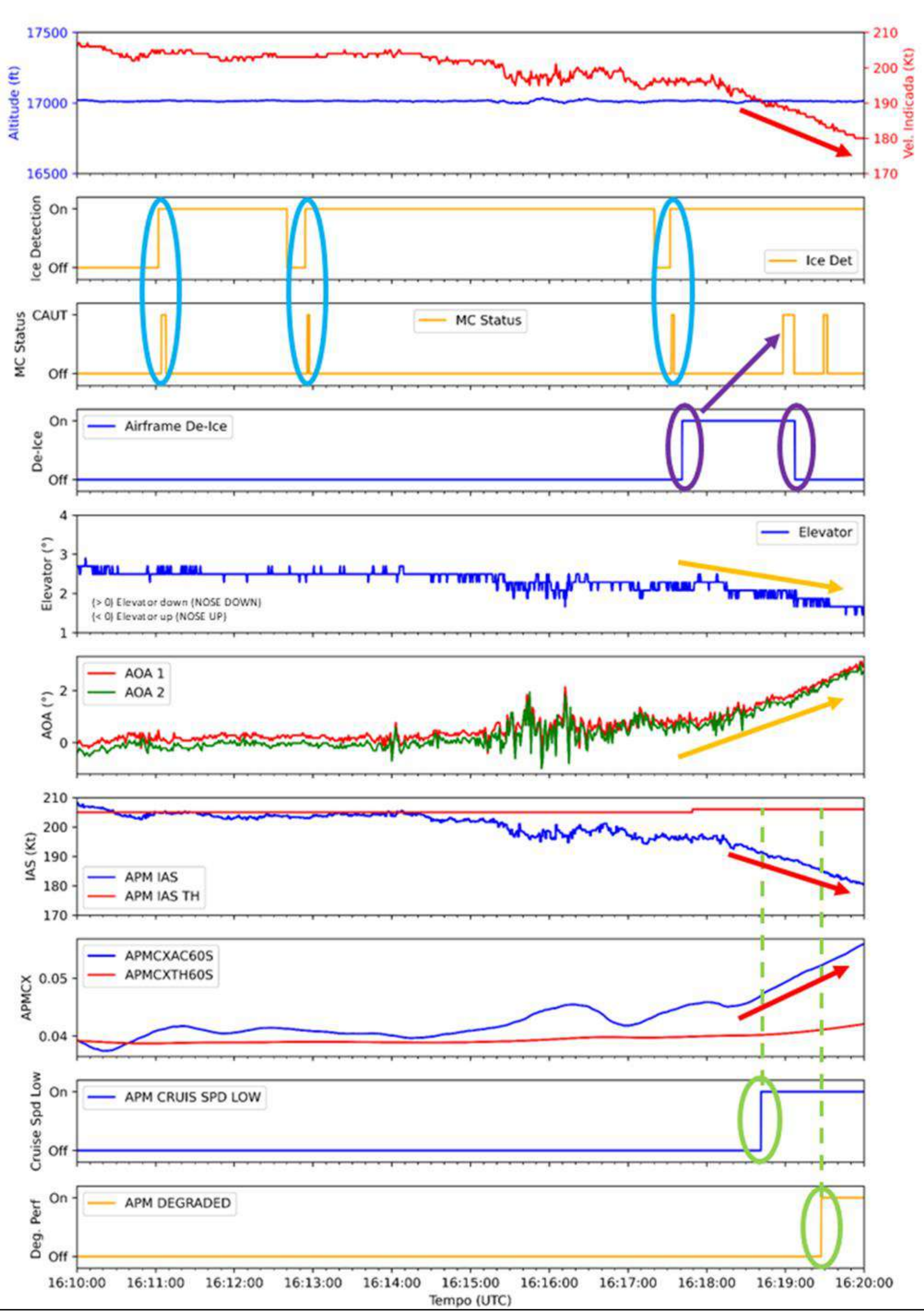


Figure 164 – Graph of flight data parameters highlighting the moments of ice detection, degradation of indicated airspeed, and the warnings/alerts issued by the APM during the cruise phase.

It is noteworthy that, during the approximately 6-minute interval between the three ice accretion detections, the Airframe De-Icing system remained off, while the Anti-Icing system remained active. After the third ice accretion detection, at 16:17:41 UTC, the flight crew activated the Airframe De-Icing system (first purple ellipse).

At 16:17:33 UTC, during the speech, the third icing detection by the Electronic Ice Detector occurred, triggering the MASTER CAUTION alert associated with the single chime aural warning. Subsequently, at 16:17:41 UTC, the Airframe De-Icing system was turned on.

It was observed, during this cruise interval, an increase of drag calculated by the APM, and a decrease in the speed (red arrows). As a consequence, the AP commanded an elevator deflection in the nose-up direction. This deflection was intended to increase the AOA (orange arrows) in order to maintain the altitude since the ALT HOLD mode was engaged. It is important to note that, during this cruise period, there was no variation in the engine or propeller parameters.

At that moment, the SIC was communicating with the company base at SBGR (Dispatch), while the PIC was coordinating with APP-SP for the approach to the destination airport. At 16:18:24 UTC, the PIC reported that the aircraft was at the optimal top-of-descent point, and APP-SP instructed them to maintain FL170.

At 16:18:42 UTC, upon reaching an airspeed of 191 kt and with the drag calculated by the APM being 16.5% higher than the theoretical value, the last CRUISE SPEED LOW alert was issued (first green ellipse).

At 16:18:58 UTC, a MASTER CAUTION alert occurred (purple arrow). Nine seconds after the MASTER CAUTION alert, the Airframe De-Icing system was turned off (purple ellipse).

At 16:19:23 UTC, APP-SP instructed PS-VPB to maintain FL170 due to traffic restricting its descent. At that moment, the aircraft was flying at FL170, approximately 3 NM away from the GR249 fix.

According to coordination with APP-SP, the GLO1455 traffic, which was temporarily restricting the descent of PS-VPB, was descending through FL149 and positioned at 10 o'clock relative to PS-VPB, approximately 2.7 NM away, following the DOSPI 1A STAR profile (Figure 165).

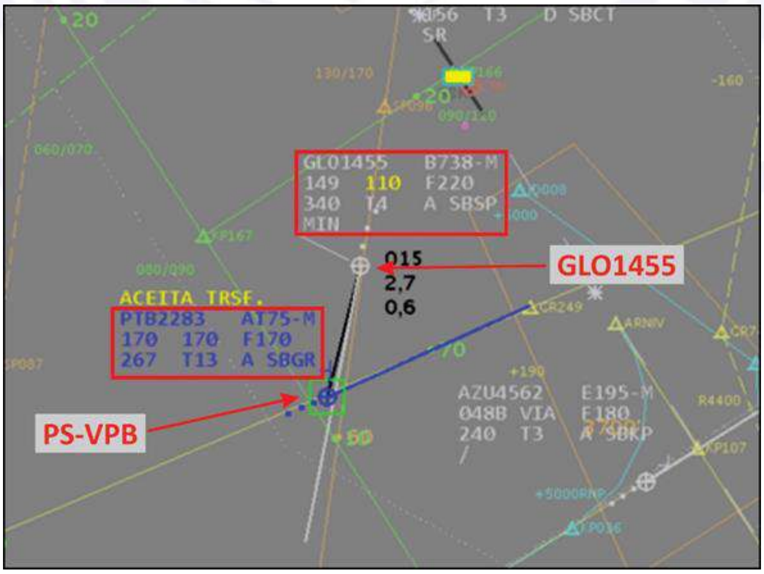


Figure 165 – Radar replay of the moment when PS-VPB (PTB2283) was subject to a descent restriction due to the GLO1455 traffic.
Source: DECEA.

Subsequently, at 16:19:26 UTC, the SIC reported to APP-SP that he would maintain the flight level and was at the optimal top-of-descent point, awaiting clearance.

During these interactions, at 16:19:28 UTC, with an IAS of 185 kt and the drag calculated as 27% higher than that specified by the APM, the DEGRADED PERFORMANCE alert was triggered (as indicated by the green ellipse in Figure 164), accompanied by a MASTER CAUTION alert and a single chime aural warning.

Following the activation of the DEGRADED PERFORMANCE alert, the flight crew ought to carry out the procedures prescribed in the QRH for that condition (Figure 153), including maintenance of the indicated airspeed above ICING BUG + 10 kt, the monitoring of VS and IAS, as well as the change of the aircraft trajectory. If operating under icing conditions, the crew ought to verify whether the Anti-Icing and De-Icing systems were on.

Additionally, there was a recommendation to increase IAS to ICING BUG + 30 kt, and, if acceleration was not possible, the QRH prescribed disengagement of the AP and selection of LOW BANK mode. The checklist also called for the execution of the Severe Icing procedures (Figure 155), should the pilots identify indications consistent with that condition.

Up to that moment, based on the CVR recordings, the flight crew had not made any comments regarding the warnings/alerts already issued by the APM, nor regarding the execution of the prescribed procedures related to the CRUISE SPEED LOW warnings and the DEGRADED PERFORMANCE alert.

At 16:20:04 UTC, the SIC commented on the presence of "significant ice" ("*bastante gelo"*) and stated that he would turn on the Airframe De-Icing system. At that moment, the ICING, CRUISE SPEED LOW, and DEGRADED PERF warnings/alerts were active (Figure 166). The PIC then made a remark indicating that the Airframe De-Icing system was not functioning.

Subsequently, the Airframe De-Icing system was activated for the last time (blue ellipse) at 16:20:05 UTC, and the SIC initiated the reading and execution of the Descent Checklist, completing the task at 16:20:25 UTC. During this interval, a continuous trend of decreasing airspeed and increasing aircraft drag was also observed (red arrows of Figure 166).

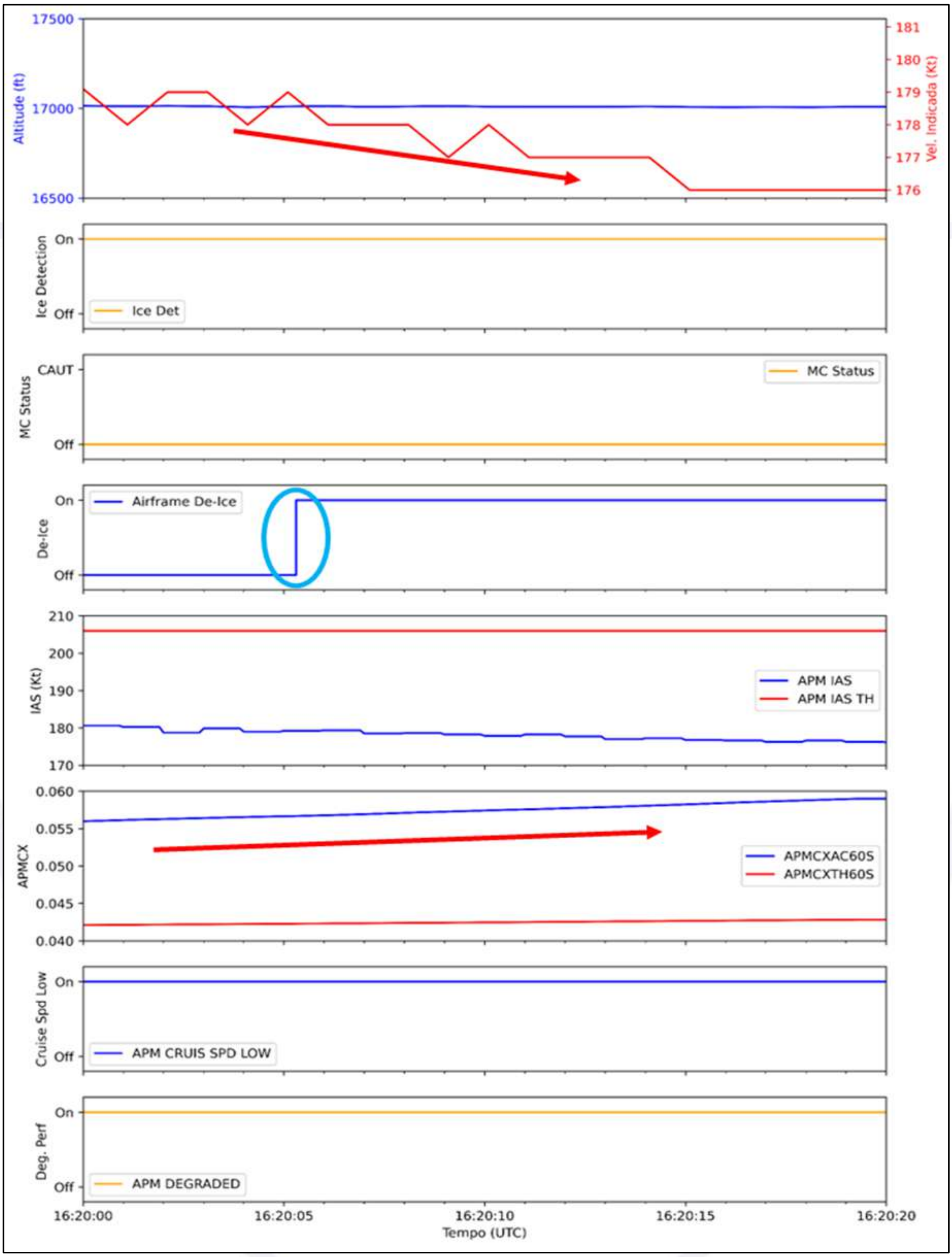


Figure 166 – Graph of flight data parameters highlighting the activation of the Airframe De-Icing system following the DEGRADED PERFORMANCE alert.

At 16:20:33 UTC, APP-SP cleared the aircraft to proceed direct to SANPA, while still maintaining FL170, and advised that descent would be authorized in two minutes. The instruction was acknowledged by the SIC.

At that moment, PS-VPB (PTB2283) was overflying the GR249 fix, maintaining FL170. There was another aircraft in the vicinity restricting its descent (TAM3230) positioned at 2 o'clock relative to PS-VPB, approximately 5.8 NM away, level at FL150 and heading north (Figure 167).

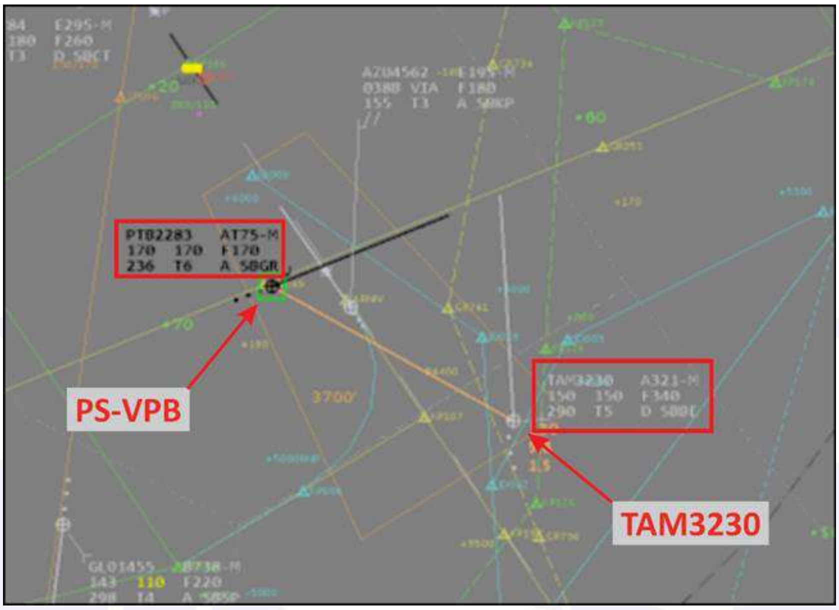


Figure 167 – Radar replay of the moment when PS-VPB (PTB2283) was subject to a descent restriction due to TAM3230 traffic.
Source: DECEA.

At 16:20:49 UTC, the aircraft initiated a right turn, with an IAS of 171 kt. At that moment, the YD and AP were engaged. The following modes were selected: vertical ALT HOLD and lateral LNAV. For this configuration, the bank angle was commanded in HIGH BANK mode. The theoretical speed specified by the APM for the cruise flight condition at that moment was 206 kt.

In order to execute the turn, the AP commanded aileron deflections to induce a right roll (purple ellipse in Figure 168), initiating a right bank as a result of asymmetric aileron deflection, with no initial spoiler deployment. Through the action of the YD, a slight right rudder deflection could be observed for coordination of the turn (purple arrow).

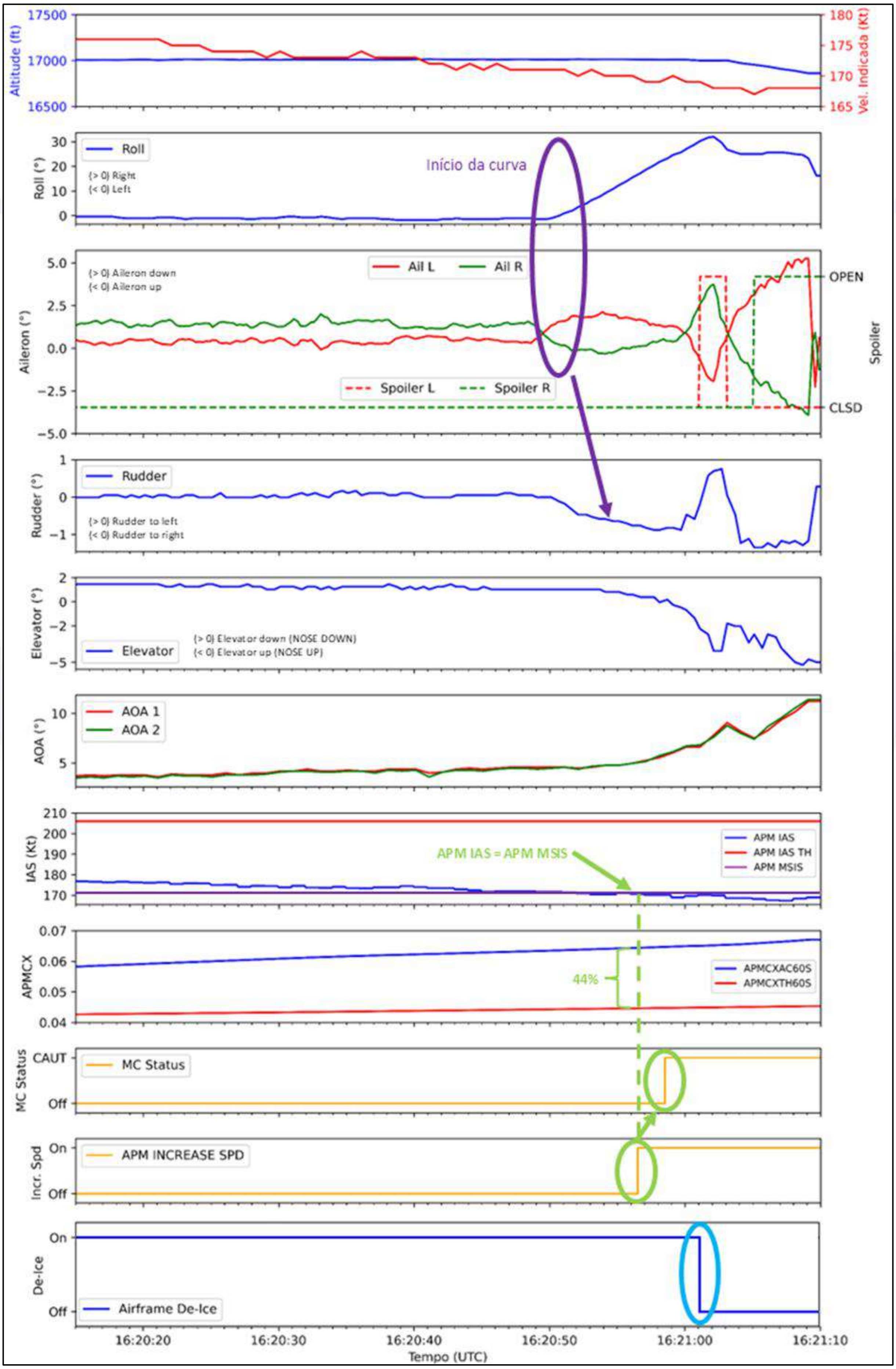


Figure 168 – Graph of flight data parameters highlighting the moments of performance degradation, the alerts issued, and the turn performed by the aircraft.

At 16:20:57 UTC, upon reaching 18° of right bank, the INCREASE SPEED alert was triggered, with the activation of a MASTER CAUTION alert (green ellipses), accompanied by a single chime aural warning, at the moment when the IAS reached the MSIS computed by the APM. At that time, the calculated drag was 44% higher than the theoretical drag specified by the APM.

Based on the flight data and CVR recordings, no flight crew actions were observed to carry out the memory item of the QRH procedure associated with the INCREASE SPEED alert (Figure 154), aimed at achieving the ICING BUG + 30 kt. speed.

The SIPAER Investigation Commission verified that the Airframe De-Icing system was turned off at 16:21:01 UTC, four seconds after the activation of the MASTER CAUTION alert (blue ellipse in Figure 168).

During the turn, the AP sought to achieve the bank angle prescribed for the lateral module in HIGH BANK mode (27°). During this bank angle acquisition, the aircraft reached a maximum value of 32° to the right (Figure 169).

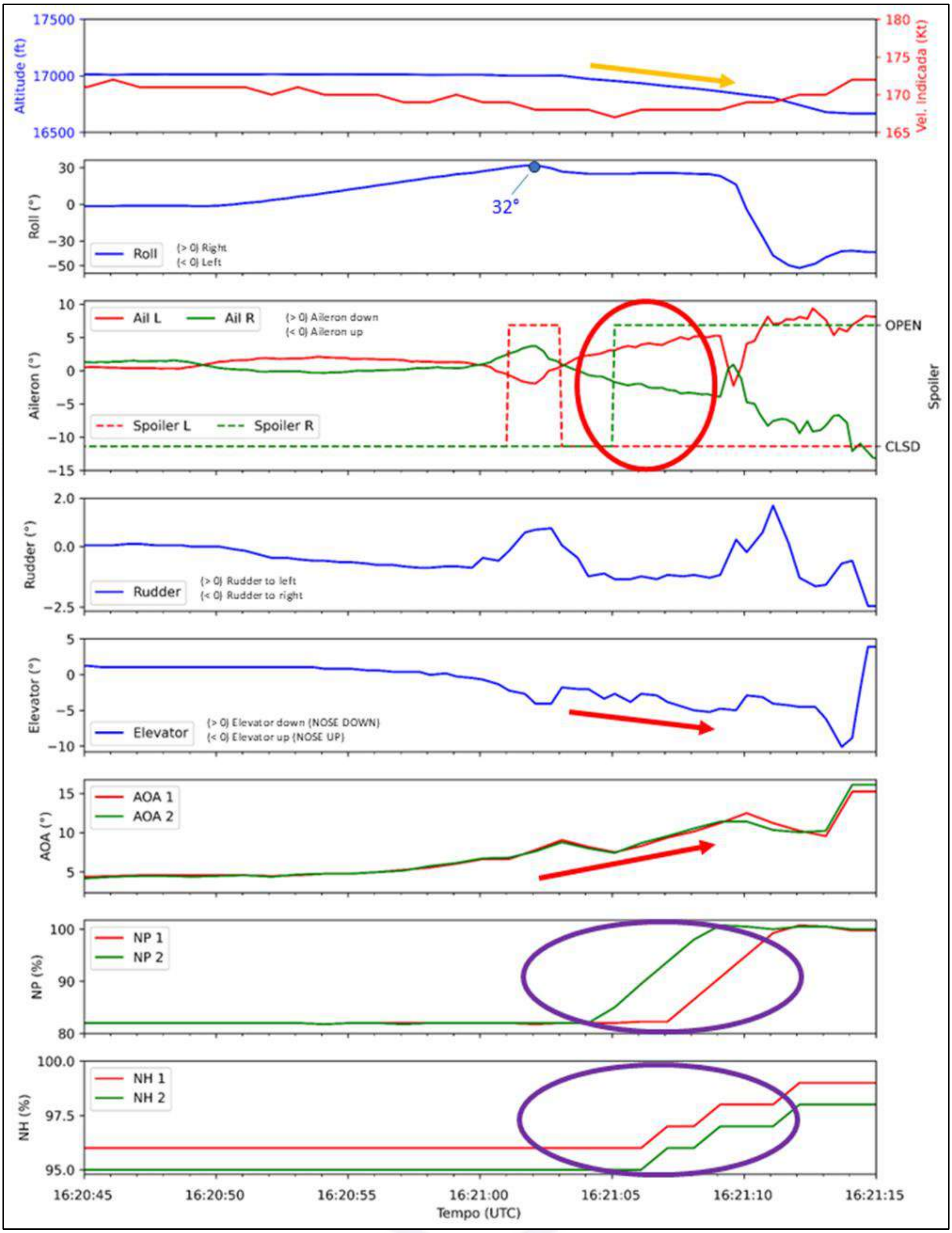


Figure 169 – Graph of flight data parameters highlighting the AP inputs during the turn toward SANPA position.

Subsequently, in order to stabilize the bank angle, the AP reduced the roll rate using left aileron input, which required deployment of the left spoiler. During the bank adjustment, rudder deflections were observed, commanded by the YD to coordinate the turn.

In order to simultaneously maintain the bank angle in HIGH BANK mode and altitude in ALT HOLD, the AP applied progressive elevator deflection to increase the angle of attack (red arrows), seeking the lift required to maintain altitude during the turn, with continuous elevator trim tab deflection as a result of AUTO TRIM.

In the roll axis, in order to maintain a constant bank angle in HIGH BANK mode, the AP applied progressive aileron deflection, which consequently led to the deployment of the right spoiler (red ellipse).

As a result of the AP inputs in the pitch axis, the angle of attack and drag increased significantly, leading to a further decrease in IAS and a progressive loss of altitude (orange arrow).

At that moment, the CVR recorded the SIC commenting on the presence of ice and sounds of intense vibration consistent with the approach to stall (aerodynamic buffet).

Subsequently, just after the onset of altitude loss, an increase in the NL, NH, and NP parameters was recorded, with the latter rising from 82% to 100% in both engines (purple ellipses).

At 16:21:09 UTC, the AOA reached the activation threshold for the stall warning under icing conditions in cruise, at 11.2°, enabling activation of the stick shaker motors on the pilots' control columns (vertical dashed line in Figure 170).

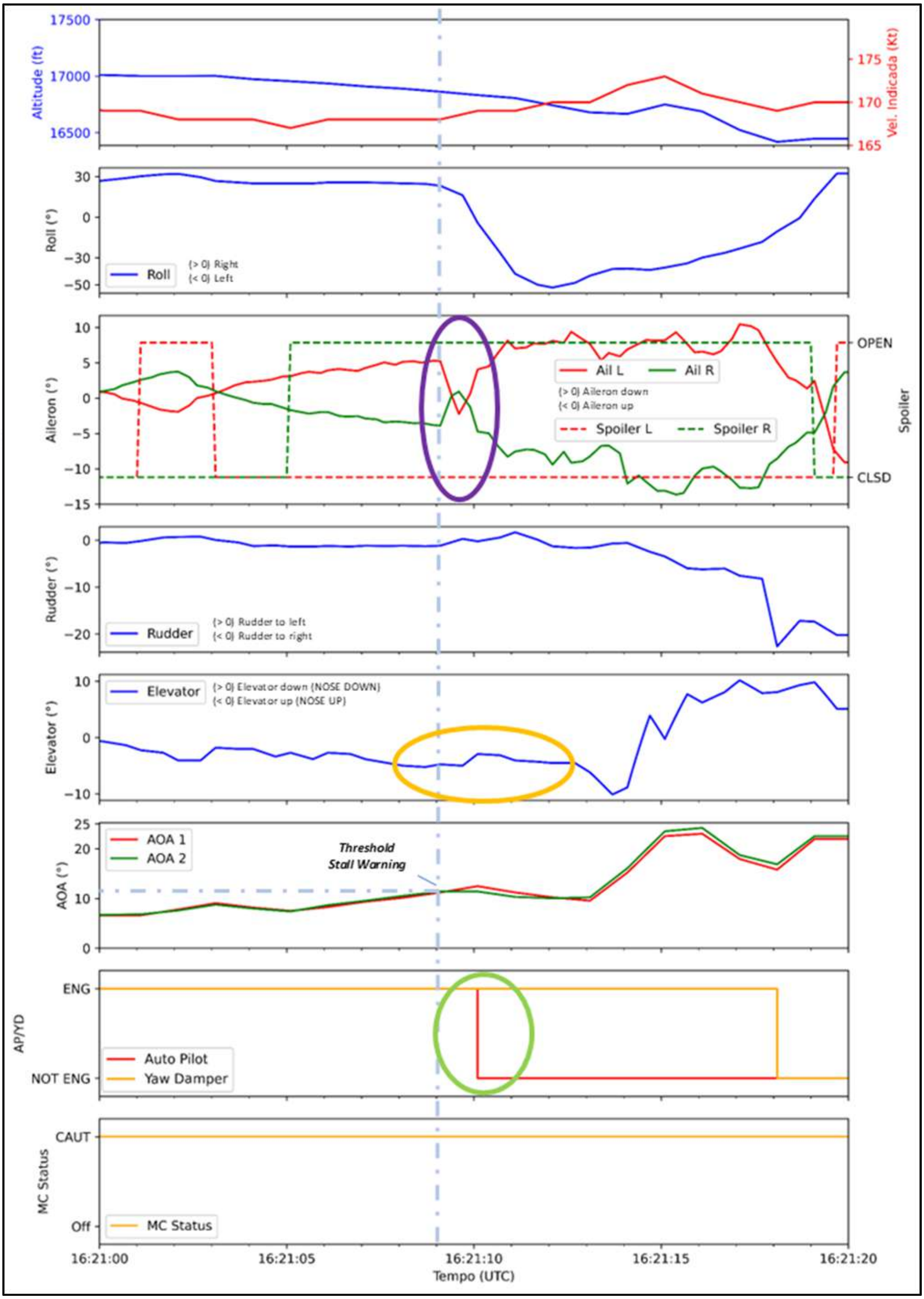


Figure 170 – Graph of flight data parameters indicating the final moments prior to AP disengagement. The vertical baseline indicates the moment of stall warning activation.

Although the FDR did not directly record stick shaker activation, the SIPAER Investigation Commission was able to identify it through the CVR audio, which captured the associated *cricket* aural warning.

As a consequence of the stick shaker activation, the AP disengaged. As a result, lateral control of the aircraft was no longer commanded by the AP, and the ailerons exhibited an immediate tendency to return to the zero-hinge moment position (purple ellipse). Due to the aircraft's inherent lateral stability characteristics, a pronounced roll rate to the left toward wings-level was induced.

In the pitch axis, the elevator trim remained at the last position commanded by the AP due to AUTO TRIM. This trim setting held the elevators in a nose-up position (orange ellipse).

The YD remained engaged, as its automatic disengagement was not associated with the stall warning (green ellipse).

The time intervals recorded between the last APM warnings/alerts available to the pilots and the activation of the stall warning and AP disengagement were as follows:

- CRUISE SPEED LOW: 2 min 28 s;
- DEGRADED PERFORMANCE: 1 min 42 s; and
- INCREASE SPEED: 13 s.

There was a procedure prescribed in the QRH for a stall condition (Figure 171).

58995808-e615-41b3-8bb9-b0f2175ed226 28 NOV 2017

E99.09 STALL

► CONTROL COLUMN.. PUSH
► ENG PWR ....INCREASE
■ **If FLAPS 0**
► FLAPS..EXTEND TO 15
► BANK...WINGS LEVEL

WARNING
► STICK PUSHER ACTIVATION : NO OPPOSITE ACTION
► FLAPS : DO NOT RETRACT
► RUDDER : USE WITH CARE

► ATC ....NOTIFY
● **When out of stall**
► FLIGHT PATH..RECOVER SMOOTHLY

Figure 171 – Stall procedure.

The stall recovery procedure required that the control column be pushed forward and that engine power be increased.

If the aircraft was in the flaps 0 configuration, the flaps were to be extended to 15°, and the wings were to be leveled.

During stick pusher activation, no opposite action was to be applied. The flaps were not to be retracted, and the rudder was to be used with caution. Air Traffic Control (ATC) was to be notified.

Following recovery from the stall condition, the flight path was to be restored smoothly.

It should be noted that the first four items of the checklist, highlighted within a boxed line, were considered memory items.

Additionally, the SOP reinforced, through a warning note, the need to command flap extension to 15° if the aircraft was in an abnormal attitude or in a stall condition.

⚠ WARNING

Caso exista condição anormal de atitude na aeronave ou estol, deverá ser aplicado FLAPS 15, e completado o procedimento de STALL do QRH (E99.09).
Caso o FLAP 15 já esteja selecionado, não selecionar FLAPS 0 até que a aeronave esteja completamente livre de gelo.

Figure 172 – Warning indicating the application of flaps to the 15° position when in an abnormal attitude or stall condition.
Source: SOP, Code M-POR-FST-001-12, Version 05.01, dated 26MAR2024.

Based on the FDR and CVR recordings, no immediate actions by the pilots were observed at that moment to comply with the memory items prescribed in the QRH for the stall procedure.

At 16:21:12 UTC, the pronounced roll to the left reached a rate of approximately 40°/s, inducing an increase in the local angle of attack of the left wing and its aerodynamic stall. At that moment, the aircraft experienced a sharp drop of the left wing, reaching a maximum bank angle of 52°, as shown in Figure 173.

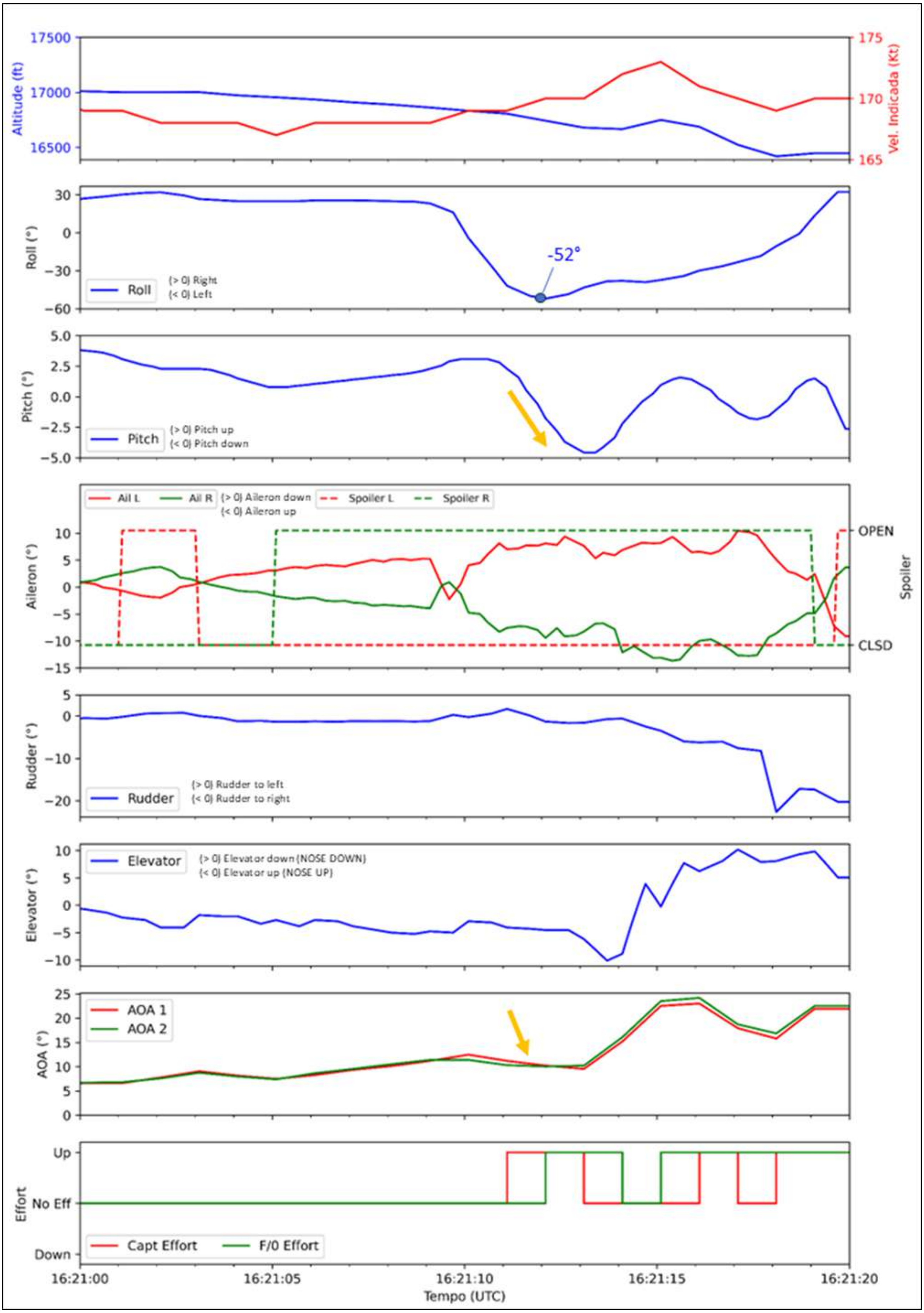


Figure 173 – Graph of flight data parameters at the moment of the stall.

Due to the stall, the aircraft exhibited a natural nose-down tendency (pitch down), reaching a nose-down attitude of approximately -5°, which led to a momentary reduction in AOA (orange arrows).

The fact that the aircraft exhibited a nose-down tendency indicated that it did not enter a deep stall, a critical condition often associated with a loss of lift that is difficult—or even impossible—to recover from and commonly observed in aircraft with a T-tail configuration.

A deep stall occurs when the turbulent airflow originating from a stalled wing envelops the horizontal stabilizer, reducing or eliminating elevator effectiveness. Under this condition, the pilot is unable to command a nose-down pitch, which makes recovery difficult or even prevents it altogether.

In the yaw axis, the aircraft did not exhibit any significant yaw tendency at the moment of the stall, and no substantial rudder inputs commanded by the YD were observed at that time.

In response to the sudden drop of the left wing during the stall, the flight crew applied right control column input through nearly its full travel, which resulted, in addition to aileron movement, in the deployment of the right spoiler to increase the commanded roll rate to the right (purple ellipse in Figure 174). It was observed that this lateral control input reduced the left roll rate until its reversal, allowing the initial recovery from the wing drop (purple arrow).

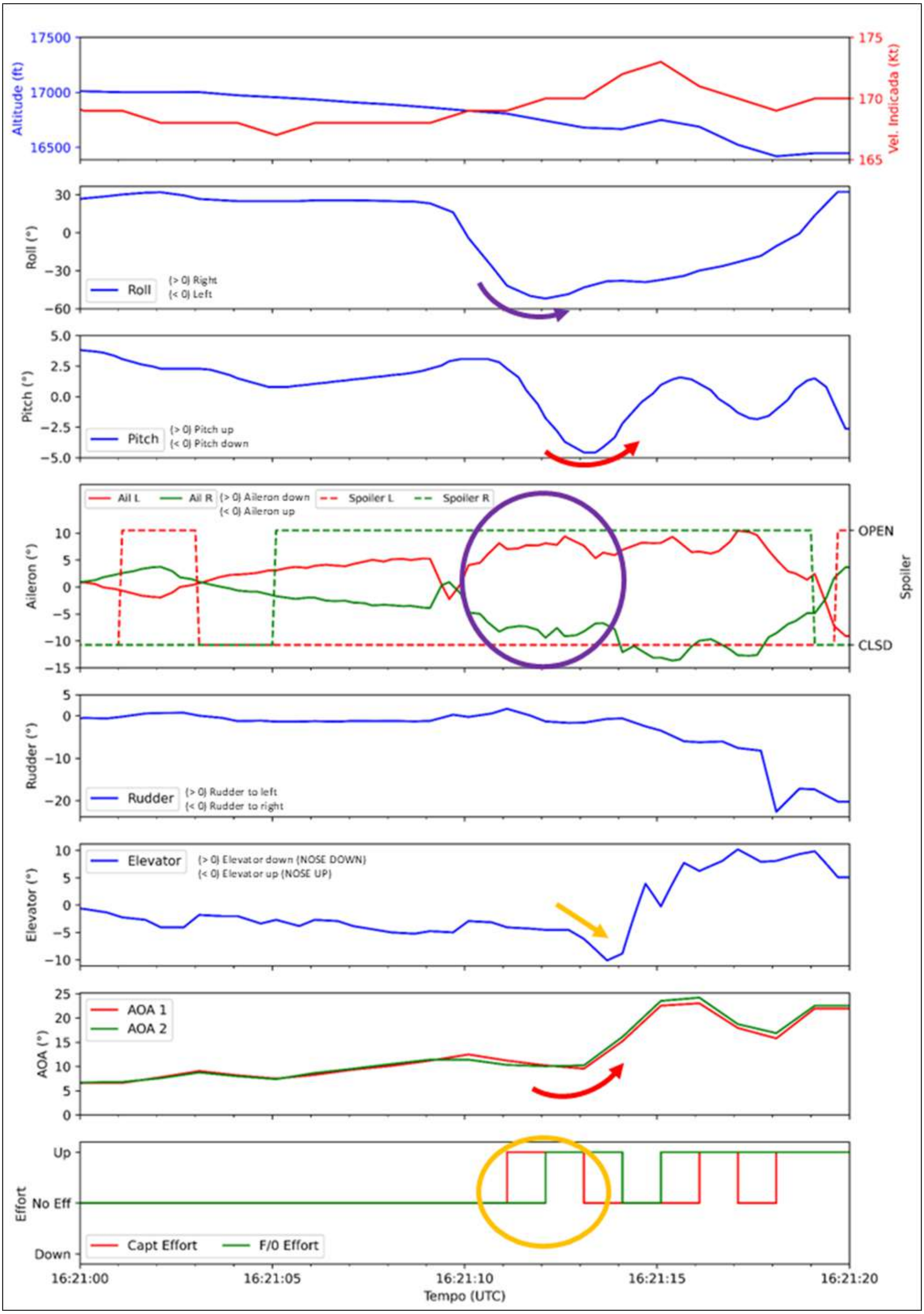


Figure 174 – Graph of flight data parameters during the attempt to regain control of the aircraft, with nose-up control inputs and a right roll command.

As previously highlighted, in the pitch axis the aircraft exhibited a nose-down tendency following the stall; however, simultaneous control column inputs by both pilots were recorded, with forces exceeding 10 daN (approximately 10 kgf) in the nose-up direction (orange ellipse). The pilots' actions were contrary to the guidance established in the QRH, which calls for applying forward pressure on the control column in the event of a stall (Figure 171).

It was thus verified that, concomitantly with the inputs about the longitudinal axis to recover from the wing drop, the pilots applied aft forces on the control column, resulting in an increase in elevator deflection in the same direction (orange arrow).

The pilots' nose-up control input resulted in a pitch-up response, with a change in longitudinal attitude, leading to a further increase in the angle of attack (red arrows).

At 16:21:14 UTC, the AOA values measured by the aircraft sensors reached 15.3°, corresponding to the activation threshold of the stick pusher under icing conditions in cruise, as specified in the manufacturer's documentation (Figure 35). At that moment, the aircraft's nose was close to the horizon (approximately -1° of pitch and about 38° of left bank).

The stick pusher activation parameter was not recorded by the FDR; however, the sudden change in the left elevator position recorded by the synchro transmitter and the examinations performed as presented in section 1.16.4 indicated that the system was activated (vertical dashed line in Figure 175).

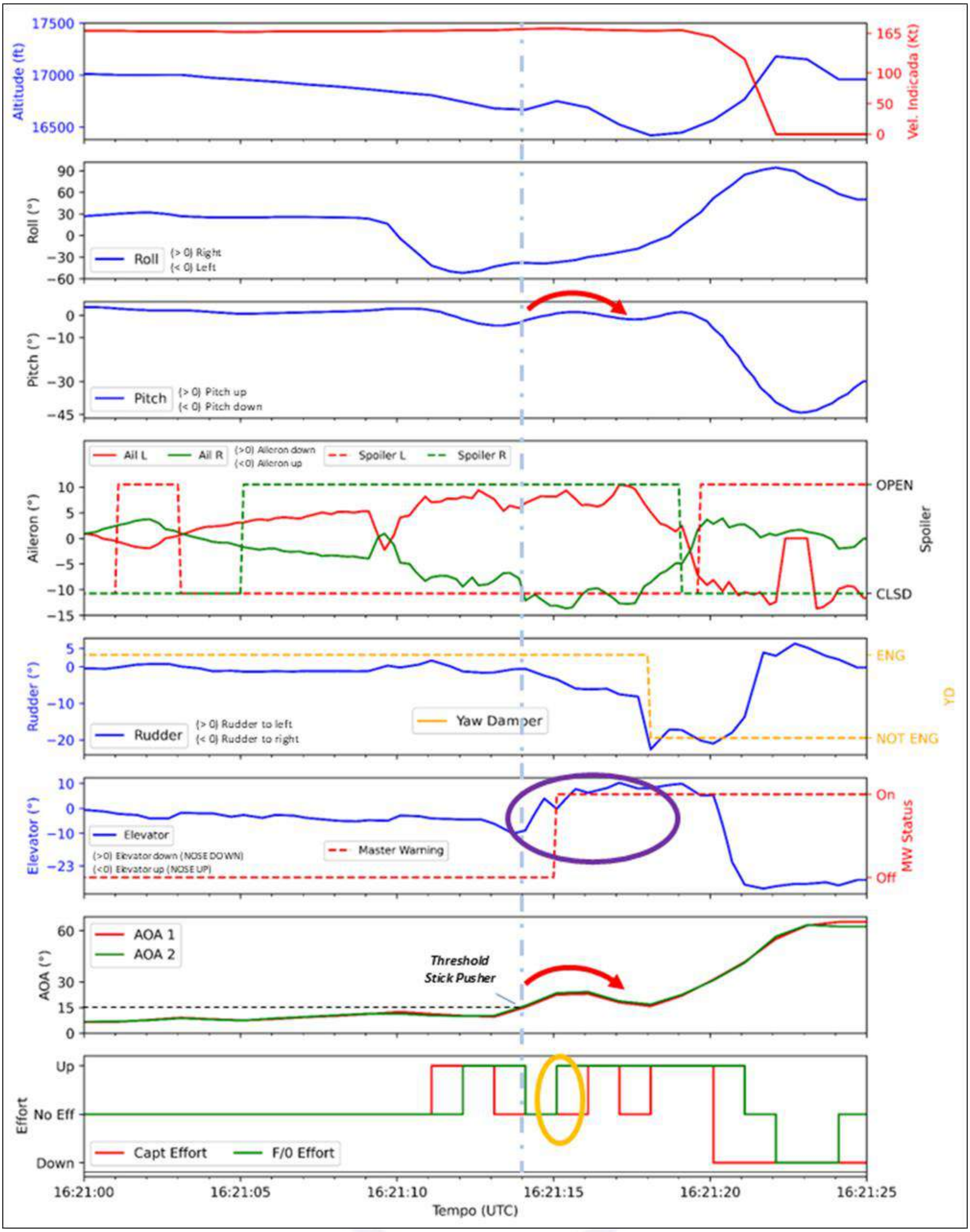


Figure 175 – Graph of flight data parameters highlighting the various indications during the time interval in which the stick pusher was activated.

This activation resulted in an effective forward movement of the control columns (purple ellipse). With the activation of the stick pusher, a reduction in longitudinal attitude was observed, along with a consequent decrease in AOA (red arrows).

In addition to the previously mentioned memory items, the QRH stall procedure (Figure 171) included a warning advising the flight crew not to oppose the stick pusher activation, not to retract the flaps, and to use the rudder pedals with caution.

During stick pusher activation, the recorded data showed that the SIC again applied forces exceeding 10 daN in the NOSE-UP direction, that is, in opposition to the stick pusher action (orange ellipse), contrary to the QRH guidance.

As the elevators were still coupled, the SIC's NOSE-UP control column input, opposite to the stick pusher action, generated a differential force sufficient to activate the Pitch Uncoupling Mechanism at 16:21:15 UTC, resulting in elevator decoupling (PITCH DISCONNECT) and the triggering of a MASTER WARNING alert (purple ellipse).

Due to the disconnection caused by the Pitch Uncoupling Mechanism, the elevators began to operate independently and to respond only to their respective control columns. As a result, the Stick Pusher started acting only on the left elevator, and it was no longer possible to estimate the position of the right elevator.

It is also worth noting that, during the stick pusher activation, after the disconnection caused by the Pitch Uncoupling Mechanism, force inputs were recorded on both control columns in the NOSE-UP direction, opposite to the stick pusher actuation direction (NOSE-DOWN). Despite the PIC's recorded nose-up input, the position of the left elevator did not significantly change.

Nevertheless, with the stick pusher acting only on the left elevator, the aircraft exhibited a change in longitudinal attitude and a consequent reduction in AOA from 24° to approximately 16° (red arrows).

Immediately after the uncommanded roll to the left, which reached 52° of bank, flight control inputs in roll and pitch were applied, resulting in a reduction of the left bank to 38° and an increase in AOA, for approximately 2 seconds (green ellipse in Figure 176).

Due to the coupling of the aircraft's lateral–directional dynamics, the aircraft presented a tendency for left yaw, producing a right sideslip (orange arrow in the Lat Accel parameter). This yaw motion required right rudder deflection commanded by the YD to counteract left yawing moment (orange arrows in the Rudder parameter).

Upon reaching a value of approximately 8° of right rudder deflection, an abrupt movement of the rudder toward the right stop was observed, reaching 23°—equivalent to 85% of the maximum deflection of 27°—within an interval of half a second, remaining in that position for approximately 3 seconds. Subsequently, at 16:21:18 UTC, due to the sudden rudder displacement, the YD disengaged (red arrows in the Rudder parameter).

The significant rudder deflection, at a rate of 30°/s, resulted in a right yaw, which can be observed through the aircraft's lateral acceleration values and the rapid change in heading shown in Figure 176. This directional motion produced an immediate aircraft response, with a significant increase in right roll (purple arrow), at a rate close to 40°/s.

At that moment, there was control input on the roll axis, with the ailerons deflected to near the left stop and the consequent retraction of the right spoiler and deployment of the left spoiler (purple ellipse).

A rapid increase in AOA and a drastic reduction in speed, reaching a value of 0 kt, were also observed, even with a nose-down attitude (red ellipses). With the AOA approaching 30°, the left elevator abruptly reversed from the NOSE-DOWN position, still commanded by the stick pusher, to a NOSE-UP position close to its stop (red arrow in the Elevator parameter).

Subsequently, the aircraft entered a dive with a pitch attitude of −43°. The maximum right bank angle reached 94°. The rudder remained near a centered, neutral position, and the AOA reached values close to 63°.

At that moment, all APM alerts were deactivated. The control column force parameter recorded a period of forward (nose-down) inputs; however, no significant change was observed in the position of the left elevator (orange ellipses).

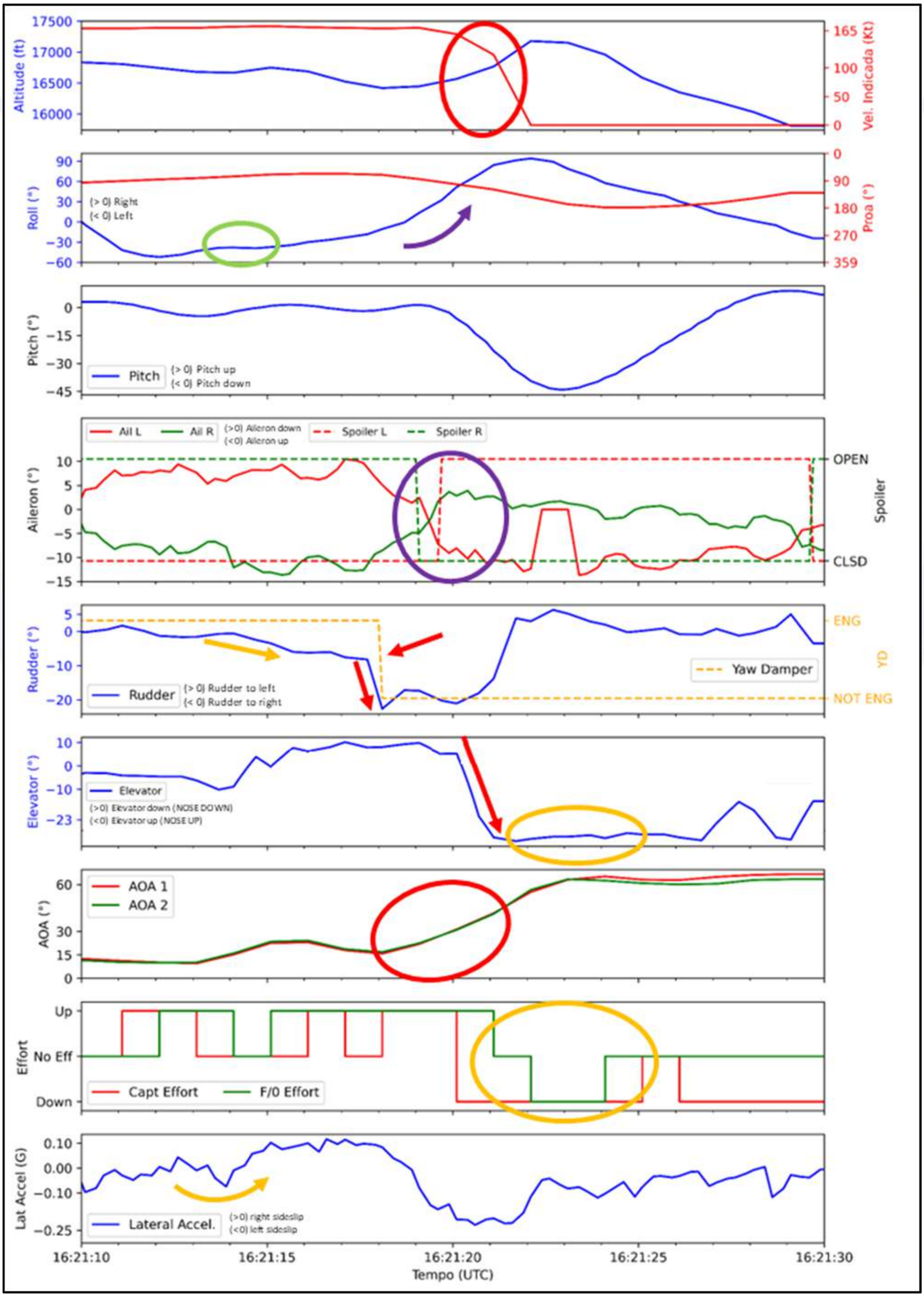


Figure 176 – Graphs of flight data parameters highlighting the initial phase of the loss of control of the aircraft.

Following the sudden and abrupt right rudder deflection, a yaw and a heading change of approximately 110° to the right was observed. After that, the aircraft reversed the direction of rotation, now yawing to the left in a counterclockwise direction (purple arrow in Figure 177). From that point onward, the aircraft entered a left spin.

During the time interval between the loss of control and ground impact, control column forces were recorded on both columns in both the nose-up and nose-down directions.

It should be noted that, as the elevators were disconnected, the FDR records related to the Elevator parameter corresponded to the position of the left elevator, which remained near the nose-up stop throughout the uncontrolled descent (orange ellipse).

During the rapid descent, the AOA sensors indicated divergent values greater than 4° for more than 5 seconds, resulting in inhibition of the stick shaker and stick pusher functions, with illumination of the FAULT light on the STICK PUSHER/SHAKER button, in addition to the activation of a MASTER CAUTION alert (green ellipse).

It was also verified that there were throttle inputs on both engines during the initial phase of the spin (purple ellipse), as well as a recorded rudder deflection of approximately 15° to the right, consistent with pilot inputs intended to arrest the left rotation.

Subsequently, the pitch and roll oscillations were damped, characterizing the development of a flat spin, with an indicated angle of attack close to the mechanical stop of the AOA sensor (70°) and a rotation rate of approximately 45°/s. From that moment onward, with the stabilization of the rotation, no further discrepancy between the AOA sensors was identified. As a result, the stick pusher became available again until the aircraft reached 500 ft RALT, when the stick pusher was once again inhibited.

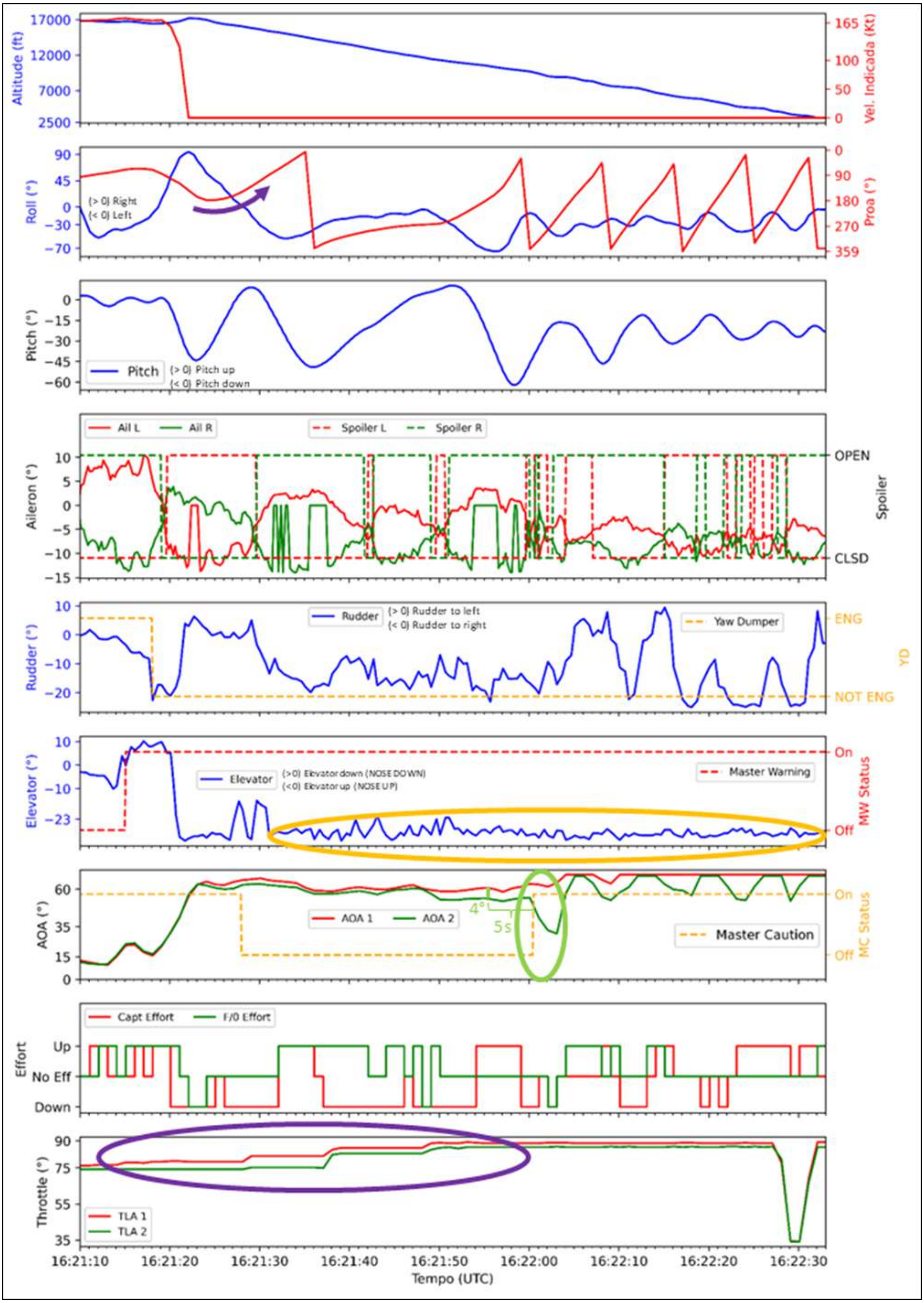


Figure 177 – Graph of flight data parameters highlighting the final moments before and after entry into the spin.

The maximum peak vertical acceleration reached approximately +1.8 g at the onset of the loss of control, followed by fluctuations between +1.2 g and +1.6 g from the aircraft lost of control until ground impact (Figure 178).

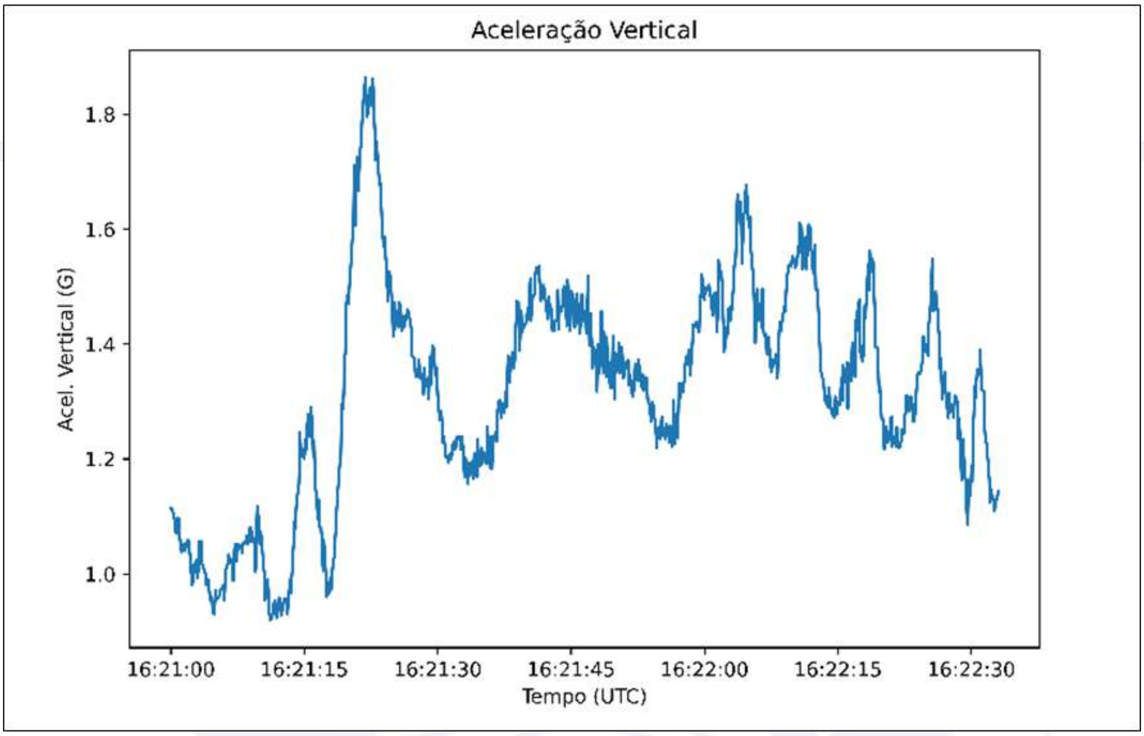


Figure 178 – Vertical acceleration data.

Furthermore, the aircraft exhibited an almost constant rate of descent of approximately 14,000 ft/min (Figure 179). The aircraft completed 5 left-hand spin rotations over an interval of 68 seconds, with pitch varying between +10° and −62° and left bank angles ranging from 10° to 75° until ground impact. Figure 179 illustrates this loss of altitude as a function of time (UTC).

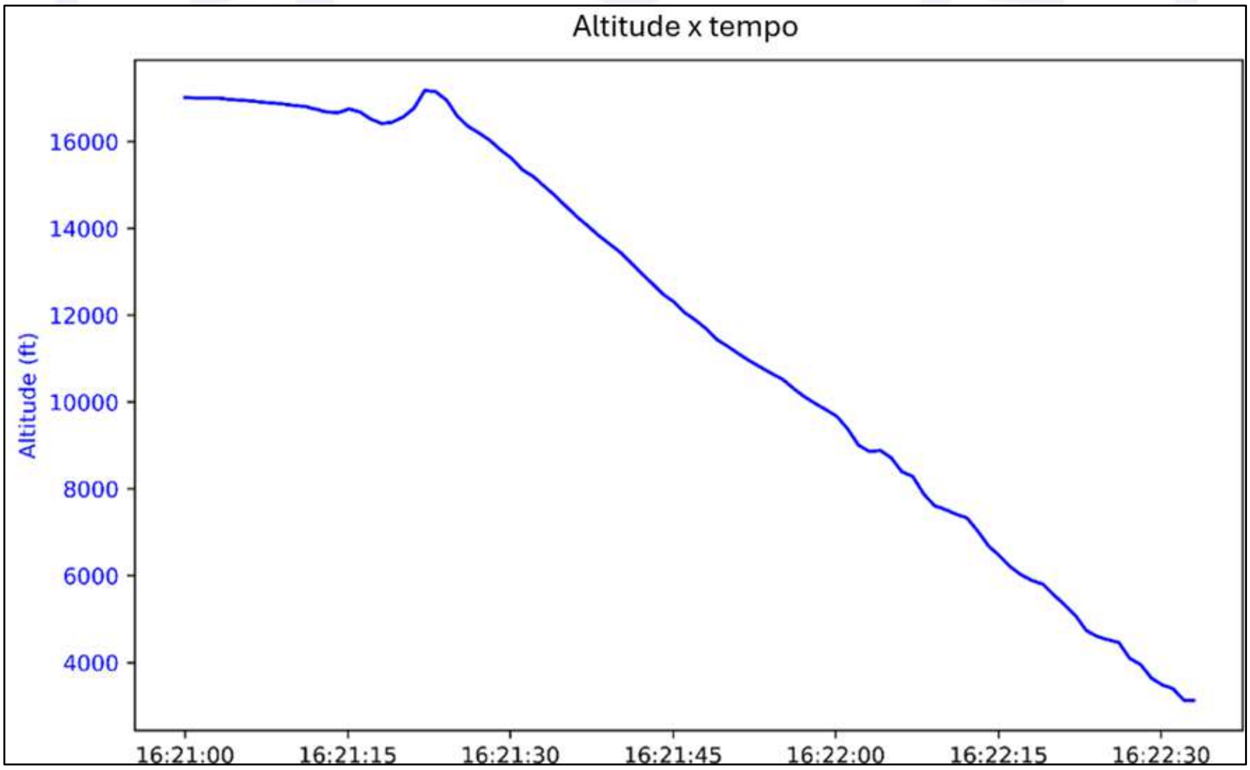


Figure 179 – Altitude data recorded versus UTC time following the loss of control.

1.19. Additional information.

1.19.1. Flight data provided by the aircraft manufacturer

During the loss of control, the rudder deflected at a rate of 30°/s, moving from 8° to the right to 23° to the right in approximately half a second. The position of 23° to the right was equivalent to 85% of the maximum deflection of 27°.

In order to better characterize the rudder behavior, the aircraft manufacturer provided the Investigation Commission with aircraft certification flight test data. The data provided revealed that, in one of the flights, a rudder deflection rate applied by the pilot was recorded at a value consistent with that recorded during the event (30°/s). However, this rate was recorded with the rudder moving from the neutral position (0°) to a maximum deflection of 15°.

Furthermore, the manufacturer provided flight data from AT-72-212A (-500) aircraft in which pilot input was sufficient to override the YD command without reaching the 30 daN pedal force threshold that would cause YD disengagement.

The SIPAER Investigation Commission requested that the manufacturer analyze the operation of the YD system with respect to its rudder deflection inputs during the final moments of the accident flight. In response, the manufacturer provided a reconstruction of the YD software operation within the directional control chain, based on the replay of the data recorded during the event, which will be further developed in the analysis section of this Final Report.

The aircraft manufacturer provided flight test data in which representative long-exposure ice shapes installed on the vertical stabilizer and rudder, with no ice shape on the horn, did not demonstrate rudder pedal force reduction or significant non-linear rudder behavior for sideslip angles of up to 10° on either side.

In addition, the manufacturer indicated that the ATR-72-212A rudder incorporates a spring-tab configuration with a spring, which tends to generate an opposing hinge moment under separated-flow conditions, thereby reducing the aerodynamic tendency for further rudder deflection.

1.19.2. Requirements related to operations, training, dispatch, and flight release.

RBAC 121, Amendment 21, in force at the time of the occurrence, established requirements for flight operations applicable to all operators, as well as for training, dispatch, and flight release.

The training requirements for UPRT were set forth in Section 121.423.

> 121.423 – Pilots: Training for Airplane Upset Prevention and Recovery (UPRT).
>
> (a) Each certificate holder must include, in its approved training program, the UPRT established in this section for each airplane type and for each pilot. The UPRT required by this section must be conducted in a flight simulator approved by ANAC in accordance with section 121.407.
>
> (1) Each program must provide ground and flight training for the prevention and recovery of loss of control of the airplane.
>
> (2) For maneuvers that include full aerodynamic stall or the effects of ice accretion on the airframe and engines of the simulated airplanes, the simulators must be specifically approved for such conditions.

Resolution No. 719, dated 05JUL2023, which approved Amendment 19 to RBAC 121, established the following deadlines for UPRT implementation:

> Article 2. The implementation of UPRT by certificate holders operating under RBAC No. 121 shall comply with the following deadlines:
>
> I - by 01FEB2025, certificate holders must be capable of providing UPRT, with an approved training program, qualified instructors, and adequate infrastructure; and

II - by 01FEB2026, all pilots employed by the certificate holder in its operations must have completed the training.

With regard to the operational control of flights conducted by the company, Section 121.533, Amendment 21, established the following requirements:

121.533 – Responsibility for Operational Control – Scheduled Operations

(a) Each certificate holder conducting scheduled operations is responsible for the operational control of its flights.

(b) The pilot in command and the flight dispatcher are jointly responsible for the preflight planning, delays, and dispatch release of a flight in accordance with this regulation and the operations specifications.

(c) The flight dispatcher is responsible for:

(1) monitoring the progress of each flight;

(2) issuing information necessary for the safety of the flight; and

(3) canceling or redispatching the flight if, in his or the pilot in command's opinion, the flight cannot be conducted or continued with the level of safety with which it was originally planned or released.

(d) The pilot in command of an airplane is, at all times during the flight, in command of the airplane and the crew and is responsible for the safety of the passengers, crew members, cargo, and the airplane.

(e) The pilot in command has full control and authority over the operation of the airplane and the other crewmembers and their in-flight duties, without limitation, even if not properly certificated to perform the duties of those crewmembers.

(f) No pilot may operate an airplane in a careless or reckless manner so as to endanger life or property.

121.551– Restriction or Suspension of Operations – Scheduled Operations

Whenever a certificate holder conducting scheduled operations becomes aware of conditions, including aerodrome and runway conditions, that may pose a risk to its operations, they must restrict or suspend such operations until those conditions are corrected or no longer exist.

121.557 Emergencies. Scheduled Operations (wording as amended by Resolution No. 526, dated 06AUG2019)

(a) In an emergency situation requiring immediate decision and action, the pilot in command shall act as they deem necessary under the circumstances. In such cases, in the interest of safety, they may deviate from established operational procedures, applicable weather minimums, and the provisions of this Regulation to the extent required.

(b) In an emergency situation requiring immediate decision and action by a flight dispatcher that is known to them, the dispatcher must notify the pilot in command of the airplane, must ascertain the decision made by the pilot in command, and must record such decision. If the dispatcher is unable to communicate with the pilot in command, they must declare the emergency and take whatever action they consider necessary under the circumstances.

(c) Whenever the pilot in command or the flight dispatcher exercises emergency authority, the air traffic control units involved must be kept fully informed of the progress of the flight by the certificate holder's ground personnel. The person who declared the emergency must submit a written report to ANAC, through the certificate holder's chief of operations, describing the facts and any deviations that occurred. The report must be submitted within 10 days—counted for the flight dispatcher from the declaration of the emergency, and for the pilot in command from return to his base.

With regard to the reporting of malfunctions observed during flight operations, section 121.563, Amendment 21, established the following requirements:

> 121.563 Aircraft discrepancy reports
>
> The pilot in command must ensure that all operating irregularities observed during flight are entered in the aircraft maintenance log at the first landing. Before each flight, the pilot in command must verify the status of each discrepancy recorded in the log at the end of the preceding flight.

With regard to aircraft dispatch under adverse weather conditions, RBAC 121, Amendment 21, at the time of the accident, established the following requirements:

> 121.601 Dispatcher Information to the Pilot in Command – Scheduled Operations
>
> (a) The flight dispatcher must provide the pilot in command with all known available information, including information on irregularities at aerodromes and in navigation or communications facilities that may affect the safety of the flight.
>
> (b) Before the start of the flight, the dispatcher must provide the pilot in command with all known meteorological information, as well as forecasts of atmospheric phenomena that may affect operational safety, such as clear air turbulence, thunderstorms, low-level wind shear, for each route to be flown and for each aerodrome to be used.
>
> (c) During the flight, the flight dispatcher must provide the pilot in command with any additional available meteorological information and inform them of irregularities in facilities and services that may affect operational safety.
>
> 121.613 – Dispatch or Flight Release Under IFR
>
> (a) When dispatching or releasing an airplane to conduct an IFR flight, including in-flight redispatch actions, the certificate holder must ensure that:
>
> (1) the weather conditions at the departure aerodrome, at the time of use, are at or above the operator's established takeoff minimums for that aerodrome.
>
> (2) except as provided in 121.619(b), the updated meteorological information indicates that the weather conditions at the destination aerodrome, at the estimated time of use, will be at or above the operator's established landing minimums for that aerodrome; and
>
> (3) updated meteorological information indicates that the weather conditions at each required en route alternate aerodrome and destination alternate aerodrome, at the estimated time of use, will be at or above the respective planning minima for landing at each aerodrome established by the operator.
>
> 121.627 – Continuation of a flight under unsafe conditions
>
> (a) No pilot in command may allow a flight to continue to any aerodrome to which it has been dispatched or released if, in the opinion of that pilot in command or, in the case of a scheduled operation, the flight dispatcher, the flight cannot continue safely. However, if the pilot in command determines that no safe course of action remains, the continuation of the flight constitutes an emergency and must be handled in accordance with 121.557 or 121.559, as applicable.
>
> (b) If any instrument or item of equipment required by this regulation for the particular operation becomes inoperative en route, the pilot in command must comply with the approved procedures for such occurrence, as specified in the certificate holder's manual.
>
> 121.629 – Operations in icing conditions
>
> (a) No person may dispatch or release an airplane, continue operating an airplane en route, or land an airplane at an aerodrome when, in the opinion of the pilot in command or the flight dispatcher (in the case of a certificate holder conducting scheduled operations), icing conditions exist or are expected that may adversely affect operational safety.

The SIPAER Investigation Commission found that ANAC had established a regulatory agenda for the 2023–2024 biennium. Within that agenda, Item 18 provided for the evaluation of aircraft-to-ground bilateral communication requirements and their adequacy in light of the technological evolution of the systems available, in order to promote a more agile, accurate, and efficient exchange of information within the scope of air operations governed by RBAC 121.

This process began on 10MAR2023. Initially, it addressed only the bilateral air-ground communication requirements set forth in sections 121.99 and 121.122, related to scheduled and non-scheduled operations, respectively.

> 121.99 Communication Facilities
>
> (a) Each certificate holder conducting scheduled operations must demonstrate that, along its routes, there is a reliable and rapid system of two-way air-ground communications which, under normal operating conditions, ensures radio contact between each aircraft and the appropriate air traffic control radio station.
>
> [...]
>
> (c) Each certificate holder conducting scheduled international operations must provide voice communication means for ETOPS operations. Where such facilities are available, in determining whether they are available, the certificate holder must consider the potential routes and altitudes that may be required in the event of diversions to ETOPS en-route alternate aerodromes. If such facilities are not available, or if their quality is so poor that voice communication is not possible, another communication system must be made available.
>
> (d) Each certificate holder conducting scheduled ETOPS operations beyond 180 minutes must demonstrate that an additional communication system exists, beyond that required by paragraph (c) of this Section. This system must provide satellite voice communication with the same fidelity as a terrestrial telephone system. Furthermore, it must be capable of providing communications between the flight crew and air traffic control services, as well as between the flight crew and the certificate holder. In determining the availability of such communications, the certificate holder must consider the potential routes and altitudes that may be required in the event of diversions to ETOPS en-route alternate aerodromes. If the satellite communication system is unavailable or of insufficient quality, another communication system must be made available.
>
> 121.122 Communication Facilities
>
> (a) Each certificate holder conducting non-scheduled operations must demonstrate that, along its routes, there is a reliable and rapid system of two-way air-ground communications which, under normal operating conditions, ensures radio contact between each aircraft and the appropriate air traffic control radio station.
>
> (b) Each certificate holder conducting non-scheduled operations, other than all-cargo operations, in airplanes with more than two engines must demonstrate that a voice communication system for ETOPS operations exists where such capability is available. In determining the availability of such communications, the certificate holder must consider the potential routes and altitudes that may be required in the event of diversions to ETOPS alternate aerodromes. If such capability is unavailable or of insufficient quality, another communication system must be made available.
>
> (c) Each certificate holder conducting non-scheduled ETOPS operations beyond 180 minutes, other than all-cargo operations, in airplanes with more than two engines must demonstrate that an additional communication system exists beyond that required by § (b) of this Section. This system must provide satellite voice communication with the same fidelity as a terrestrial telephone system. Furthermore, it must be capable of providing communications between the flight crew and air traffic services, as well as between the flight crew and the certificate holder. In determining the availability of such communications, the certificate holder must consider the potential routes and altitudes that may be required in the event of diversions to ETOPS alternate aerodromes. If the satellite communication system is unavailable or of insufficient quality, another communication system must be made available.

Both sections included requirements for communication between the flight crew and the air operator’s dispatch center, as well as between the flight crew and air traffic control. Within the process, Extended Range Twin-Engine Operational Performance Standards

(ETOPS) operations and communications between the aircraft and air traffic control were not considered.

The public consultation on the subject was conducted between 20NOV2023 and 04JAN2024, resulting in only three submissions, two of which were duplicates, made by an aircraft manufacturer, and a third submitted by an airline representative expressing a favorable position regarding the proposed changes. Thus, in practice, there was only one submission to be analyzed, which was ultimately not accepted. There was no participation by the other airlines in the public consultation process.

In December 2024, while the process was still underway, ANAC identified a possible inconsistency in the requirements under revision, particularly regarding paragraph (c) of section 121.601, since the amendment to section 121.99 would no longer require direct bilateral communication between the ground and the aircraft.

ANAC also identified that the amendment to paragraph (c) of section 121.601 could still imply, according to the process, the notification of a difference to the International Civil Aviation Organization regarding Standards and Recommended Practices (SARPs), item 4.6.1(e) of Annex 6, Part I, whose English text established that:

> 4.6 DUTIES OF FLIGHT OPERATIONS OFFICER/FLIGHT DISPATCHER
>
> 4.6.1 A flight operations officer/flight dispatcher in conjunction with a method of control and supervision of flight operations in accordance with 4.2.1.3 shall:
>
> [....]
>
> e) furnish the pilot-in-command while in flight, by appropriate means, with information which may be necessary for the safe conduct of the flight; and

Despite these findings, the process continued without a new public hearing involving the participation of the airlines and still without a new Regulatory Impact Analysis (AIR).

Thus, on 22JAN2026, Amendment 24 was published, modifying certain RBAC 121 requirements, particularly paragraph (c) of section 121.601, without, however, amending paragraph (a) of section 121.629. The requirements published in this Amendment are presented below:

> 121.601 Information on facilities and services. Scheduled operations
>
> (a) The flight dispatcher must provide the pilot in command with all available information regarding aerodrome conditions and irregularities in communication and navigation facilities that may affect operational safety.
>
> (b) Before the start of the flight, the flight dispatcher must provide the pilot in command with all available meteorological information, including reports and forecasts of meteorological phenomena that may affect operational safety, such as clear air turbulence, thunderstorms, and low-level wind shear, for each route to be flown and for each aerodrome to be used.
>
> (c) During the flight, the pilot in command must seek to obtain any additional available information regarding meteorological conditions and irregularities in facilities and services that may affect operational safety.

In turn, paragraph (c) of section 121.601 of the CFR, published by the FAA and serving as the basis for the Brazilian regulation, established the following requirements:

> § 121.601 Aircraft dispatcher information to pilot in command: Domestic and flag operations.
>
> (a) The aircraft dispatcher shall provide the pilot in command all available current reports or information on airport conditions and irregularities of navigation facilities that may affect the safety of the flight.
>
> (b) Before beginning a flight, the aircraft dispatcher shall provide the pilot in command with all available weather reports and forecasts of weather phenomena that may affect the safety of flight, including adverse weather phenomena, such as

clear air turbulence, thunderstorms, and low altitude wind shear, for each route to be flown and each airport to be used.

(c) During a flight, the aircraft dispatcher shall provide the pilot in command any additional available information of meteorological conditions (including adverse weather phenomena, such as clear air turbulence, thunderstorms, and low altitude wind shear), and irregularities of facilities and services that may affect the safety of the flight.

1.19.3. Aircraft Icing

The effects of ice accretion on aircraft develop progressively. Propulsive efficiency decreases, aerodynamic drag increases, lift is reduced, and weight increases. As a result of all these factors, there is an increase in stall speed and a degradation in aircraft performance. An accumulation of only a few centimeters of ice on the aircraft surfaces may reduce lift capability and increase aerodynamic drag.

According to the manufacturer's ATR Cold Weather Operations manual, a pilot could anticipate the possibility of ice accretion when flying in visible moisture conditions, such as rain or clouds containing water droplets, whenever the outside air temperature was equal to or below 5°C. According to the same manual, aircraft icing could be classified as follows:

- Trace: ice becomes perceptible; however, the accretion rate is only slightly greater than the sublimation rate. The recommendation to the flight crew was to monitor the situation due to the possible increase in icing severity.
- Light: the accretion may become a problem if the flight is prolonged under such conditions. Occasional use of the Anti-Icing/De-Icing system is sufficient to prevent or remove the accretion. It does not represent a significant hazard to flight safety, provided that the equipment is properly used. According to the ATR Cold Weather Operations manual, under these conditions, the atmospheric air contains less than 0.6 g of water per cubic meter of air, which may result in an ice accretion of one centimeter within 15 to 60 minutes of flight.
- Moderate: the ice accretion rate is sufficient to turn even brief aircraft exposure into potentially hazardous situations, requiring the immediate use of Anti-Icing/De-Icing equipment or a change in route/flight level. According to the ATR Cold Weather Operations manual, under these conditions, the atmospheric air contains between 0.6 and 1.2 g of water per cubic meter of air, which may result in an ice accretion of 1 cm within 5 to 15 minutes of flight; and
- Severe: the accretion rate exceeds the capability of the Anti-Icing/De-Icing equipment to reduce or control the hazard. In this case, it is necessary to maintain the speed recommended for the situation and remove the aircraft from such conditions by changing route and/or flight level. According to the ATR Cold Weather Operations manual, under these conditions, the atmospheric air contains more than 1.2 g of water per cubic meter of air, which may result in an ice accretion of 1 cm in less than 5 minutes of flight.

The Manual stated that icing conditions were characterized by the volumetric mean diameter of the droplets, liquid water content, outside air temperature, and exposure time. Exceeding any one of these parameters could cause ice accretion beyond the capability of the protection systems or in areas that are normally unprotected.

The certification standards in force at the time of the accident referred to supercooled clouds containing droplets with a volumetric mean diameter between 15 and 50 microns. Larger droplets, known as Supercooled Large Droplets (SLD), may be considered severe icing conditions. Freezing rain and freezing drizzle are forms of SLD.

It should be emphasized that, according to the ATR Cold Weather Operations manual, the aircraft in question was not certified for flight under severe icing conditions. The recommendation to the flight crew was to exit such conditions immediately, since aircraft performance and maneuverability would be severely affected after only a few minutes of exposure.

Also according to the ATR Cold Weather Operations manual, the following meteorological conditions could indicate the presence of SLD:

- visible precipitation with SAT near 0°C, and
- droplets splashing or splattering on the cockpit windows when the SAT was near 0°C.

The same manual identified several indications of SLD based on reports from ATR flight crews, namely:

- unexpected loss of airspeed or rate of climb;
- total or partial ice coverage on non-heated side windows;
- ice accretion in areas not normally subject to icing;
- ice covering a larger-than-usual area on the spinner, and
- ice accretion on the lower surface of the wing aft of the protected area.

The Manual further established that the flight crew should identify conditions classified as severe whenever at least half of the pilots' non-heated side window was covered by ice accretion.

1.19.4. Previous accidents involving icing conditions

Some accidents and incidents involving ATR-72 and ATR-42 aircraft had in-flight ice accretion as a contributing factor. The study of these occurrences revealed operational patterns, technical limitations, and challenges faced by flight crews in managing adverse meteorological conditions.

The information presented below was extracted from the published final reports.

1.19.4.1. Aero Trasporti Italiani 460 – 15OCT1987

Flight 460 of *Aero Trasporti Italiani* (a subsidiary of Alitalia) was one of the first major accidents involving the ATR 42 model.

On 15OCT1987, the ATR 42-312 aircraft (registration marks I-ATRH) departed from Milan Linate Airport bound for Cologne Bonn Airport, carrying 34 passengers and 3 crewmembers on board.

During the initial climb, the aircraft encountered conditions conducive to ice accretion near FL150. A few minutes later, the aircraft entered abrupt rolling oscillations, alternating between sides with bank angles exceeding 100°.

The flight crew lost control of the aircraft in flight, and it collided with terrain in the mountainous region of Lombardy, northern Italy. All 37 occupants sustained fatal injuries.

The investigation conducted by the Italian authorities revealed that one of the contributing factors was severe ice accretion on the wings, which significantly degraded the aircraft's performance. This accretion increased the stall speed, leading to loss of control and the subsequent crash.

The report also pointed out that the aircraft's behavior under icing conditions was not yet fully understood. The investigation revealed limitations in the ice protection system and raised questions regarding the aircraft's design and certification in prolonged icing scenarios.

As a consequence, the manufacturer conducted a study on the aircraft model's behavior under icing conditions, leading to revisions of operational procedures and flight crew training aimed at rapidly recognizing performance degradation situations.

1.19.4.2. American Eagle 4184 – 31OCT1994

On 31OCT1994, an AT-72-212 operated by American Eagle (Flight 4184), departed from Indianapolis International Airport bound for O'Hare International Airport, carrying 64 passengers and 4 crewmembers on board.

The meteorological conditions along the route were conducive to ice accretion, and the flight data recorder registered the activation of the ice protection system.

During the descent to FL080, the aircraft rolled abruptly to the right and the angle of attack increased rapidly. A loss of control in flight then occurred, and the aircraft entered a steep dive, impacting the ground near Roselawn, Indiana. All 68 occupants sustained fatal injuries.

The investigation concluded that one of the contributing factors was ice accretion on the wings that exceeded the protection capability of the Airframe De-Icing system.

The National Transportation Safety Board (NTSB), the American investigative authority, also identified that, during the loss of control, an unexpected aileron reversal (aileron hinge moment reversal) occurred. This reversal resulted from ice accretion in areas not protected by the boots of the Airframe De-Icing system, allowing changes in the airflow behavior over the aerodynamic surfaces.

Following this event, the manufacturer performed significant modifications to the Airframe De-Icing systems of the ATR 42 and 72 aircraft, including the extension of the boots to 12.5% of the Mean Aerodynamic Chord, significantly increasing the coverage area of the pneumatic boots, as well as the development of aileron spring tabs to reduce the magnitude of the phenomenon.

1.19.4.3. TransAsia Airways 791 – 21DEC2002

TransAsia Airways Flight 791 was a scheduled cargo service operated by an ATR-72-200, registration marks B-22708. On 21DEC2002, the aircraft departed from Taipei bound for Macau, with two pilots and one flight engineer on board. There were no passengers.

During the cruise phase, the aircraft encountered adverse meteorological conditions conducive to ice accretion, resulting in ice accumulation on the aircraft surfaces in a volume exceeding the protection capability of the Anti-Icing and De-Icing systems.

FDR data showed that there was a significant degradation in aerodynamic performance, with reduced lift and increased stall speed. Subsequently, the aircraft entered an unusual attitude, followed by a stall and loss of control in flight. The aircraft impacted the sea approximately 17 kilometers off the southwestern coast of Taiwan. All three crew members sustained fatal injuries.

The investigation, conducted by the Taiwanese investigation authority, concluded that the aircraft encountered severe icing conditions that were not detected in time by the flight crew. Ice accretion on the wings and control surfaces exceeded the capability of the protection systems, leading to a rapid degradation in performance.

The report also highlighted the absence of an immediate reaction to the indications of performance degradation, the flight crew's lack of experience in severe icing conditions, and limitations in operational training regarding the specific hazards associated with this phenomenon as factors that contributed to the event.

Following the accident, the manufacturer and the primary certification authority, European Union Aviation Safety Agency (EASA), reinforced operational procedures for icing conditions. The measures included flight crew training aimed at rapidly recognizing signs of degraded performance, including deviations or flight level changes upon identification of severe icing, as well as modifications to checklist procedures related to this type of condition in order to provide greater clarity in the wording.

1.19.4.4. Empire Airlines 8284 – 27JAN2009

Empire Airlines Flight 8284 was operated by an ATR-42-320 freighter aircraft. On 27JAN2009, the aircraft departed from Fort Worth Alliance Airport bound for Lubbock Preston Smith International Airport, with two crew members on board. During the en route phase of flight, the aircraft encountered moderate to severe icing conditions.

During the final approach phase for landing, the flight crew received a terrain proximity warning from the aircraft system. The accumulated ice degraded the aircraft's performance, which increased the rate of descent to approximately 2,000 ft/min.

Despite the corrective attempts made by the flight crew, the aircraft entered an aerodynamic stall condition, with loss of altitude, culminating in a collision with the ground approximately 300 meters before the runway threshold. Both crew members sustained serious injuries but survived.

The National Transportation Safety Board (NTSB) concluded that the ice protection system was active; however, the ice accretion on the aircraft surfaces exceeded the protection capability of the systems. The final report highlighted that the procedures published in the manufacturer's QRH and FCOM for operations under icing conditions were unclear and contained ambiguities, particularly regarding the recommended airspeed in situations involving degraded performance.

Also according to the Final Report, there was, in all probability, a failure by the crew to monitor and maintain a minimum safe airspeed while executing an instrument approach in icing conditions, which resulted in a stall at low altitude.

The NTSB listed the factors that contributed to the accident: failure by the pilots to follow published operating procedures in response to a flap anomaly; the PIC's decision to continue with an unstabilized approach; poor CRM; and fatigue resulting from the time of day at which the accident occurred, combined with cumulative sleep debt, which likely impaired the PIC's performance.

The investigation also indicated that flight crew training for operations in icing conditions was insufficient to deal with the conditions encountered.

1.19.5. Considerations regarding the APM

Aircraft of the ATR-42 and ATR-72 series were certified in accordance with the requirements of the American and French authorities, under the provisions of 14 CFR Parts 21 and 25 and Joint Aviation Requirements (JAR) 25, including the requirements for operation under icing conditions, in accordance with Appendix C of FAR/JAR 25.

On 12OCT2005, the French Civil Aviation Authority issued Recommendation Bulletin BR 2005/31 (B) with the objective of informing ATR aircraft operators, as well as foreign civil aviation authorities, about a design improvement involving the installation of the APM system. This functionality became part of the new MPC computer, originally developed for flight data recording.

1.19.5.1. APM Background

The Recommendation Bulletin issued by the French authority presented a summary of the factors that motivated the development of this APM system modification in the aircraft design.

At that time, the ATR Aircraft Flight Manual already included a description of the indications required for pilots to identify severe icing conditions, such as ice accretion on the side windows, reduction in airspeed, and loss of rate of climb, as well as the procedures to be followed in such cases. According to the Bulletin, those procedures had already been mandated by previously issued Airworthiness Directives: ATR-42-1999-014-076 R2 and ATR-72-1999-015-040 R2.

However, according to the Bulletin, in certain situations, flight crews did not correctly apply the procedures, either due to lack of situational awareness or because of a deliberate decision to continue the flight under severe icing conditions. In some cases, prolonged exposure to such conditions resulted in performance degradation and, eventually, aircraft stall.

As described in the Bulletin in question, in all occurrences analyzed up to the date of its issuance, no case was identified in which the strict application of the procedures was impracticable or required exceptional capabilities or skills from the flight crew. In all reviewed situations, the correct execution of the procedures would have enabled the safe continuation of the flight, whether through a flight level change, route deviation, or return to the departure aerodrome.

Accordingly, the French authority concluded that there was no intrinsic unsafe condition whenever the procedures in force at the time were correctly applied. Nevertheless, it recommended that, whenever necessary, flight crew awareness regarding severe icing conditions and the importance of strict compliance with those procedures should be reinforced.

As a consequence, ATR developed and distributed to operators a new training package entitled *Be Prepared for Icing*. This material assisted airlines in reviewing severe icing-specific procedures within their recurrent training programs. The package included documents, interactive media, and specific modules for use in simulators.

Additionally, with the objective of transforming icing-related performance degradation conditions into objective information for the flight crew, thereby improving situational awareness, ATR designed the APM system. This system began supporting flight crews in identifying severe icing conditions, promoting decision-making aligned with the operational procedures in force.

The APM also began recording the alerts issued, storing them on the MPC PCMCIA card, thereby providing an enhanced tool for the analysis and tracking of icing-related events.

Accordingly, the final recommendation of the Bulletin was intended to facilitate the recognition by flight crews of severe icing conditions, as well as to support operational decision-making in such situations. The French authority was emphatic in stating that it is “strongly recommended that ATR operators install the APM on their respective fleets.”

1.19.5.2. Integration of the APM into ATR-42 and ATR-72 aircraft.

The implementation of the APM in ATR aircraft was carried out through ATR Modification No. 5567 (*mod* 5567), incorporated into the ATR-42-500 production line beginning with SN641 and into the ATR-72-212A (500) production line beginning with SN726. Therefore, this meant that aircraft SN908, namely PS-VPB, had already been manufactured with the APM incorporated at the factory.

On 11DEC2006, the ATR manufacturer issued a general message to all operators through the document referenced as All Operators Message (AOM) 42/72/2006/08, addressing two subjects, including the APM system.

In the document, ATR reinforced the same points previously highlighted in the Recommendation Bulletin issued by the French authority, noting that analyses of in-service experience continued to indicate that, on several occasions, flight crews failed to strictly follow the procedures, either due to lack of situational awareness or because of a deliberate decision to continue the flight under severe icing conditions.

On 10AUG2009, EASA (European Union Aviation Safety Agency) issued Airworthiness Directive No. 2009-0170, with an effective date of 24AUG2009. The measure applied to all ATR-42 and ATR-72 aircraft models, making the installation of the APM system mandatory for aircraft that were still operating without this modification.

This Directive was intended to minimize the risks associated with inadvertent entry into severe icing conditions involving ATR-42 and ATR-72 aircraft by providing the flight crew with measurable and objective indications, as well as issued advisories/alerts.

1.19.5.3. APM system logic

The APM was intended to monitor aircraft performance and operational airspeeds, in addition to providing advisories and alerts to the flight crew whenever an unexpected performance degradation occurred or when the aircraft approached the minimum operational airspeeds.

For the activation of the advisories/alerts, two conditions had to be met:

- condition 1: increase in aerodynamic drag to a specific threshold value for each advisory/alert; and
- condition 2: reduction in indicated airspeed to a specific threshold value for each advisory/alert.

The drag difference (delta_drag) was calculated by comparing the percentage difference between two parameters computed by the APM:

- APMCXAC: average aircraft drag coefficient calculated by the APM. The nomenclature indicated that it referred to the aircraft (AC) drag coefficient (CX) calculated by the APM; and
- APMCXTH: reference value (TH for Theoretical) of the theoretical drag coefficient calculated by the APM for that flight condition.

The indicated airspeed difference (delta_speed), in turn, was calculated by comparing the values of the following parameters:

- APMIAS: indicated airspeed computed by the APM; and
- APMIASTH or IAS_TH: theoretical indicated airspeed calculated by the APM for that flight condition.

For each advisory/alert, both conditions (delta_drag increase and delta_speed reduction) had to reach values predetermined within the system algorithm

For activation of the CRUISE SPEED LOW advisory, two conditions had to be met:

1) drag increase of 10%, that is, APMCXAC > 1,1 x APMCXTH; and
2) reduction in indicated airspeed by 10 kt, that is, APMIAS < APMIASTH - 10 kt.

Table 4 presents the activation conditions of the eight APM CRUISE SPEED LOW advisories recorded during the accident flight.

CRUISE SPEED LOW Advisory	UTC Time	Indicated airspeed (kt)	Theoretical airspeed (kt)	Speed differential	Drag differential
		APMIAS	APMIASTH	(kt)	(%)
1	15:24:57	194	206	-12	13.3
2	15:25:49	196	206	-10	13.6
3	15:34:46	194	205	-11	12.5
4	15:51:58	189	204	-15	15.5
5	15:54:12	188	205	-17	12.5
6	16:00:12	196	207	-11	12.9
7	16:01:42	194	208	-14	16.8
8	16:18:42	191	206	-15	16.5

Table 4 – Conditions for activation of the APM CRUISE SPEED LOW advisories during the accident flight

Activation of the DEGRADED PERFORMANCE alert occurred whenever one of the following combinations was reached:

- combination A: drag increase of at least 22% (APMCXAC > 1.22 x APMCXTH) and reduction in indicated airspeed by 20 kt (APMIAS < APMIASTH - 20 kt); or
- combination B: drag increase of at least 28% (APMCXAC > 1.28 x APMCXTH) and reduction in indicated airspeed by 15 kt (APMIAS < APMIASTH - 15 kt).

For activation of the INCREASE SPEED alert, the two required conditions were:

- condition 1: drag increase of at least 22% (APMCXAC > 1.22 x APMCXTH); and
- condition 2: reduction in indicated airspeed to the value known as MSIS, defined as the VmLB0icing value (ICING BUG) plus 10 kt.

The VmLB0icing value was calculated in real time by the APM based on the aircraft's estimated current weight. During the accident flight, the aircraft weight, considered by the APM, at the moment of activation of the INCREASE SPEED alert was 20,989 kg, which corresponded to a VmLB0*icing* value of 161.1 kt. Thus, the MSIS value was 171.1 kt (VmLB0icing + 10 kt).

The INCREASE SPEED alert was classified as a Level 2 alert (CAUTION), within the CCAS philosophy established by the aircraft manufacturer.

1.19.6. Rudder hinge moment reversal

Rudder hinge moment reversal is an aerodynamic phenomenon that occurs when changes in the aerodynamic characteristics of a control surface, resulting, for example, from airflow disturbances caused by ice accretion, significantly alter the aerodynamic moment acting on the movable portion of the surface.

Under such conditions, the aerodynamic force that normally opposes control surface motion (restoring force) may be substantially reduced or even reverse direction, beginning to act in the same direction as the deflection of its movable portion, thereby ceasing to function as a restoring force and instead augmenting the motion induced by the applied control inputs. As a consequence, significant loads may be transmitted through the control chain, promoting rapid control surface movement and potentially compromising directional control.

1.20. Useful or effective investigation techniques.

NIL.

2. ANALYSIS

Passaredo Transportes Aéreos had commenced its operations in 1995, with an initial fleet composed of EMB-120 *Brasília* aircraft, operating short-haul routes between inland cities and major capitals.

In 2002, the company suspended its operations due to financial difficulties, remaining inactive for two years and resuming operations in 2004, following an internal reorganization that included fleet adjustments and route restructuring. Later, in October 2012, it entered into judicial reorganization proceedings, which lasted until 2017.

During the period in which it was under judicial reorganization, the company entered into commercial agreements with other operators, allowing the purchase of integrated tickets so that passengers could access regional destinations.

In 2019, the operator announced a corporate and operational integration agreement with *MAP Linhas Aéreas* and undertook a brand renewal process, adopting the trade name "*VoePass Linhas Aéreas*."

In the months preceding the accident, the company envisioned short-term growth, with new hires and the arrival of additional aircraft to expand the fleet of 15 ATR-72 and ATR-42 aircraft operated at the time.

The company had an organizational structure composed of Senior Management, an Administrative Board, a Presidency, and Directorates.

In addition to scheduled public air transport operations under RBAC 121, the company's activities also encompassed the provision of maintenance services governed by RBAC 145, featuring a Maintenance Directorate responsible for oversight of aircraft maintenance, regulatory compliance, and the planning of scheduled and corrective inspections.

To this end, it had maintenance bases located at some of the aerodromes operated by the company to provide maintenance services for the fleet aircraft, establishing the type of service authorized at each base and the classification of maintenance complexity, without provision for the hiring of third-party companies.

Only the bases located at SBRP and SBSV had a higher level of maintenance complexity, being qualified to perform tasks such as detailed visual inspections and other ones involving the use of special tools which required calibration control.

However, during the investigation, it was identified that the operator concentrated the execution of most corrective maintenance actions and complex inspections at the SBRP base. With regard to corrective maintenance actions performed on the Airframe De-Icing system boots, the records demonstrated that repair and replacement activities were conducted exclusively at the SBRP base.

In this context, it is important to highlight that the SIPAER Investigation Commission identified a scenario of weaknesses in the company's maintenance working conditions. At some secondary bases, limitations in maintenance resources were identified, as well as the absence of institutional uniforms for personnel and even restrictions on access to the aerodrome apron due to the lack of airport credentials, which had been denied as a result of outstanding debts with the terminal administration.

The accounts collected described that, on most occasions, the mechanics had only a few hours, usually during the nightshift period, to perform corrective and preventive maintenance on the aircraft, which, on several occasions, were already scheduled for flights the following morning.

The reduced interval between the aircraft's arrival at the base and its subsequent departure limited the time available for the performance of maintenance activities, particularly those of greater complexity, thereby generating additional pressure on the maintenance teams. Besides, the accounts pointed to the existence of exhausting work schedules, which at times exposed personnel to fatigue.

The pressure placed on mechanics to expedite the release of aircraft conflicted with the lack of time available for troubleshooting and resolving failures reported in the TLB, thereby contributing to the performance of maintenance tasks in a superficial manner, without completion of the required documentation, culminating in failures in item traceability or the delegation of critical activities to assistants without proper oversight.

Furthermore, the organizational processes did not prove sufficient to retain a qualified workforce properly prepared to use the aircraft manuals, an essential element in the work of maintenance mechanics. According to reports, personnel assigned to secondary maintenance bases frequently had to contact the MCC by telephone in order to receive guidance on how maintenance tasks should be performed, due to difficulties in understanding the manuals written in English.

The working conditions identified within the maintenance sector, together with reports of exhausting work schedules, fatigue, shortage of qualified personnel, and lack of basic resources, characterized an environment marked by an organizational climate of pressure on the company's mechanics.

These conditions constituted latent conditions within the organization that, cumulatively, increased the company's exposure to risks and weakened the protective barriers of the operational safety system.

At the secondary bases, since the infrastructure was limited, there was an "operational standard" focused on releasing aircraft with inoperative items dispatched under the MEL, with the expectation that definitive resolution of the malfunction would occur when the aircraft returned to the main base.

This model, in itself, did not constitute noncompliance with the applicable requirements, provided that the MEL validity limits and criteria were respected. However, recurrent situations were identified in which MEL deadlines expired during overnight stays at secondary bases. On those occasions, the solution adopted consisted of performing operational tests, the results of which were recorded in the TLB, certifying the respective system as functional, or even recording the resolution of malfunctions without the proper corrective action having actually been performed, resulting in the removal of the MEL item and the release of the aircraft for operation.

In subsequent flights, however, the same failures were frequently recorded, evidencing that the malfunction persisted and that the operational test logged in the TLB, at best, had not restored system functionality. The failure was then recorded again in the TLB, establishing a new rectification deadline. In practice, this conduct resulted in the successive renewal of the MEL item without effective correction of the malfunction, masking its chronic nature and postponing its definitive resolution.

There was also the practice of replacing an inoperative component with another known to be malfunctioning and dispatching the aircraft for flight. As a consequence, a new malfunction entry would be recorded on the subsequent flight, allowing a new dispatch based on the MEL and the temporary and exceptional continuation of operations. This conduct enabled the successive renewal of the MEL item without effective correction of the malfunction.

In practical terms, these combined actions resulted in aircraft being operated under knowingly degraded conditions, exceeding the time limits established by the regulations in force.

Another relevant aspect identified was the culture among flight crews of not recording malfunctions in the TLB. It was possible to ascertain that these patterns of deviation were encouraged by the company and directed toward the pilots. This informal process constituted a form of pressure on pilots in command, aimed at avoiding the recording of discrepancies that could result in the prolonged unavailability of the aircraft for flight due to the need to correct the reported failures.

A clear example of this culture of absence of formal reporting was identified in relation to problems with the Airframe De-Icing system, which had been perceived by several flight crews prior to the accident. The SIPAER Investigation Commission was able to verify that several flight crews reset the Airframe De-Icing system more than once during flight and did not log it in the TLB. This conduct evidenced the normalization of operational deviations in the face of recurrent failures.

This behavior generated a recurring pattern of verbal communications between pilots and mechanics without proper technical recording, thereby hindering the monitoring of failure history and the traceability of intermittent events. This practice contravened civil aviation regulatory procedures and compromised the company's ability to identify trends and act proactively.

Verbal communication between flight crews and maintenance personnel, without formal documentation, contributed to the company's technical and operational sectors not implementing mitigating measures, such as dispatch under the MEL, aircraft substitution, route replanning, or even corrective maintenance to resolve the malfunction.

In light of this context, it was concluded that the company's maintenance activities frequently took place close to safety limits and that deviations had become normalized in order to maintain operational continuity.

The normalization of these deviations, the performance of assistants without supervision, and the prioritization of operational continuity to the detriment of safety constituted a set of widely accepted, although undocumented, behaviors that reflected deficiencies in managerial oversight and a permissive organizational culture.

Effective managerial oversight not only corrects failures but also strengthens the safety culture by encouraging professionals to perceive themselves as both valued and accountable for their actions.

However, the absence of active oversight or the adoption of overly permissive models creates fertile ground for complacent behaviors and, consequently, small errors cease to be corrected and come to be regarded as acceptable, conveying to teams the idea that deviations from procedures carry no consequences. Over time, these deviations become normalized, creating a false sense of safety and increasing the vulnerability of the system's defenses. Conversely, when properly structured, however, oversight acts as a natural counterbalance to complacency and the consequent normalization of deviations.

The scenario identified by the SIPAER Investigation Commission within the operator's maintenance sector was not new to ANAC, since several oversight actions conducted by the Agency had already detected numerous nonconformities.

ANAC, as the authority responsible for the regulation and oversight of civil aviation, conducted continuous surveillance activities aimed at the systematic monitoring of the performance of operators, aircraft, processes, services, and certified personnel in a planned and recurrent manner.

Annually, a planning process was carried out to define the quantity and types of continuous surveillance actions to which each operator would be subjected during the following year. After the execution of the surveillance activities, based on the data and evidence collected, ANAC could adopt certain administrative measures, with progressively increasing severity and impact, such as preventive measures, specific precautionary measures, removal of personnel, operational restrictions, and suspension of the *COA*.

The SIPAER Investigation Commission requested data regarding the number of surveillance actions carried out on airline operators (RBAC 121) operating in Brazil, according to the metric used by the Agency, which considered the ratio between the number of questions raised during surveillance activities and every 1,000 takeoffs performed by each air carrier.

The results showed a number of findings, considering the *VoePass* Group (*Passaredo* and MAP), considerably higher than the combined total for the main RBAC 121 operators, corresponding to 82% of all findings in 2023 and 77% in 2024. It is worth noting that, at the time, the operator represented approximately 0.6% of the Brazilian scheduled air transport network volume.

During the period from January 2022 to August 2024, several surveillance actions were carried out by the Agency, both within the operational scope (RBAC 121) and maintenance scope (RBAC 145), including the following regulatory activities: ramp inspections, reduced-scope inspections, and follow-up flight surveillance inspections.

The audits and inspections revealed several technical and procedural nonconformities, particularly related to aircraft maintenance, component traceability, noncompliance with MEL conditions, and the recurrent practice of informal reporting or non-reporting of malfunctions. It was notably observed that there were improper repairs to the De-Icing boots and failures that were not recorded in the TLBs, contrary to the technical manuals.

Although the manuals did not specify an interval for the overhaul of the boots, there were limits regarding repairs and appropriate execution techniques. These conditions evidenced systemic deficiencies in the company’s maintenance management.

After the issuance of ten notices of irregular condition related to the Airframe De-Icing system by ANAC between 2022 and 2024, the company progressively replaced all boots of this system throughout its fleet during the first half of 2024.

ANAC identified recurrent situations in which, after MEL deadlines had expired during overnight stays at secondary bases, operational tests were performed and their results recorded in the TLB as indicating the system was functional, thereby allowing the aircraft to be dispatched. The reappearance of the same failures on subsequent flights evidenced that the malfunction persisted and that the tests had not been capable of resolving the failure. As a result, the MEL item was successively renewed.

According to ANAC, the operator employed practices that were unacceptable with regard to operational safety, and its SASC was not functioning properly, with deficiencies in maintenance oversight and even the possibility of its nonexistence, representing an imminent risk to operational safety.

In addition to the notices of irregular condition, ANAC adopted administrative enforcement measures associated with each situation. Among these enforcement measures, several precautionary aircraft suspensions were identified between 2022 and 2024. The peak in suspensions occurred in 2023, when aircraft were prevented from being operated on 24 occasions.

The progress of these proceedings depended on the complexity of the nonconformities identified during the surveillance activities. It was possible to verify that there were proceedings initiated as a result of an RBAC 121 Technical Audit that began on 27OCT2023 and remained under processing until 19AUG2024. The nonconformities identified during this audit were considered closed, with the exception of one for which the proposed mitigating action was accepted, subject to the reservation that it would be verified again during the next audit.

Within this temporal context, it was also possible to identify proceedings initiated as a result of an inspection conducted on 13 and 14MAR2024, for the verification of RBAC 121 requirements, which remained under processing until 19DEC2024, when the recorded nonconformities were considered closed and resolved.

There were also proceedings initiated as a result of an Inspection for the Verification of RBAC 121 Requirements conducted on 17 and 18JUN2024, which remained under processing until 19AUG2024, when one of the recorded nonconformities was considered closed while the others remained open. The nonconformities that remained open were related to maintenance services performed on the aircraft of registration marks PR-PDS, PR-PDP and PR-PDT.

The findings of the SIPAER Investigation Commission indicated that the signs identifying hazards, degradation of technical conditions, and latent conditions prior to the accident were not capable, when analyzed within the scope of ANAC's risk management process, of supporting the strategic decision-making necessary for the mitigation and control of risks in the operational environment regulated and overseen by the Agency.

Thus, it may be concluded that the means for recording, processing, and monitoring data and information related to hazards for the purpose of risk management were still in a maturation phase, allowing the degradation of safety levels in the company's operations without those operations being interrupted prior to the accident.

Despite the identification of several problems related mainly to the maintenance area, the SIPAER Investigation Commission identified positive aspects in the employees' perception of the work environment, particularly within the administrative and operations areas.

As a smaller-sized company, there was close proximity between employees and management, and the administrative staff demonstrated appreciation for the company, valuing the more accessible environment and the direct relationship with the Board of Directors.

Among the flight crews, it was common to perceive that the company offered a better quality of life compared to other air operators. The schedulers adopted a flexible approach, frequently allowing spontaneous schedule exchanges among crew members, which favored the balance between professional and personal life. In addition, overnight stays in the crew members' cities of residence and the reduced weekly flight workload (around 40 flight hours per month, practically half of what was required at other companies) were regarded as positive differentiating aspects of the company's operational routine.

This set of factors produced an ambiguous organizational culture in which benefits related to employee well-being coexisted with technical and doctrinal weaknesses. Although the positive aspects contributed to a work environment described as favorable among flight crews and administrative personnel, the critical elements observed — especially within the maintenance area, with regard to the informal handling of procedures essential to operational safety — weakened the institutional barriers for risk control and mitigation.

In addition to the other directorates comprising the company's organizational structure, there was also an Operational Safety Directorate, responsible for implementing and monitoring the SMS, conducting internal audits, and following up on the investigation of incidents and operational safety occurrences.

The company's SMS was structured through an Operational Safety Management Manual (MGSO), based on four components: operational safety policy and objectives; risk management; operational safety assurance; and operational safety promotion. Although the MGSO formally provided for data collection, hazard identification, risk analysis and management, and the adoption of mitigating measures, the SIPAER Investigation Commission identified deficiencies in the practical implementation of the operator's MGSO.

During the investigation, a high number of operational safety occurrences and deviations were identified, including in-flight performance degradation due to ice formation; failure to record system malfunctions in the TLB; noncompliance with standardized operational procedures by flight crews; dispatch practices inconsistent with the documentation issued by the manufacturer and ANAC; and the acceptance of errors and normalization of deviations.

Within this context, the investigation concluded that the data collected were not converted into useful knowledge for decision-making, which represented weaknesses in the SMS. Such circumstances demonstrated that the operator's SMS was not consolidated and presented a maturity index below the average of the other operators governed by RBAC 121, thereby failing, in practice, to fulfill its proactive role in ensuring operational safety, as prescribed by International Civil Aviation Organization Annex 19 and ANAC regulations.

Furthermore, based on the survey conducted by the Commission, no analyses related to the collected data were presented that demonstrated that the Flight Data Monitoring Program (PAADV) was being effectively applied in a continuous and comprehensive manner. The absence of analyses based on information made available by the PAADV, not incorporated into risk management and the adoption of mitigating actions, evidenced inadequate oversight by the organization's management of operational planning and execution activities.

It should be emphasized that, because the company operated aircraft with an MTOW below 27,000 kg, it was not required to implement a Flight Data Monitoring Program (PAADV), as provided for under ANAC regulations. Nevertheless, the operator voluntarily chose to submit its PAADV to ANAC, thereby formally assuming the commitment to implement it in accordance with the applicable regulatory parameters.

By assuming this commitment, the company became obligated to maintain the program active, functional, and compliant with its intended scope, including the submission of reports upon ANAC's request, the implementation of corrective measures, and the continuous feedback of the SMS. Thus, the absence of concrete actions in response to recurrent events or identifiable risk patterns through FDM represented noncompliance with the very program proposed by the company, thereby weakening its operational safety policy.

Thus, the SIPAER Investigation Commission concluded that, although the company possessed the infrastructure and the necessary data to identify hazards based on actual flight parameters, no evidence was found that such information had been systematically converted into corrective, doctrinal, or procedural actions, especially with regard to operations under icing conditions, a context directly related to the occurrence under investigation.

As a result, robust predictive measures were not adopted prior to the occurrence, allowing the escalation of risks. This gap in managerial oversight may, over time, have contributed to flight crews adopting a passive and complacent posture toward the alerts and failing to implement the structured actions prescribed in the operational procedures.

The investigation analyzed operational data from the company's ATR fleet, focusing on the identification of hazardous situations similar to those observed in this accident. A total of 15,365 flights performed by the company's ATR aircraft between August 2023 and August 2024 were analyzed.

Additionally, a comparative study was conducted using data from other airlines operating the same aircraft model (ATR-72-212A), resulting in a database comprising more than 120,000 analyzed flights.

The objective was to identify deviations and operational trends of the company in comparison with other operators. This cross-sectional analysis made it possible to assess the company's level of exposure to recurrent operational risks, especially in situations associated with performance under icing conditions, compliance with operational envelopes, and response to the aircraft's automated alerts.

The analysis of this volume of data revealed that the company presented the highest percentage of occurrences related to APM system events. Of the 15,365 flights analyzed, 10.9% of the total presented the activation of at least one APM advisory/alert. Of this total, 8.5% presented the CRUISE SPEED LOW advisory; 1.8% the DEGRADED PERFORMANCE alert; and 0.6% the INCREASE SPEED alert, values higher than those observed among the other operators (Figure 180).

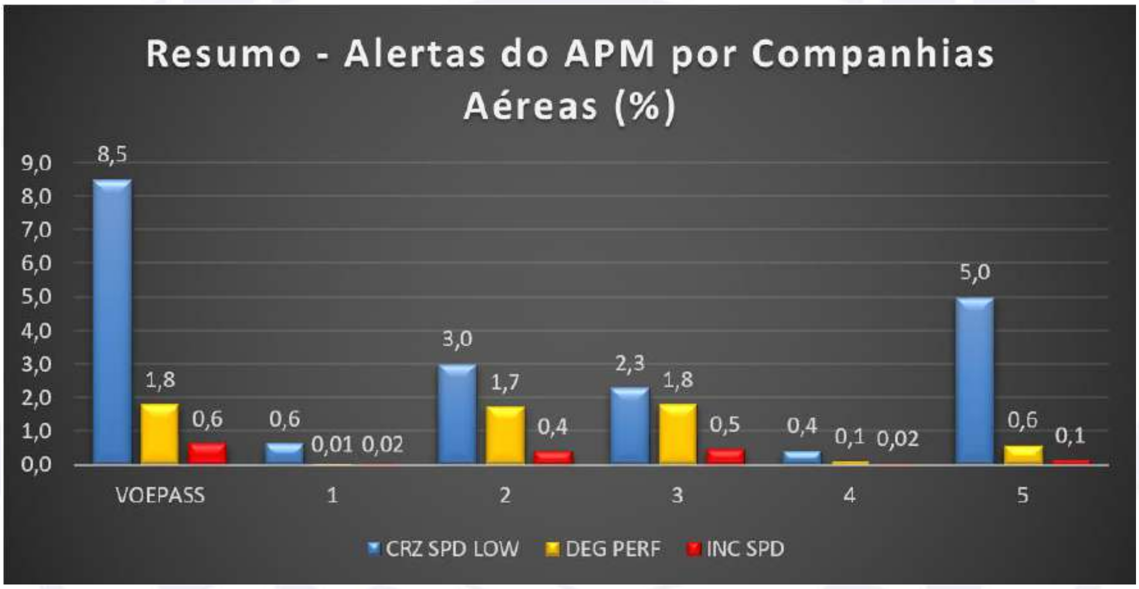


Figure 180 - Events related to the APM and percentage of CRUISE SPEED LOW (blue), DEGRADED PERFORMANCE (yellow), and INCREASE SPEED (red) advisories/alerts, comparing the company with the other operators.

The high occurrence rate of the CRUISE SPEED LOW advisory indicated that the company's aircraft were operating in cruise with indicated airspeeds averaging between 5 and 10 kt below the IAS Theoretical. These results pointed to greater operational exposure to the risk of aircraft performance degradation under icing conditions.

The analysis of the data evidenced that events similar to those observed on the flights preceding the accident — such as performance degradation in an icing environment, failures involving multiple resets of the Airframe De-Icing system, and activation of APM alerts during cruise — had already been recorded on other flights within the operator's ATR-72-212A fleet in quantities sufficient to require internal mitigation actions, training, or revision of procedures.

Other operational nonconformities were identified, such as a high rate of unstable approaches, premature application of reverse thrust after touchdown during landing, and the failure to perform ATPCS tests between the last flight of the day and the first flight of the following day, contrary to the manufacturer's manual recommendations and the company's own internal procedures.

However, the SIPAER Investigation Commission did not identify structured responses to these occurrences, especially those related to performance degradation due to ice accretion, which demonstrated weaknesses in the use of the PAADV as a managerial instrument, indicating its underutilization as a preventive and internal risk management tool.

According to the operator's PAADV, the degrees of risk tolerance were established as follows: Class 1 – Acceptable risk; Class 2 – Acceptable risk with restrictions; and Class 3 – Unacceptable risk.

Of the 15,365 flights, 1,674 were identified in which the APM generated performance alerts/warnings. The Commission found that events related to performance degradation due to ice accretion were not being classified as Class 3 and, therefore, concluded that they were not receiving the priority and urgent treatment consistent with their severity and potential consequences, such as loss of aircraft control.

Additionally, 1,206 flights of aircraft PS-VPB conducted between August 2023 and August 2024 were analyzed separately, revealing operational risk occurrences similar to those observed throughout the remainder of the company's fleet, including performance degradation events associated with ice formation.

Within this context, it is worth noting that a case of an unstable approach performed by aircraft PS-VPB, identified by the Investigation Commission, culminated in an abnormal runway contact (tail strike) at SBSV on 12MAR2024.

Following the event, the manufacturer and the operator acted jointly to assess the damage and submitted an official notification to CENIPA, which, based on the information received, classified the occurrence as an aeronautical incident.

Subsequently, the operator ferried the aircraft to the SBRP maintenance base for the performance of maintenance and repair services. Upon completion of the required activities, the aircraft received its APRS issued by ANAC on 26JUN2024.

However, during the course of the investigation of the present accident, while analyzing the engineering reports concerning the extent of the damage and the repairs performed on the aircraft following the incident that occurred at SBSV, the SIPAER Investigation Commission identified that the damage resulting from the tail strike was more severe than initially estimated, requiring interventions of greater technical complexity.

It should be emphasized that, in similar scenarios, it would be expected that CENIPA be updated regarding the extent of the damage identified during the repair services. Had this information been shared, the classification of the event would likely have been changed to an accident or serious incident, with the opening of a formal investigation process aimed at identifying contributing factors and issuing safety recommendations intended to prevent similar events.

Despite this condition, no connection was identified between the damage resulting from the tail strike that occurred on 12 MAR 2024 and the accident that occurred on 09 AUG 2024.

Still based on the 1,206 flights performed by aircraft PS-VPB, three flights were identified with significant reductions in IAS. In one of these flights, the airspeed decreased to values below the VmLB0icing, accompanied by a progressive increase in AOA, which favored the approach to a stall condition. Cases were also identified in which ice detection was not followed by the proper activation of the protection systems, in addition to flights involving multiple resets of the Airframe De-Icing system in flight, contrary to the operational procedures prescribed in the FCOM.

Similarly to what was verified for the remainder of the fleet, the SIPAER Investigation Commission did not identify documentary evidence or objective records demonstrating the structured treatment of these operational safety issues within the scope of the company's

PAADV. The absence of formalized corrective actions in response to recurrent and technically identifiable operational deviations indicated low effectiveness of the program in risk mitigation.

Thus, the pilots' decisions during the accident flight were influenced by an organizational context marked by multiple vulnerabilities in the safety culture, in which the acceptance of deviations had become normalized, and the aircraft alerts had become trivialized, reducing risk perception.

This scenario involving recurrent performance degradation under conditions conducive to ice formation, failures with multiple resets of the Airframe De-Icing system, and activation of APM alerts during cruise flight was repeated in the three flights preceding the accident.

On the night prior to the accident, aircraft PS-VPB operated "flight -3" between SBGR and SBRP, flown by a different crew from the one that would operate the aircraft on the following day. During this flight, the Electronic Ice Detector identified icing conditions while the Airframe De-Icing system was off, resulting in the illumination of the ICING light. In response, the flight crew activated the Airframe De-Icing system.

Upon identification of conditions favorable to ice condition, the aircraft manuals prescribed the execution of specific procedures, to be adopted according to the severity level of the ice formation identified, namely: maintaining the IAS equal to or above the speed corresponding to the ICING BUG marking on the airspeed indicator, activating the Anti-Icing systems, and continuously monitoring ice accretion.

Once ice accretion on the aircraft had been identified, the De-Icing systems should have been activated, and the IAS should be maintained at or above the ICING BUG + 10 kt, considering the aircraft configured with flaps at 0°, with continuous monitoring of both the indicated airspeed and the rate of climb.

There was also a need to verify whether severe icing conditions were present, highlighting the main indications described in the QRH, including ice covering substantial portions of the unheated side windows (visual check); or inability to maintain the IAS above ICING BUG +10 kt; or inability to maintain an average rate of climb above 100 ft/min at ICING BUG +10 kt airspeed; or abnormal vibrations. Other supplemental indications assisted in identifying severe icing conditions, such as water splashing and streaming across the windshield; or extensive ice accretion on structural areas where it is not normally observed; or ice accumulation on the lower surface of the wings behind the protected area; or ice accumulation on the propeller spinner farther aft than normally observed.

With regard to the meteorological conditions conducive to severe in-flight icing, the QRH highlighted visible rain at temperatures near 0°C *Static Air Temperature* (SAT) and droplets that spread or splash upon impact at temperatures near 0°C SAT.

The QRH further established in the PROCEDURE FOR ICE CONDITIONS (Figure 143), that once the conditions conducive to ice formation had ceased, the Anti-Icing and De-Icing systems could be turned off at the pilots' discretion, emphasizing that the visual verification of the absence of ice was performed through the IEP. Once the aircraft was visually confirmed to be free of ice accumulation, the ICING AOA button could be turned off, allowing a return to the use of normal operating speeds.

Approximately two minutes after activation of the Airframe De-Icing system, the MASTER CAUTION alert, accompanied by the single chime aural warning, was recorded once again. Subsequently, the Airframe De-Icing system was turned off and on three times. This scenario was characteristic of an Airframe De-Icing system failure condition, with reset attempts being carried out by the flight crew.

The Airframe De-Icing system failures were recorded by the MFC through messages related to the B chambers of the right and left wing boots (Right Wing Boot B Fault and Left Wing Boot B Fault) and by the MPC through message AIRFRAME FAULT.

The failure message related to the right wing boots (Right Wing Boot B Fault) remained active during the subsequent flights, including the accident flight. In contrast, the message related to the left wing boots (Left Wing Boot B Fault) was not activated again and did not appear in the MFC memories during the following flights. As there was no record whatsoever of corrective maintenance action, the SIPAER Investigation Commission concluded that the message related to the left wing boots possibly resulted from an intermittent system failure condition.

According to the aircraft FCOM, the flight crew was allowed, at its discretion, to attempt a reset of systems generating a MASTER CAUTION alert, which consisted of selecting the respective push button to the OFF position for three seconds and then returning it to the ON position.

If the failure alert disappeared after this procedure, the operation could continue normally, and the event should be recorded by the flight crew in the aircraft TLB. If the alert persisted, the flight crew should apply the corresponding abnormal procedure prescribed in the QRH.

Despite the guidance provided in the FCOM, there was neither a record in the aircraft TLB of the malfunction related to the Airframe De-Icing system nor a record of dispatch under specific MEL conditions, once again highlighting the culture among flight crews of not recording malfunctions in the TLB, motivated by concerns over prolonged aircraft unavailability.

It is worth emphasizing that the procedure established in the aircraft FCOM was also provided for in item 5.4.1.3 of the SOP, which addressed the “Reset policy”. However, there was no guidance regarding recording the failure in the aircraft TLB, nor were there instructions concerning which procedure should be adopted if the failure alert persisted after the reset attempt.

After the first system reset and the occurrence of a new failure, the flight crew should have followed the DE ICING AIRFRAME FAULT procedure, which instructed the crew to exit icing conditions, avoid them, and turn off the Airframe De-Icing system, regardless of the level of ice accretion. The procedure indicated that, should the aircraft have ice accretion or remain flying under such conditions, the following operational measures should be adopted: the IAS should be greater than ICING BUG + 15 kt; the Vapp could not be lower than Vref + 15 kt; the landing distance should be multiplied by 1.25; and landing approaches with an angle equal to or greater than 4.5° were prohibited.

During the interviews conducted in the course of the investigation, the Commission received reports that members of the night-shift maintenance team had become aware, through verbal communication with the pilots, of the occurrence of a failure in the Airframe De-Icing system during “flight -3”, although there was no formal communication recorded in the TLB.

It is worth emphasizing that, according to the applicable MEL, the aircraft could be dispatched with a failure in the Airframe De-Icing system boots, provided that it was not operated in known or forecast ice formation, a condition that would subsequently be present during the following flights.

It should be emphasized that, in accordance with the applicable regulations, it was the PIC’s responsibility to record all observed malfunctions in the TLB. Once again, this situation demonstrated a weakened organizational culture within the company.

Between “flight -3” and the subsequent flight, a routine inspection (Daily Check) was performed in *Ribeirão Preto*, as recorded in the TLB. Due to its preventive nature, this inspection did not include a functional check of the Airframe De-Icing system, being limited to an external visual inspection of the boots, which prevented the identification and possible correction of the failure.

On the day of the occurrence, the first flight performed by aircraft PS-VPB was the leg from SBRP to SBGR (“flight -2”), with a crew different from the one that would operate the two subsequent legs. During the cruise phase at FL150, ice was detected twice by the Electronic Ice Detector sensor, with activation of the MASTER CAUTION alert, associated with the single chime aural warning and illumination of the ICING light.

Following the ice detections, the QRH prescribed the execution of the PROCEDURE FOR ICING CONDITIONS, with the possibility of progression to the SEVERE ICING DETECTION procedure.

It should be highlighted that the MPC recorded on the PCMCIA card the message ICE DETECTED WHILE D/ICE SYSTEM IS OFF, since the Airframe De-Icing system remained turned off following the ice detection.

At the moment the first ice accretion was detected, the aircraft’s IAS in cruise flight transitioned from a stable condition to a fluctuating and progressively decreasing trend, dropping by more than 20 kt until the activation of the CRUISE SPEED LOW warning, which indicated performance degradation resulting from ice accretion on the aircraft structure.

Shortly after the second ice detection by the Electronic Ice Detector, the flight crew activated the Airframe De-Icing system, which remained on for approximately 50 seconds, until the appearance of a new MASTER CAUTION alert, associated with the illumination of the FAULT label on the Airframe de-ice pushbutton was triggered.

Through the data recorded in the MFC memories, it was verified that the failure message was related to the right wing boots (Right Wing Boot B Fault), which had already appeared during the previous flight and remained active during the subsequent flights, including the accident flight. In contrast, the message related to the left wing boots (Left Wing Boot B Fault), recorded during “flight -3”, was not activated again. The Commission concluded that the message possibly resulted from an intermittent system failure condition.

Immediately after this alert, the pilots performed a system reset; however, shortly thereafter, the Electronic Ice Detector no longer detected ice accretion. Approximately one minute later, a new failure was observed, but at that moment the flight crew elected to turn off the Airframe De-Icing system. In this context, the flight data records made it possible to determine that the two MASTER CAUTION alerts that occurred while the Airframe De-Icing system was turned on were due to the AIRFRAME FAULT condition associated with the Right Wing Boot B Fault message.

It should once again be emphasized that, according to the FCOM, after the system reset and the reappearance of the failure, the flight crew should follow the DE ICING AIRFRAME FAULT procedure. However, on “flight -2”, this condition occurred when the aircraft was already in the descent phase for approach.

Similarly to what had occurred during “flight -3”, no record whatsoever was found in the aircraft TLB regarding the Airframe De-Icing system malfunction, nor was there any record of dispatch under specific MEL conditions, once again evidencing the culture among the group of pilots of not officially recording failures occurring during flight.

The analysis of the data related to “flight -2” made it possible to verify the occurrence of ice detection, performance degradation, activation of the CRUISE SPEED LOW warning, failure of the Airframe De-icing system, execution of a reset attempt, and the absence of any record of this occurrence in the aircraft TLB, which once again prevented the failure from being identified for the subsequent flights.

The second flight of the day departed from SBGR bound for SBCA ("flight -1") and was operated by the same crew that would later operate the accident flight.

The climb was performed in two stages. Initially, the aircraft leveled off at FL140 in order to increase speed. It then resumed the climb to FL160, where cruise flight was established.

Still during the climb phase, between FL130 and FL140, the Electronic Ice Detector recorded the first ice accretion detection, triggering the ICING light and the MASTER CAUTION alert, associated with the single chime aural warning, while the Airframe De-Icing system was turned off. The FDR subsequently recorded activation of the Airframe De-Icing system by the flight crew.

Once again, at that moment, the QRH prescribed the execution of the PROCEDURE FOR ICING CONDITIONS, with the possibility of progression to the SEVERE ICING DETECTION procedure.

A few seconds later, another MASTER CAUTION alert, associated with a single chime aural warning, was issued once again. The data recorded on the MPC memory card indicated that this alert was associated with the AIRFRAME FAULT message.

Despite the alerts, the flight crew kept the Airframe De-Icing system turned on, contrary to the procedure prescribed for DE ICING AIRFRAME FAULT in the QRH, which established that the pilots should exit and avoid icing conditions, as well as turn off the Airframe De-Icing system.

The aircraft remained at FL140 for slightly more than three minutes while accelerating from 170 kt to 200 kt. During this period, the CRUISE SPEED LOW warning was activated. At that moment, according to the QRH, the flight crew should monitor both the icing conditions and the aircraft indicated airspeed.

As the aircraft approached FL160, the DEGRADED PERFORMANCE and INCREASE SPEED alerts were activated simultaneously, accompanied by a MASTER CAUTION alert. In this situation, the QRH indicated that the pilots should adopt a series of procedures related to maintaining aircraft performance, especially with regard to monitoring the IAS.

With regard to the DEGRADED PERFORMANCE alert, the flight crew should maintain the indicated airspeed 10 kt above the ICING BUG indication, monitor the VS and IAS, and alter the flight path. The manual also established that, should the aircraft be operating under icing conditions, it should be verified whether the Anti-Icing and De-Icing systems were turned on.

In addition, there was a recommendation to accelerate the IAS to ICING BUG + 30 kt and, should acceleration not be possible, the QRH prescribed disengagement of the AP and selection of the LOW BANK mode.

The checklist prescribed for the DEGRADED PERF warning also included the execution of additional procedures, considered memory items, should the pilots identify conditions compatible with Severe Icing, including the need to maintain the speed at ICING BUG + 30 kt (or ICING BUG, if operating with flaps extended to 15°); select PWR MGT – MCT; adjust the power levers; and select the CLs to 100% OVRD.

Subsequently, the flight crew should initiate the descent, verify the minimum en-route altitude, hold the control column firmly in order to prevent unexpected movements during AP disengagement, and disengage the AP.

Additionally, should it not be possible to accelerate the aircraft to values above ICING BUG + 30 kt with flaps at 0°, or above the ICING BUG with flaps at 15°, the procedure prescribed the following actions: select the LOW BANK mode; exit the severe icing condition; notify ATC; in the event the aircraft exhibited abnormal roll behavior, the stall recovery procedure should be immediately executed; the flaps should not be retracted while visible ice accretion remained on the fuselage; and the TCAS should be selected to TA ONLY mode.

Similarly, according to the aircraft QRH, following activation of the INCREASE SPEED alert, the IAS should be maintained at ICING BUG + 30 kt (memory item), and the procedures applicable to severe icing conditions should also be executed.

Around 50 seconds after activation of the DEGRADED PERFORMANCE and INCREASE SPEED alerts, the flight crew performed a reset of the Airframe De-Icing system. Following the reset, the FAULT light on the Airframe push button illuminated once again, accompanied by a MASTER CAUTION alert, once again indicating a failure condition of this system.

It is worth noting that, since the APM panel Weight Rotator Position was set to 22.5 tonnes, the VmLB0icing speed corresponding to that weight was 167 kt. However, the aircraft reached a minimum IAS of 161 kt and an AOA of 6°.

Due to the storage space and recording memory limitations of the aircraft CVR, the audio segment corresponding to that flight was overwritten, with only the approach and landing phase at SBCA remaining available. Therefore, the internal cockpit communications regarding those events were not available.

However, through the analysis of the communications recorded with APP-SP, the SIPAER Investigation Commission verified that the flight crew requested a descent from FL160 to FL140 due to ice formation, and the request was promptly approved by the air traffic control unit.

The descent was conducted with the AP engaged in VS mode, at a descent rate of 1,500 ft/min, with wings level and without any turns (zero-degree Bank Angle). During the descent, there was an increase in IAS and a reduction in AOA. Approximately 2 minutes and 30 seconds after the APM alerts were triggered, the increase in the aircraft indicated airspeed resulted in the extinguishing of the DEGRADED PERFORMANCE and INCREASE SPEED alerts.

It is worth highlighting that, after leveling off again and re-establishing cruise flight at FL140, the CRUISE SPEED LOW alert, also generated by the APM, was activated on two additional occasions. During the same period, ice detection occurred five more times, indicating the presence of ice accumulation throughout virtually the entire flight.

The flight crew kept the Airframe De-Icing system activated and performed two additional resets, both followed by MASTER CAUTION alerts and illumination of the FAULT light on the Airframe button.

Therefore, the SIPAER Investigation Commission concluded that, despite changing flight level and recovering aircraft performance, the flight crew did not comply with the DE ICING AIRFRAME FAULT checklist, remaining in conditions conducive to ice accumulation during a significant portion of the flight, with the Airframe De-Icing system selected ON while inoperative for most of the time.

During this flight, the message F/O ALPHA PROBE HEAT was recorded in the MPC 16 times, indicating intermittent operation of the right-side AOA sensor heating system.

This failure message indicated the absence of alternating electrical current to the heating system of the right-side AOA probes (F/O). The consequences of this failure included illumination of the ALPHA light on the PROBES HTG F/O panel, accompanied by the ANTI-ICING light on the CAP, the MASTER CAUTION alert, and the single chime aural warning.

The FCOM emphasized in the Additional Information section of Abnormal Procedure 30.4 – PROBES HTG FAILURE alert that, if the AOA probes were not properly heated, ice accumulation could occur, resulting in altered indications.

Indeed, during the time interval in which the F/O ALPHA PROBE HEAT messages were recorded, ice detection by the Electronic Ice Detector occurred on five occasions. It can therefore be concluded that ice accumulated on the right-side AOA sensor, generating a difference greater than 4° in relation to the left-side sensor for a period longer than 5 seconds, causing illumination of the FAULT light on the Stick Pusher/Shaker button and the inhibition of the stick shaker and stick pusher.

Due to the discrepancies identified, examinations and tests were conducted at the component manufacturer’s facilities, encompassing the evaluation of the electrical and mechanical conditions of the right-side AOA sensor.

During the examinations, it was verified that both power supply wires for the heating elements were electrically connected to their respective pins in the connector, and that both the sensor housing and its connector were in good condition.

The examinations and tests performed on the right-side AOA sensor demonstrated its overall good condition, with most quantitative measurement parameters remaining within the specified ranges. The bench tests conducted did not reproduce the condition observed during “flight -1”.

Therefore, the SIPAER Investigation Commission concluded that the condition was compatible with a scenario involving intermittent failures in the heating system of the right-side AOA sensor. These failures resulted in reduced effectiveness of its ice protection system, leading to ice accumulation during a specific phase of flight -1, with a discrepancy between the AOA values provided by the left and right sensors and temporary illumination of the FAULT light on the STICK PUSHER/SHAKER button.

Once the values measured by the two AOA sensors became consistent with each other again, the alert was suppressed and the Stick Pusher and the Stick Shaker returned to normal operation.

No record of this malfunction was found in the aircraft TLB, nor was there any information regarding dispatch under specific conditions provided for in the MEL, once again evidencing a culture of absence of formal reporting of aircraft system failures that could have guided troubleshooting actions and correction of the intermittent failure identified.

Despite the records obtained during “flight -1”, this failure related to the heating of the right-side AOA sensor was not reproduced during the accident flight, indicating a scenario compatible with the normal operation of that component during the accident flight.

The discrepancies and failure messages related to the AOA sensors occurred with the ICING light illuminated, allowing the conclusion that, even after the change in flight level, the flight continued under conditions conducive to ice accumulation on the aircraft.

During the approach phase for landing at SBCA, the CVR recorded a noise similar to an external bang, followed by a comment in which the PIC mentioned ice shedding from the aircraft surfaces, corroborating the conclusion that the aircraft was flying under ice accretion conditions.

Despite the large number of discrepancies observed during “flight -1”, no records whatsoever were found in the aircraft TLB, nor any information regarding dispatch under specific conditions provided for in the MEL, or any record of communication between the flight crew and maintenance personnel, once again evidencing a culture of absence of formal reporting of aircraft system failures.

This culture of failing to formally record discrepancies in the TLB prevented the company's technical and operational sectors from implementing mitigating measures, such as MEL dispatch, aircraft substitution, route replanning, or even corrective maintenance to rectify the malfunction, thereby contributing to aircraft PS-VPB operating in meteorological conditions conducive to icing formation with the Airframe De-Icing system inoperative.

Within the company's organizational structure, the Operations Directorate was responsible for the route network, crew allocation, and coordination between the CCO and the other operational sectors. According to the company's MGO, the CCO was responsible for the operational coordination and control of flights, including aircraft flight plans and the transmission of meteorological and operational information to the flight crews

The flight planning conducted by the company encompassed multiple operational, technical, and meteorological variables that were required to be considered by both the flight crew and the company's CCO during flight preparation. This phase was essential to ensure that flight operations were conducted within safe parameters, taking into account any aircraft technical restrictions, meteorological conditions, appropriate flight levels, and compliance with procedures contained in manuals and requirements established by civil aviation regulations.

In the case of the accident under investigation, the SIPAER Investigation Commission identified relevant aspects related to flight planning, whose decisions, omissions, or simplifications contributed to the aircraft's exposure to an unmitigated risk scenario. The set of data demonstrated that certain assumptions were adopted without full integration among the sectors involved or without due consideration of the prevailing meteorological context and the existing technical limitations of the aircraft.

The third flight of aircraft PS-VPB on that day was conducted by the same crew as the previous flight. It was a scheduled public air transport flight departing from SBCA bound for SBGR, with 4 crew members and 58 passengers on board.

Aircraft PS-VPB had been incorporated into the operator's fleet on 29SEP2022 and had a valid Certificate of Airworthiness. The engines and propellers were approved for operation, with their maintenance records updated and in compliance with the operator's maintenance program.

According to the records collected from the TLB and from the dispatch documents related to the aircraft's technical condition, there was a total of 10 inoperative items dispatched under the conditions established in the MEL, with particular emphasis, for the purposes of this investigation, on the failures of Pack No. 1 and the right-side windshield wiper, corresponding to the SIC. It is further noteworthy that there were no TLB entries or dispatch information regarding MEL conditions related to components of the aircraft Airframe De-Icing system.During the planning, the failure of Pack No. 1 was taken into consideration. However, since the ATR-72-212A aircraft operated with two units (Pack No. 1 and Pack No. 2), dispatch with one of them inoperative was permitted, as provided for in the MEL, provided that the specific operational restrictions were observed.

This type of inoperative condition fell under Category C, and the company had up to 10 days to correct the malfunction. According to the documentation, Pack No. 1 had been inoperative since 05AUG2024, which characterized a condition in compliance with the time limits established in the MEL.

According to the aircraft MEL, operation with Pack No. 1 inoperative imposed a maximum cruise altitude limitation of FL170, with the purpose of ensuring adequate pressurization performance using the remaining Pack unit. This technical limitation was recorded in the operational dispatch documents.

With regard to fuel planning, it was observed that the calculations performed for refueling considered fuel consumption at FL100, as prescribed by the operational procedure established in the MEL when one of the Packs was inoperative. This practice indicated a conservative margin, since, in the event of a failure of the remaining Pack, the emergency procedure would require the aircraft to descend to lower altitudes, where fuel consumption is higher.

Thus, the flight planning regarding the cruise level and fuel quantity, due to the restriction imposed by the MEL, was properly carried out.

The aircraft dispatch documentation also included the failure of the SIC's windshield wiper since 30JUL2024. According to the MEL, the aircraft could be dispatched in that condition provided that meteorological forecasts indicated no precipitation from one hour before to one hour after the estimated departure time at the departure aerodrome, and the estimated landing time at the destination or alternate aerodrome. If precipitation conditions were forecast within this period, dispatch could not be authorized (NO GO).

On the date of the accident, the flight plan indicated an EOBT of 14:40 UTC, with an estimated flight time of 1 hour and 55 minutes up to SBGR (ETA 16:35 UTC). According to the meteorological data, precipitation was forecast between 14:00 and 16:00 UTC, a period that fell within the time window established by the MEL (± one hour from the estimated landing time). Therefore, under those conditions, dispatch of the aircraft with this failure would not have been permitted, since the weather forecast rendered the dispatch irregular due to the forecast precipitation at the destination aerodrome within the time interval prescribed in the MEL.

The release of the aircraft under this condition, without any effective mitigating action by the operational dispatch sector or even by the CCO, evidenced a systemic deviation in conduct regarding compliance with MEL criteria. None of the analyzed documents indicated that a formal assessment of the operational impacts of this failure on the forecast meteorological scenario had been conducted, nor that restrictions had been applied or clear communication provided to the flight crew regarding the potential risks.

Therefore, although the failure of the SIC's windshield wiper might, in isolation, appear to be a low-criticality item, within the specific flight context, under forecast precipitation conditions, it represented a breach of the technical safety criteria established in the dispatch documentation. Although it did not directly contribute to the accident, this fact once again demonstrated the fragility of the company's organizational culture.

Based on the analysis of the dispatch documents, it was verified that two compilations of meteorological information had been made available to the flight crew. The first contained a meteorological assessment issued at 10:18:11 UTC. The second compilation provided to the flight crew consisted of an update of the meteorological information and contained, among other information, the 08:45 UTC TAF for SBGR and SIGMET 6, valid for the *Curitiba* FIR from 11:30 UTC to 15:30 UTC.

Among the meteorological information presented in this second document, particular emphasis was placed on the forecast rain condition (RA) for SBGR between 14:00 UTC and 16:00 UTC in the TAF and, in SIGMET 6, on the forecast severe icing condition (SEV ICE FCST) for the *Curitiba* FIR between FL120 and FL210.

Through the analysis of this documentation, the SIPAER Investigation Commission verified that the flight crew had access to meteorological information containing a forecast of severe icing formation along the planned flight route.

The meteorological analysis conducted by the SIPAER Investigation Commission also verified that, at the time of the flight on 09AUG2024, the aircraft was flying over the southeastern region under the influence of a well-defined frontal system associated with a low-pressure center over the Atlantic Ocean and the presence of a high-level jet stream, which generated atmospheric instability with significant cloud development and changes in the thermal and hygrometric profiles.

The atmospheric sounding conducted at SBMT showed that the conditions between FL120 and FL230 characterized an environment conducive to severe icing formation (SEV ICE), which contributed to a high potential for compromising aircraft performance and operational safety.

A survey regarding the frequency of SEV ICE SIGMET messages covering the area of the State of *São Paulo* between AUG2023 and AUG2024 was conducted by the SIPAER Investigation Commission in order to contextualize the abnormality of the meteorological conditions encountered.

It was found that the meteorological conditions encountered by the aircraft were not unprecedented from a climatological standpoint and represented a concrete operational threat that could be identified through the meteorological forecasting and warning systems available and in use within Brazilian civil aviation.

The SIGMETs issued for the *Curitiba* FIR (No. 9) and *Brasília* FIR (No. 2), valid between 15:30 UTC and 19:30 UTC, forecast severe icing formation between FL120 and FL210, covering an area and period that encompassed virtually the entire route of the flight in question. The aircraft trajectory at FL170 coincided, both spatially and temporally, with areas under severe icing meteorological warnings.

Although the meteorological information indicated the existence of atmospheric layers with potential icing formation between FL120 and FL210, no initiative by the CCO was identified to adapt the flight profile to the forecast conditions along the route in view of the performance characteristics of the ATR-72, as provided for in Sections 121.601 and 121.629 of RBAC 121 in force at the time of the accident.

Thus, the fact that the aircraft had been dispatched to operate at a flight level where severe icing formation (SEV ICE) had been forecast characterized the inadequacy of the flight planning conducted by the CCO, which contributed to the aircraft operating under conditions for which it was not certificated.

Indeed, based on the available data, the SIPAER Investigation Commission concluded that the meteorological conditions contributed to the occurrence by creating an environment unfavorable to the safe operation of the aircraft. Prolonged exposure to SEV ICE conditions resulted in performance degradation and a significant increase in aerodynamic drag, making it difficult to maintain the desired flight regime.

In this scenario, the flight planning at FL170, within the range of flight levels forecast to experience severe icing conditions, evidenced that the CCO and the DOV did not adequately consider the forecast meteorological conditions along the route prior to dispatch, in noncompliance with Section 121.629 of RBAC 121, which prohibited dispatch whenever existing or forecast icing conditions capable of adversely affecting operational safety were present.

Furthermore, the pilots' agreement with the proposed flight planning, without identifying or questioning the incompatibility between the selected cruise level and the forecast meteorological conditions along the route, also characterized a complacent attitude and noncompliance with operational procedures, thereby contributing to the accident under analysis.

In addition, no records were found of any communication between the flight crew and the CCO after "flight -1", during which the DEGRADED PERFORMANCE and INCREASE SPEED alerts had occurred. Such communication could have triggered a closer monitoring protocol by the company. The lack of active monitoring of the flight operational parameters evidenced weaknesses in the real-time operational support and risk management processes.

Thus, the SIPAER Investigation Commission concluded that the flight planning and execution process lacked effective integration among the responsible sectors, as well as continuous and proactive support from the CCO, failing to mitigate foreseeable risks arising from documented hazards. This deficiency was a contributing factor to the aircraft remaining at a flight level susceptible to ice accretion, culminating in the progressive degradation of performance and in the development of the occurrence scenario.

For this reason, the SIPAER Investigation Commission analyzed the process that led to the publication of Amendment 24, issued on 22JAN2026, which modified the wording of paragraph (c) of section 121.601 of RBAC 121, assigning solely to the PIC the responsibility for obtaining additional available information regarding meteorological conditions and irregularities in facilities and services that may affect operational safety, in order to identify possible latent conditions or conflicting requirements that could contribute to future occurrences.

Hence, the SIPAER Investigation Commission found that the amendment to Section 121.601, together with the maintenance of the wording of paragraph (a) of Section 121.629, created a potential conflict of responsibilities by removing the requirement for in-flight communication by the flight dispatcher from Section 121.601 while retaining it in Section 121.629.

Therefore, it is possible that the amendment made to paragraph (c) of Section 121.601 of RBAC 121, within the context of the reality of Brazilian civil aviation and the facts observed during the process of amendment of the requirement conducted by ANAC, particularly the limited participation of air carriers in the public consultation process, may create latent conditions contributing to new occurrences under circumstances similar to those observed in this accident, making it necessary to assess the pertinence of revising such amendment.

With regard to the aircraft weight and balance, the SIPAER Investigation Commission identified that, considering the weight of the passengers, the cargo carried, and the fuel consumed on the ground, the takeoff weight was 21,665 kg, with the CG at 26.9% of the Mean Aerodynamic Chord. Thus, the aircraft was within the limits established by the manufacturer in the operational envelope.

It was further calculated that, at the time of the accident, the aircraft had approximately 2,189 kg of fuel remaining in the tanks, which corresponded to a total weight of 20,654 kg and a CG located at 26.3% of the Mean Aerodynamic Chord, values that were also within the prescribed weight and balance limits.

However, it is important to emphasize that the effects of ice accretion impact both the aircraft weight and balance, making the exact weight value and CG position at the moment of loss of control uncertain. Even so, based on the margin between the CG value and the limits of the balance envelope, the aircraft CG was considered to have remained within the envelope limit parameters, even in the presence of ice accretion, and therefore did not contribute to the accident under analysis.

The SIPAER Investigation Commission found that all crew members met the applicable requirements and were therefore qualified to conduct the flight. No physiological or incapacitating conditions that could have affected crew performance were identified, nor was there evidence that fatigue-related aspects contributed to the accident under investigation.

The PIC joined the operator company in NOV2022, where he remained employed until the date of the accident. He was initially hired to serve as a copilot, with the expectation of being promoted to captain in the short term. During the selection process, he achieved outstanding performance in the simulator and underwent a psychological attention test, the results of which were considered favorable. His promotion to the position of captain occurred approximately one year before the accident.

The interviews revealed that, over time, the PIC developed good interpersonal relationships and was well regarded among his coworkers. Despite this, he reportedly expressed dissatisfaction to people close to him regarding organizational aspects of the operation, especially concerning the condition and state of preservation of the aircraft.

The SIC, in turn, demonstrated ease in establishing interpersonal relationships and was regarded as a good listener, helpful, and empathetic. He joined the company's roster of copilots in AUG2019 and remained in the same position until the date of the accident.

According to the CVR recordings and the accounts obtained throughout the investigation, the PIC was experiencing personal problems at the time of the accident, which became the subject of informal conversations between the pilots during the flight, including during critical phases of the operation.

The air navigation aids covering the area of interest where the accident occurred, as well as the Area Control Center, were operating without technical or operational restrictions.

The PIC's airspeed indicator was found at the accident site with the RED BUG adjusted to approximately 165 kt, corroborating the setting of the VmLB0icing speed, as indicated by the audio recordings.

According to the flight data, the aircraft took off from SBCA at 14:58:05 UTC, with the APM Weight Rotator Position set to 22 tonnes, a value consistent with the ICING BUG setting discussed by the pilots.

An intermittent and inconsistent behavior was identified in the status of the DC_BUS1 parameter during the aircraft taxi phase. The records indicated continuous oscillation, in contrast with the behavior of the DC_BUS2 parameter, whose operation remained stable and continuously energized throughout the entire analyzed period.

However, during the analysis of the flight data, no activation of the MASTER CAUTION alert related to a failure or malfunction of the DC BUS 1 was identified. Therefore, the SIPAER Investigation Commission inferred that the absence of MASTER CAUTION alerts was consistent with a scenario in which the DC BUS 1 remained effectively energized throughout the entire flight and that the recorded oscillations occurred spuriously, without correlation to actual system failures, being compatible with an intermittent contact in the electrical grounding of the DC BUS 1 indicator light.

After takeoff, the AP was engaged at 14:59:54 UTC, with the LNAV and IAS modes activated, the selected climb speed set to 173 kt, and ALT SEL set to FL170. Shortly thereafter, ACC-CW cleared the aircraft to proceed direct to the BUXUK fix while maintaining the climb to the planned cruise level.

During the climb phase, at 15:12:40 UTC, while passing approximately FL110, the flight crew activated the propeller and horn anti-icing system (Level 2), in accordance with the operational procedures recommended for flight in conditions conducive to ice formation. From that moment on, the ICING AOA indication remained illuminated, demonstrating that the Stall Warning thresholds had been redefined for icing conditions.

At 15:14:56 UTC, while passing approximately FL130, the Electronic Ice Detector detected ice accretion, triggering the MASTER CAUTION alert, accompanied by the single chime aural warning and illumination of the ICING light on the ICE DETECT panel (Figure 181).

Figure 181 - MASTER CAUTION alert, accompanied by the single chime aural warning, associated with the illumination of the ICING light.

At that moment, the MPC recorded an ICE DETECTED WHILE D/ICING SYSTEM IS OFF message.

At 15:15:03 UTC, seven seconds after the illumination of the ICING light, the aircraft Airframe De-Icing system was activated. This action demonstrated the flight crew's initial response to the ICING alert. However, no reading of the PROCEDURE FOR ICE CONDITIONS checklist prescribed in the QRH was identified in the CVR recordings.

At 15:15:42 UTC, 39 seconds after activation of the Airframe De-Icing system, the MASTER CAUTION alert, accompanied by the single chime, was triggered again in the cockpit. At that moment, the MPC recorded the AIRFRAME FAULT message, associated with the operation of the right wing boots (Right Wing Boot B Fault).

Figure 182 – MASTER CAUTION alert accompanied by the single chime alarm, associated with the illumination of the ICING FAULT light.

The improper operation recorded by the MPC could have been related to a failure of the DDV found at the wreckage site near the tip of the right wing, since, based on its location, it was inferred to be the DDV corresponding to FIN 10DM, responsible for the activation of the right-wing outer boots. However, the degradation resulting from the post-impact fire made it impossible to perform any functional testing, as well as to identify elements that could indicate the operating condition of the component prior to the impact and fire exposure.

Despite the guidance contained in the FCOM, the FDR data indicated that, following this failure, the pilots did not perform any attempt to reset the Airframe De-Icing system.

According to the data contained in the CVR, at 15:15:44 UTC, immediately after the MASTER CAUTION alert associated with the single chime alarm, the PIC commented that the Airframe De-Icing system had failed and then stated that it was already inoperative. Subsequently, at 15:15:49 UTC, the Airframe De-Icing system was turned off by the flight crew.

It should be noted that, during the flight preceding the accident flight, which was conducted by the same flight crew, the Airframe De-Icing system failure had already occurred. Therefore, based on this information, the SIPAER Investigation Commission concluded that the flight crew was aware of the malfunction of the Airframe De-Icing system.

At 15:16:09 UTC, immediately after the PIC's comment regarding the failure of the Airframe De-Icing system, the SIC remarked that the failure had not been reported in the TLB and that, in order to avoid icing conditions, they would have to fly at FL110. No response from the PIC to the SIC's comment was recorded in the CVR.

The absence of any comment corroborated the identification of the PIC's low level of situational awareness regarding the stage of flight. It was also verified that CRM was not properly applied between the flight crew members.

According to the aircraft QRH, given the failure condition of the Airframe De-Icing system, the procedure DE ICING AIRFRAME FAULT should have been carried out by the flight crew. However, the FDR data indicated that the Airframe De-Icing system was manually turned off by the flight crew at 15:15:49 UTC, complying with only one of the items prescribed in the QRH.

As the ICING light was illuminated, the conditions conducive to ice accretion persisted. Nevertheless, no action by the flight crew was observed toward leaving that area or flight level in order to avoid remaining under those conditions, thereby complying with the guidance set forth in the QRH.

Furthermore, under conditions conducive to icing, the speed should have been maintained at least ICING BUG + 15 kt, which, in this case, corresponded to 180 kt. However, at the moment of the Airframe De-Icing system failure, the aircraft was in the final stage of climb with an IAS close to 170 kt, therefore below the speed prescribed in the QRH for that condition.

Only at 15:16:26 UTC, 37 seconds after the Airframe De-Icing system had been turned off, was the ICING alert deactivated, suggesting that the aircraft had momentarily left the region conducive to ice formation.

However, at 15:17:10 UTC, a new MASTER CAUTION alert, accompanied by the single chime, was recorded simultaneously with the illumination of the ICING light. The light remained illuminated until 15:19:12 UTC, and during this approximately two-minute period, no comment was made in the cockpit regarding the new illumination of the ICING light.

During that interval, the pilots were engaged in a personal conversation and, probably, that interaction diverted their attention from operational tasks, causing interpersonal support to be prioritized and contributing to a reduction in their focus on operational activities.

Furthermore, the failure to comply with the QRH guidance regarding the DE ICING AIRFRAME FAULT procedure evidenced, on the part of both pilots, a low level of situational awareness concerning the degree of risk exposure to which the aircraft was subjected, as well as deficiencies in Crew Resource Management (CRM), reflected in the absence of effective communication between the crew members regarding the worsening of the flight conditions. Taken together, these aspects reflected attitudes of complacency, passivity, and noncompliance with procedures.

Level-off at FL170 occurred at approximately 15:22 UTC through the operation of the AP, capturing the selected flight level (ALT SEL) and subsequently maintaining the assigned altitude of 17,000 feet in ALT HOLD vertical mode.

According to the FCOM, after stabilization in cruise flight, it was necessary to set the orange SPEED BUG to the calculated cruise speed in order to identify performance degradation, especially due to the increase in drag in the event of ice accretion.

However, although both the manufacturer's FCOM and the operator's SOP provided for the adjustment of the SPEED BUG, this information was not included in the Normal Checklist ATR-72-500, code L-POR-FST-004-20-01, Version 02.00. In fact, there was no checklist procedure whatsoever related to the cruise phase of flight. It is worth noting that this document was used by the operator as a checklist based on the manufacturer's operational manuals and had been approved by the Regulatory Agency.

After the aircraft leveled off at FL170, critical events related to ice accretion and aerodynamic performance degradation were identified, with the consequent reduction in the aircraft's IAS.

At approximately two minutes after the aircraft had leveled off at FL170, the Electronic Ice Detector indicated ice accretion, which was accompanied by the activation of the MASTER CAUTION alert, accompanied with the single chime aural alert and by the automatic recording by the MPC of a message related to ice detection while the De-Icing system was not activated (ICE DETECT WHILE D/ICE SYSTEM IS OFF).

Seven distinct episodes were also identified (in addition to an eighth and last one in the final moment of the flight), in which the APM issued the CRUISE SPEED LOW alert, indicating different moments when the IAS was at least 10 kt below the theoretical speed computed by the APM and with the calculated mean drag at least 10% above the theoretical drag specified for cruise flight.

Figure 183 - CRUISE SPEED LOW alert on the left-side APM panel (PIC).

The SIPAER Investigation Commission was unable to identify, based on the CVR recordings, any statement or comment by the flight crew indicating recognition, perception, or processing of those advisories/alerts, nor the execution of the corresponding procedures prescribed in the QRH. It was further verified that the Airframe De-Icing system remained turned off throughout the interval during which the alerts were issued.

The CRUISE SPEED LOW alerts occurred during two distinct periods. The first two coinciding with ice accretion detection by the Electronic Ice Detector. The remaining five were triggered during an interval of approximately 41 minutes, in which no ice accretion was detected by the Electronic Ice Detector, indicating that, despite the absence of active detection by that sensor, the aircraft was experiencing performance degradation, possibly caused by residual ice presence or by undetected ice accretion.

This situation may have occurred due to the operating principle of the Electronic Ice Detector, since detection was performed by means of a sensor that naturally vibrated at a certain frequency. With ice accretion, the vibration frequency of the sensor changed and the alert was generated through the illumination of the ICING light. After detection, the sensor was heated for 7 seconds, and a new 60-second detection cycle was initiated. If new ice accretion occurred causing a change in the sensor vibration frequency, the alert remained active. If no such detection occurred within 60 seconds, the alert would extinguish.

Thus, it is possible that, during this phase of the flight, a slow accumulation of ice occurred on the aircraft surface and that the process of freezing and sublimation caused by sensor heating inhibited the ICING alert, indicating a possible inefficiency of the Electronic Ice Detector. This possibility was highlighted in the aircraft FCOM, in Section 1.2 of Chapter 30.2 ICE AND RAIN PROTECTION ANTI ICING ADVISORY SYSTEM, with the purpose of alerting operators to this condition.

After an interval of approximately 41 minutes without detection, indications of ice accretion were again identified on three distinct occasions. These detections by the Electronic Ice Detector were associated with three MASTER CAUTION alerts accompanied by the single chime aural warning.

It is noteworthy that, during the approximately 6-minute interval between the three ice accretion detections, the Airframe De-Icing system remained turned off, while the Anti-Icing system remained activated, partially complying with the QRH requirements for flight in icing conditions, although not effectively sufficient to protect the aerodynamic surfaces of the aircraft.

During this period, the CVR recording captured a comment by the SIC stating that he had forgotten to turn on the Airframe De-Icing system. Subsequently, the PIC commented that he could turn on all the De-Icing systems. The SIC questioned what the PIC had said and received the response that the PIC had already turned on all systems.

However, the communication between the pilots lacked clarity and assertiveness, which reduced the practical effectiveness of their contributions and resulted in uncertainty regarding which system activation each pilot was referring to. As a consequence, the Airframe De-Icing system remained turned off, while the Anti-Icing system remained activated.

At 16:17:26 UTC, the PIC began the passenger announcement (speech) regarding the approach to SBGR. During the speech, the third ice detection by the Electronic Ice Detector occurred, with activation of the MASTER CAUTION alert associated with the single chime aural warning.

After the third detection of ice accretion, at 16:17:41 UTC, the flight crew finally activated the Airframe De-Icing system.

Based on the analysis of the FDR data, it was verified that, during this final cruise phase of the flight, a progressive increase in elevator deflection in the nose-up direction occurred. This deflection, commanded by the AP, aimed to increase the AOA in order to maintain altitude in ALT HOLD mode. This behavior indicated that a decrease in the aircraft's aerodynamic efficiency was occurring as a result of ice accretion. With the increase of drag, the speeds decreased and as a consequence an increase in AOA was necessary to maintain flight level. It is important to note that, during this cruise period, there was no variation in the engine or propeller parameters.

Still during the final cruise phase, the pilots were carrying out radio communications as part of the preparation for approach and landing. The SIC was interacting with the company base at SBGR, while the PIC handled the communications with APP-SP.

At 16:18:24 UTC, the PIC reported to APP-SP that the aircraft was at the ideal point for descent, and APP-SP requested that FL170 be maintained. The instruction was accepted by the PIC without any argument or comment in the cockpit indicating an intention to initiate an immediate descent.

At 16:18:42 UTC, upon reaching an IAS of 191 kt and with the drag calculated by the APM 16.5% greater than the theoretical drag expected, the last CRUISE SPEED LOW alert was issued. It was verified that the flight crew made no comment and took no action regarding the CRUISE SPEED LOW alert issued by the APM. The PIC was focused on preparing the arrival procedure, while the SIC was carrying out coordination with the company base at SBGR.

Subsequently, at 16:18:58 UTC, a MASTER CAUTION alert associated with the single chime aural warning occurred together with the illumination of the FAULT light on the Airframe De-Icing button. This failure occurred 1 minute and 17 seconds after activation of the system. Following the alert, the Airframe De-Icing system was turned off at 16:19:07 UTC. Despite this action, based on the CVR recordings, no verbal communication between the pilots regarding this situation was identified.

At 16:19:23 UTC, APP-SP instructed PS-VPB to maintain FL170 due to traffic restricting its descent. At that moment, the aircraft was flying at FL170, approximately 3 NM from the GR249 fix. Subsequently, at 16:19:26 UTC, the SIC reported to APP-SP that they would maintain the flight level and that the aircraft was at the ideal descent point, awaiting clearance. During this interaction, the pilots made neither a request for an immediate descent nor an emergency declaration. This external communication with APP-SP ended at 16:19:33 UTC.

During these interactions with the air traffic control unit, with an IAS of 185 kt, decreasing at 10kt/min, and drag calculated by the APM at 27% above the expected value, the DEGRADED PERFORMANCE alert was triggered, accompanied by the MASTER CAUTION alert and the single chime aural warning. These alerts indicated a progressive deterioration in the aircraft’s performance, consistent with ice accretion on the aerodynamic surfaces.

Figure 184 - DEGRADED PERFORMANCE APM alert associated with MASTER CAUTION, accompanied by the single chime aural warning.

Following the activation of the DEGRADED PERFORMANCE alert, the flight crew ought to carry out the corresponding QRH procedures, including maintaining the indicated airspeed at ICING BUG +10 kt and changing the flight path. As the aircraft was operating under icing conditions, the crew should also verify that the Anti-Icing and De-Icing systems were turned on.

In addition, there was a recommendation to increase the IAS to ICING BUG + 30 kt and, if acceleration was not possible, the QRH prescribed disengaging the AP and selecting the LOW BANK mode. The checklist further prescribed the execution of the Severe Icing procedures, should the pilots identify indications compatible with that condition.

At that moment, the aircraft’s indicated airspeed was 185 kt, that is, below the ICING BUG +30 kt value (165 kt + 30 kt = 195 kt) established in the QRH. Despite this condition, no comment regarding the advisories/alerts already issued by the APM, nor regarding the execution of the procedures prescribed in the QRH, was identified based on the flight data. Furthermore, as it was not possible to maintain ICING BUG +30 kt, no action by the pilots was observed concerning the disengagement of the AP and the selection of the LOW BANK mode. During this interval, the pilots were interacting while conducting the arrival briefing for SBGR. Subsequently, the PIC requested the execution of the Descent Checklist.

From a procedural standpoint, the records indicated that the flight crew continued performing the routine flight management tasks normally. However, no mention was made of the use of specific checklists for severe icing or performance degradation, nor was there any reference to the QRH in response to the advisories/alerts.

Despite the structured logic of the alert system adopted on the aircraft, the crew's response in a failure scenario required not only technical knowledge of the system, but also a state of cognitive and emotional readiness that would allow the correct interpretation of the cues and the execution of the procedures. In other words, even though the system clearly indicated the failure, the success of the corrective action was directly linked to the flight crew's perception, judgment, and coordination.

However, the decision not to carry out the DE ICING AIRFRAME FAULT procedure, for example, suggests that there was tacit acceptance by the pilots of deviations from regulations, which had become normalized under the influence of the company's organizational culture. Such practice reduced risk perception and led to the normalization of flight operations under conditions below the established safety standards.

The normalization of deviance occurs when an incorrect, non-standardized, and non-prescribed attitude becomes an informal norm experienced by the members of an organization. Among its causes are the existence of a permissive organizational culture, routinization, and the absence of immediate negative consequences. Such conduct should be prevented through a just culture, in which unintentional deviations are reported without retaliation, while intentional acts are subject to punishment. Environments in which deviations are ignored or treated with indifference ultimately create the perception that the risks are acceptable.

Thus, the inadequate management of the tasks assigned to each flight crew member, the failure in communication, and the noncompliance with operational standards characterized an inefficiency in cockpit coordination, in which threat management was not jointly mitigated, thereby contributing to the continuation of the flight in an environment of increasing risk, even in the presence of successive performance degradation alerts issued by the APM.

At 16:20:04 UTC, the SIC commented on the presence of "*quite a lot of ice*" and stated that he would turn on the Airframe De-Icing system. Subsequently, the Airframe De-Icing system was activated for the last time at 16:20:05 UTC. At that moment, the ICING, CRUISE SPEED LOW, and DEGRADED PERF advisories/alerts were active. The PIC then commented that the Airframe De-Icing system was not functioning.

Subsequently, the SIC began reading and executing the Descent Checklist, a task completed at 16:20:25 UTC. During this interval, the continuous trend of decreasing airspeed and increasing aircraft drag was also observed.

At 16:20:33 UTC, APP-SP cleared the aircraft to proceed direct to the SANPA position while still maintaining FL170 and informed the crew that descent clearance would be issued in approximately two minutes. The reason for the restriction was another aircraft level at FL150, located at the 2 o'clock position relative to PS-VPB and approximately 5.8 nautical miles away on a northerly heading.

The aircraft was operating with the AP and YD engaged, with ALT HOLD selected in the vertical mode and LNAV in the lateral mode, which corresponds to a HIGH BANK mode. The indicated airspeed was 171 kt, while the theoretical airspeed specified by the APM for the cruise flight condition at that moment was 206 kt.

Upon receiving authorization from APP-SP, the PIC actuated on the AP in order to comply with the instructions received. As a result of the PIC's inputs, the AP commanded aileron deflections to perform a right turn toward the SANPA fix. Initially, the turn was performed solely through asymmetric aileron deflection, without spoiler deployment, along with a slight right rudder deflection to coordinate the aircraft.

Upon reaching 18° of right bank at 16:20:57 UTC, the MASTER CAUTION alert, associated with the single chime aural warning, and the INCREASE SPEED alert were activated precisely at the moment when the IAS reached 171.1 kt, the MSIS computed by the APM for the considered aircraft weight at that instant (20,989 kg), and when the calculated drag was 44% greater than the theoretical value specified by the APM.

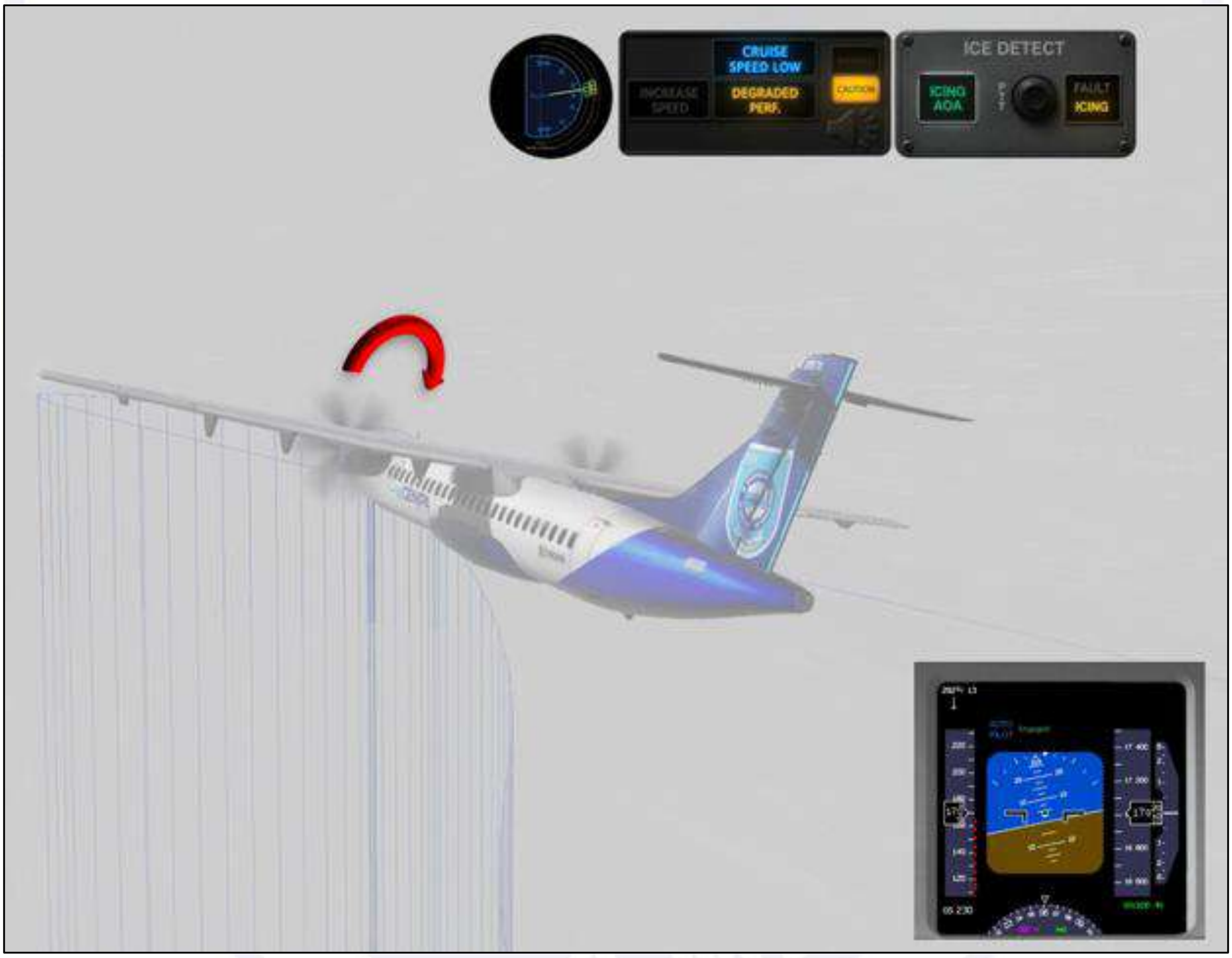


Figure 185 - Illustration[8] showing the right turn toward the SANPA position and the activation of the INCREASE SPEED alert.

[8] Image generated by reconstruction/animation software used by CENIPA's LABDATA, based on the flight data recorded by the aircraft. The image does not represent the instrument panel of the aircraft involved in the accident. It is a customized illustration incorporating the parameters considered necessary for understanding the accident dynamics.

Figure 186– APM INCREASE SPEED alert, associated with MASTER CAUTION alert, accompanied by a single chime aural alert.

According to the aircraft QRH, following the activation of the INCREASE SPEED alert, the crew should seek, as a memory item, an IAS of ICING BUG +30 kt (195 kt), as well as carry out the procedures prescribed for severe icing conditions. However, based on the flight data and CVR recordings, no pilot reactions were observed toward the execution of this memory item, nor toward the performance of the procedures for the Severe Icing condition.

On the other hand, it was identified that, four seconds after the activation of the MASTER CAUTION and INCREASE SPEED alerts, the Airframe De-Icing system was turned off. Therefore, the SIPAER Investigation Commission inferred that the pilots associated the MASTER CAUTION alert with a failure condition of the Airframe De-Icing system, which was already known to the flight crew, rather than with the activation of the INCREASE SPEED alert of the APM. The recurrent failures of the Airframe De-Icing system during the flight contributed to the reduction of the pilots' situational awareness regarding the actual reason for the activation of the MASTER CAUTION alert at that moment.

In this context, the SIPAER Investigation Commission concluded that the pilots demonstrated low situational awareness throughout the flight, which culminated in deficiencies or omissions in critical flight decisions. Mica Endsley defines situational awareness as the perception of elements in the environment within a given time and space, the comprehension of their meaning, and the projection of their future status, requiring the identification of what is occurring, the understanding of its impact, and the anticipation of its developments.

The relevance of Mica Endsley's model lies in demonstrating that many failures are not the result of ignorance or negligence, but rather of gaps in the construction of situational awareness. Studies indicate that weaknesses in situational awareness are present in a large proportion of accidents involving complex systems, whether due to the failure to perceive critical cues, the incorrect interpretation of what was perceived, or the inability to anticipate the evolution of the scenario.

It was verified that, despite prior awareness of the possibility of encountering icing conditions and confirmation from their dialogue, there was no evidence that the flight crew satisfactorily interpreted the severity of the condition they were facing. The successive APM advisories/alerts, including CRUISE SPEED LOW, DEGRADED PERFORMANCE, and INCREASE SPEED, were neither verbalized nor formally addressed.

This absence of structured communication suggested that the flight crew experienced difficulties in adequately analyzing the ongoing situation, selecting the available alternatives in order to act in a timely manner, and projecting the possible consequences of the evolution of the scenario, which contributed to the progression of the events up to the loss of control of the aircraft.

The multiplicity of simultaneous information and tasks faced by the crew may have generated a cognitive overload that impaired the perception of relevant cues, especially the alerts and the aircraft's performance degradation. This perceptual impairment may have resulted in a reduction in situational awareness and contributed to the pilots' failure to timely assimilate the extent of the worsening flight conditions.

The overload of stimuli present during the final stage of the flight in question, such as ice accretion, management of the Airframe De-Icing system failures, communications with air traffic control units, and briefings, created an environment conducive to the emergence of inattentional blindness and inattentional deafness. In particular, the DEGRADED PERFORMANCE alert coincided with interactions with air traffic control and with the briefing for approach and landing preparation, which interfered with the reaction expected from the pilots. Thus, these concepts may explain the absence of an immediate response by the flight crew to critical alerts, despite their correct issuance by the aircraft systems.

Furthermore, the conversations related to the PIC's personal life affected the performance of the flight crew and diverted their attentional focus from operation-related cues. Such conditions indicated that the PIC's emotional state constituted an intervening factor in the chain of events that culminated in the accident, insofar as it may have compromised the flight crew's ability to identify and adequately respond to the ongoing risk situation.

Such phenomena highlighted the importance of training programs emphasizing attention management in complex scenarios, including CRM practices that foster explicit communication and cross-monitoring, in order to reduce the likelihood that crucial cues may be overlooked during periods of high cognitive workload.

On the other hand, an important aspect regarding cockpit perceptions in this accident must be highlighted. According to the information obtained, the occurrence of alerts and warnings of the most varied indications was frequent in the aircraft operated by the operator, especially those related to the APM system. The Investigation Commission even identified other flights involving different crews in which APM system warnings/alerts were triggered without the corresponding appropriate action being taken by the flight crew.

Therefore, it is possible to conclude that there was complacency regarding the APM system alerts, which had become trivialized among the operator's pilot group. In this context, complacency may be understood as a mental state characterized by reduced vigilance and relaxation in response to highly repetitive warnings and alerts, whereby the pilots tended to underestimate the system's warnings/alerts, relying on a false sense of safety justified by previous experience in which no consequences had been associated with such actions.

During the turn toward SANPA, the AP sought to achieve the prescribed 27° bank angle for the lateral mode (HIGH BANK). Due to ice accretion on the aircraft, during this bank angle acquisition, an overshoot was observed and the aircraft reached a maximum value of 32° to the right. Subsequently, in order to stabilize the bank angle, the AP reduced the roll rate by applying left aileron, which also required the deployment of the left spoiler. During the lateral bank adjustment, rudder deflections commanded by the YD occurred in order to coordinate the turn.

With the objective of simultaneously maintaining the lateral bank in HIGH BANK mode and ALT/HOLD, the AP applied progressive elevator deflection to increase the angle of attack, seeking the lift required to maintain altitude during the turn, with continuous elevator trim tab deflection as a function of AUTO TRIM. Due to aircraft aerodynamic contamination, on the roll axis, in order to maintain a constant bank angle in HIGH BANK mode, the AP applied progressive aileron deflection and, consequently, the right spoiler was deployed.

The SIPAER Investigation Commission concluded that, given the aircraft icing condition and loss of aerodynamic efficiency, the AP inputs in ALT HOLD and HIGH BANK modes resulted in an increase in AOA, with a consequent increase in aerodynamic drag during the turn, leading to a reduction in indicated airspeed and progressive altitude loss, bringing the aircraft increasingly closer to stall condition (Figure 187).

Figure 187 - Illustration demonstrating the altitude loss during the turn due to performance degradation, with the AP engaged in ALT HOLD and the lateral bank in HIGH BANK mode.

Subsequently, intense vibration noises were recorded on the CVR, consistent with the onset of an approach-to-stall condition (aerodynamic buffet), reinforcing the analysis that the aircraft was already operating in a severely degraded aerodynamic regime. At that moment, the SIC made a comment regarding the presence of ice.

Immediately after the onset of the altitude loss, an increase in the NL, NH, and NP parameters was recorded, the latter varying from 82% to 100% in both engines. The engine response occurred as a result of the PWR/MGT switch being changed from CRZ to MCT and constituted the first action taken by the pilots in response to the condition being experienced up to that moment.

At 16:21:09 UTC, the AOA reached the activation threshold of the stall warning for icing conditions in cruise flight (11.2°), resulting in the activation of the stick shaker motors in the pilots' control columns.

Although the FDR did not directly record the stick shaker activation, the SIPAER Investigation Commission was able to identify it through the CVR audio, which captured the cricket-type aural warning associated with an increase in the perception of the characteristic stick shaker vibration, indicating the expected sequence of system operation.

As a consequence of the stick shaker activation, the AP disengaged. As a result, lateral control of the aircraft was no longer commanded by the AP, and the ailerons exhibited an immediate tendency to return to their zero-hinge moment position (purple ellipse). Due to the aircraft's lateral stability characteristics, combined with the aerodynamic condition resulting from prolonged ice accretion, a pronounced roll rate to the left toward wings-level was induced.

Figure 188 - Illustration demonstrating the moment of stick shaker activation and AP disengagement.

On the pitch axis, the elevator trim tabs remained in the last position commanded by the AP as a function of AUTO TRIM. This trim condition kept the elevators in a pitch-up position. Despite the AP disengagement, the YD remained engaged, since its automatic disengagement was not associated with the stall warning.

There was a procedure prescribed in the QRH for a stall condition, which established as memory items that the flight crew should apply forward pressure on the control column; increase engine power; if the flaps were at the 0° position, extend them to the 15° position; and level the wings. Additionally, the SOP reinforced, by means of a warning, the need to command flap extension to the 15° position if the aircraft was in an abnormal attitude or stall condition.

However, based on the FDR and CVR recordings, no immediate actions by the pilots aimed at complying with the memory items prescribed in the QRH stall procedure were identified at that moment.

At 16:21:12 UTC, the pronounced roll to the left reached a rate close to 40°/s, inducing an increase in the local angle of attack of the left wing. This fact, combined with the ice accumulation on that surface, caused its aerodynamic stall. At that moment, the aircraft experienced a pronounced left wing drop, reaching a maximum bank angle of 52°.

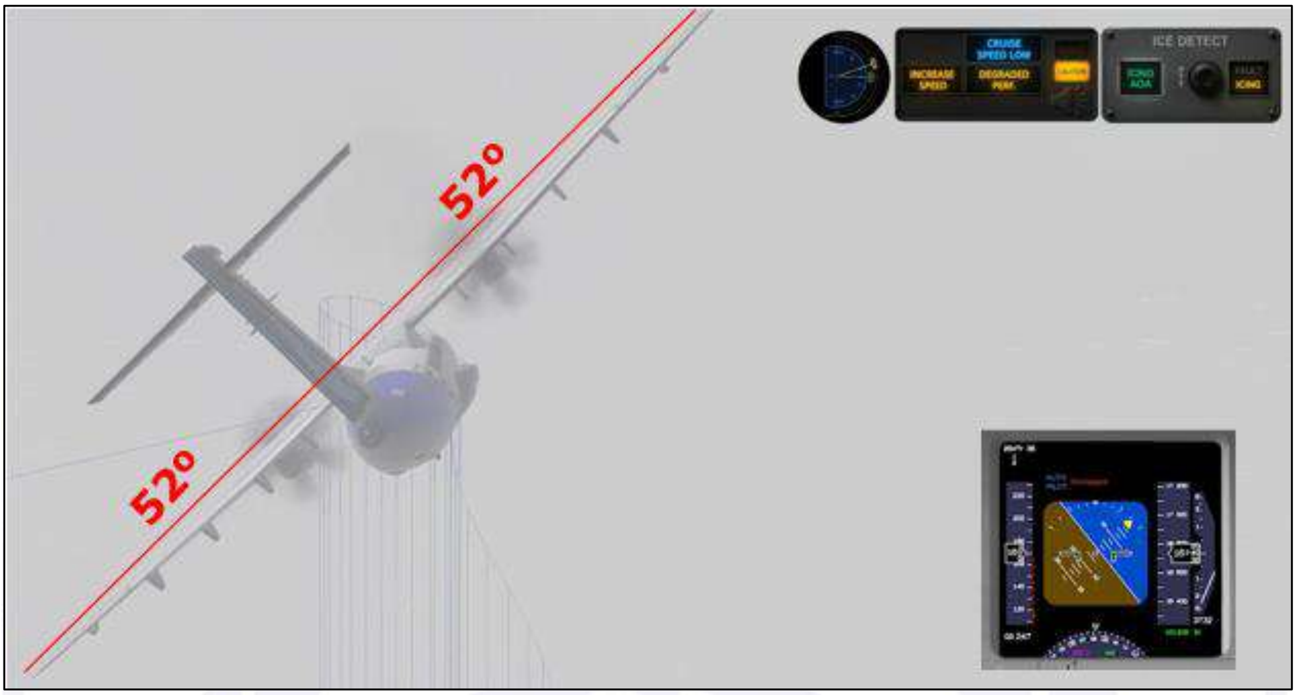


Figure 189 - Illustration demonstrating the 52° bank angle following the stall.

The SIPAER Investigation Commission concluded that the stall resulted from the roll rate imposed by the sudden AP disengagement during the right turn, which generated an uncommanded roll to the left, causing an increase in the local angle of attack of the left wing that, combined with ice accumulation, led to the aerodynamic stall of that surface.

Due to the stall, the aircraft also exhibited a natural nose-down tendency (pitch down), reaching a nose-down attitude close to -5°, which led to a momentary reduction in AOA to a value close to 10°.

The fact that the aircraft exhibited a pitch-down tendency indicated that it still retained stability on the pitch axis, with no evidence that a deep stall had occurred, a critical condition frequently associated with a loss of lift that is difficult or even impossible to recover from, commonly observed in aircraft with a T-tail configuration.

On the directional axis, the aircraft did not exhibit any significant yaw tendency at the moment of the stall, and no significant rudder inputs by the YD were identified.

In response to the sudden left wing drop during the stall, the flight crew applied right control column input through almost its full range of travel, which resulted not only in aileron movement, but also in the activation of the right spoiler in order to increase the commanded roll rate to the right. It was verified that the lateral control input reduced the roll rate to the left until its reversal, demonstrating that the aircraft retained lateral control capability for the reversal, thus allowing the initial recovery from the wing drop.

At this point, it is important to highlight that the aileron movements remained as expected, such that the application of right aileron input resulted in an effective reversal of the aircraft roll. It should therefore be emphasized that no type of aileron hinge moment reversal tendency due to ice formation on the wing, as observed in the accident involving American Eagle Flight 4184, was identified in the recorded flight data.

Due to the pitch-down tendency on the pitch axis following the stall, with an attitude close to -5° (nose-down attitude), simultaneous control column inputs by both pilots applying nose-up forces were recorded. The pilots' actions were contrary to the procedures established both in the aircraft QRH and in UPRT training for a stall condition. Both documents prescribed that the control column should be pushed forward (CONTROL COLUMN – PUSH).

This pulling movement on the control column may have occurred as an involuntary response by the pilots to the neurophysiological phenomenon known as the Startle Effect, which occurs in the presence of an unexpected stimulus perceived as threatening, which in this case was the realization that the aircraft nose was below the horizon line.

These nose-up control inputs by the pilots resulted in an aircraft pitch-up response, leading to a new increase in the angle of attack, demonstrating that the aircraft still retained pitch control authority, but aggravating the stall condition.

The SIPAER Investigation Commission assessed the flight crew’s training and qualification records, with emphasis on the simulator sessions, especially those involving training for operations in icing conditions, degradation of aerodynamic parameters, and upset prevention and recovery training (UPRT).

Although such training complied with regulatory requirements and covered the necessary technical aspects, the investigation identified that the transfer of theoretical knowledge into practical action in a real-world situation may have been insufficient, particularly in the face of the combination of individual, psychosocial, and organizational factors.

Thus, the Startle Effect may have negatively influenced the pilots’ performance in this occurrence, leading to an intuitive and inappropriate action for the situation, which reinforced the importance of training in the management of unusual, yet critical, events such as UPRT.

At 16:21:14 UTC, the AOA values measured by the aircraft sensors reached 15.3°, attaining the stick pusher activation threshold for icing conditions in cruise. At that moment, the aircraft nose was close to the horizon (approximately -1° of pitch) and the aircraft was at about 38° of bank to the left (Figure 190).

Figure 190 - Illustration demonstrating the stick pusher activation during the reversal turn to the right.

The stick pusher activation parameter was not recorded by the FDR, but the sudden change in the left elevator position, recorded by the synchro transmitter, together with the spectral analysis of the CVR audio performed by the SIPAER Investigation Commission, indicated that the system was activated.

The stick pusher acted only on the left control column, pushing it forward with the objective of reducing the aircraft longitudinal attitude and thereby decreasing the AOA value, preventing entry into a stall and/or assisting in its recovery.

As the elevators were interconnected, the activation caused an effective forward movement of the control columns, culminating in a reduction of the longitudinal attitude and AOA, demonstrating that the elevator still retained aerodynamic effectiveness.

In addition to the memory items already mentioned, the QRH stall procedure contained a WARNING instructing the flight crew not to oppose the stick pusher activation, not to retract the flaps, and to use the rudder pedals with caution. The recommendation regarding pedal use was relevant, since improper rudder use during stall conditions could compromise aircraft control and contribute to entry into a spin.

However, during the stick pusher activation, the flight data showed that the SIC again applied forces greater than 10 daN in the nose-up direction, that is, in opposition to the stick pusher activation, contrary to the guidance contained in the QRH and the UPRT training.

Since the elevators were still interconnected, the SIC’s nose-up input on the control column, opposite to the stick pusher direction, generated a differential force capable of activating the pitch uncoupling mechanism at 16:21:15 UTC, causing the elevator disconnection (PITCH DISCONNECT) and triggering a MASTER WARNING alert.

In fact, the component was identified at the accident site in the disconnected position, consistent with the activation of the Pitch Uncoupling Mechanism and the illumination of the PITCH DISCONNECT light in flight.

Stereoscopic examinations of the two lamps illuminating the PITCH DISCONNECT indication on the CAP identified that the filaments were not fractured. Lamp 01 presented moderate general deformation and low local deformation, yielding an inconclusive result, whereas Lamp 02 presented high general and local deformations, consistent with the condition of being illuminated at the moment of deformation.

As the lamps were connected in a parallel electrical circuit, if one of the lamps presented poor contact or interruption in the electrical current supply, it would not prevent the other from illuminating. Therefore, although the difference between the lamp filaments was notable, the deformation characteristics observed in Lamp 02 allowed the inference that the lamp assembly was illuminated at the moment the filament deformation occurred. In other words, the PITCH DISCONNECT light was illuminated at the moment the aircraft impacted the ground.

Due to the disconnection caused by the Pitch Uncoupling Mechanism, the elevators began operating independently and responding only to their respective control columns. As a result, the stick pusher continued to act only on the left elevator, and it was no longer possible to estimate the position of the right elevator.

It is worth emphasizing that, during the stick pusher activation, after the disconnection caused by the Pitch Uncoupling Mechanism, force inputs were recorded on both control columns in the nose-up direction, opposite to the stick pusher actuation direction (nose down). Despite the PIC’s recorded nose-up input, the position of the left elevator did not significantly change.

Even so, with the stick pusher acting only on the left elevator, the aircraft exhibited a change in longitudinal attitude and a consequent reduction in AOA from 24° to a value close to 16°.

The stick pusher actuator was found in the wreckage, installed in its position and with its mechanical integrity apparently preserved. The actuator rod was found extended, which corresponded to the non-activated actuator condition. The examinations and tests performed on the actuator did not reveal any discrepancy that could have compromised its operation.

Although the position of the stick pusher actuator rod indicated that the system was not activated at the moment of impact, stereoscopic examinations of the two lamps illuminating the STICK PUSHER indication on the right panel (SIC) revealed filament fractures with high general and local deformation.

In this context, considering not only the examinations performed on the lamps, but also the spectral and flight data, it was possible to conclude that the system had been activated at a moment prior to the impact, but was deactivated seconds before the collision due to its inhibition by the RALT when the aircraft reached altitude values below 500 feet.

Therefore, the SIPAER Investigation Commission concluded that, although the lamps had been extinguished moments before the collision due to the system deactivation caused by the RALT, there was insufficient time for the filaments to cool before the aircraft impacted the ground, at which moment their fractures occurred, leaving deformations consistent with filaments that were still heated.

The right aileron input, intended to recover from the left wing drop, combined with the pitch-up control inputs and the elevator pitch trim setting, also in the nose-up direction, resulted in an increase in the AOA until the stick pusher activated. This increase in AOA reduced the aircraft's roll rate to the right, causing it to stabilize momentarily, with a left bank angle of approximately 38°, for about two seconds.

At that moment, the aircraft developed a tendency for the nose to yaw to the left due to the coupling of its lateral-directional dynamics. To automatically counteract this motion, the YD, which remained engaged, commanded an automatic right rudder deflection in an attempt to restore coordinated flight.

To better understand the YD operation, the SIPAER Investigation Commission requested that the manufacturer analyze the system's operation with respect to its rudder inputs during the recovery from the left wing drop. In response, the manufacturer provided a reconstruction of the YD software operation within the directional flight control system based on a replay of the data recorded during the occurrence.

Figure 191 presents the information provided by the manufacturer. The black line represents an estimated YD response calculated by the manufacturer's software using the QAR and FDR recordings, while the green line represents the actual rudder deflection recorded during the accident flight.

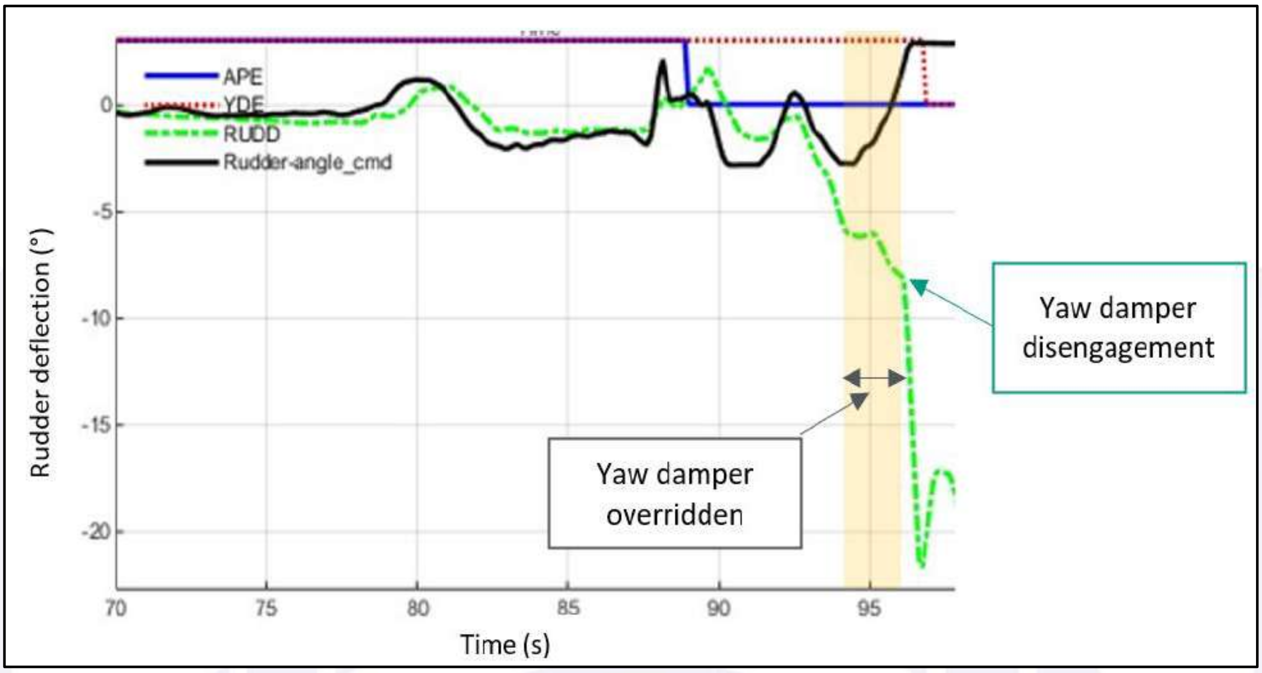


Figure 191 – Illustration comparing the actual rudder position (green) with the position recalculated based on the YD software (black).
Source: ATR.

According to the data presented, the actual rudder deflection (green line), up to approximately 6° right, was consistent with the reconstructed YD command (black line). Beyond that point, however, the software reconstruction indicated that the YD would command a reversal of the rudder toward the left, whereas the recorded flight data showed that the rudder continued to deflect progressively to the right.

The black double-headed arrow indicates the region at which the reconstructed YD behavior diverged from the actual rudder behavior recorded by the aircraft flight data recorders.

Accordingly, it was concluded that an additional force acting within the directional flight control system overrode the command that, until that moment, had been provided exclusively by the YD.

At 16:21:18 UTC, the YD automatically disengaged when the rudder reached approximately 8° of right deflection. From that point onward, the rudder moved abruptly toward its right stop, reaching approximately 23° (85% of its maximum deflection) within only 0.5 second.

Since the roll rate to the right decreased following the increase in angle of attack (AOA), and considering that the aileron inputs were already near their right stop, the SIPAER Investigation Commission considered the hypothesis that the pilots applied right rudder pedal, as no other effective control input remained available to induce additional right roll in an attempt to recover from the left wing drop.

According to this hypothesis, the pilots applied right rudder pedal opposite to the left rudder command generated by the YD, as represented by the double-headed arrow in Figure 191. Consequently, the force applied through the rudder pedals overrode the YD command, resulting in the continued right rudder deflection up to approximately 8°, as shown by the green line in Figure 191.

This hypothesis is supported by flight data provided by the aircraft manufacturer, demonstrating that, in an ATR-72-212A (500), pilot rudder pedal inputs were sufficient to override the YD command without reaching the 30 daN pedal force threshold required to trigger automatic YD disengagement.

Subsequently, once the rudder reached approximately 8° of right deflection, the opposing forces acting within the directional flight control system caused the YD to disengage automatically. As a result, the leftward force previously generated by the YD was removed, allowing the force applied by the pilots through the rudder pedals to drive the rudder abruptly to approximately 23° of right deflection.

Considering the rudder behavior, whose deflection increased from approximately 8° to 23° within only 0.5 second, the SIPAER Investigation Commission sought to determine whether such a rudder deflection rate could have been achieved by pilot inputs under the flight conditions prevailing during the occurrence.

To assess the feasibility of this hypothesis, certification flight-test data provided by the manufacturer were analyzed. The data showed that, during one of the certification flights, the pilot applied a rudder deflection rate consistent with that recorded during the occurrence (30°/s). However, this rate was achieved with the rudder moving from the neutral position (0°) to a maximum deflection of 15°.

Although the rudder deflection rate was comparable, the maximum rudder deflection recorded during the accident was greater. Nevertheless, it is important to emphasize once again that the conditions under which aircraft PS-VPB was operating were not reproduced during the manufacturer's flight tests, since they involved severe icing conditions and high angle of attack (AOA), both of which were outside the aircraft's certified operational envelope.

Furthermore, it was observed that the rudder remained deflected near its right stop even after the aircraft had passed through the wings-level attitude and the aileron input had already been reversed to the left. Therefore, if the rudder deflection is attributed solely to pilot inputs, this would imply that the pilots maintained crossed controls, that is, right rudder pedal and left control column, for approximately three seconds, which would be inconsistent with the primary reason for applying rudder pedal inputs.

Nevertheless, the SIPAER Investigation Commission also considered the history of aircraft accidents and incidents involving flight crews who, under high levels of stress during emergency situations, applied crossed control inputs. Indeed, the occurrence of such behavior under adverse operational conditions is well documented in the aircraft accident investigation literature.

In view of the limitations identified in substantiating the hypothesis of pilot rudder pedal inputs, the SIPAER Investigation Commission considered, as a second hypothesis, the possibility that the abrupt rudder deflection resulted from the rudder hinge moment reversal phenomenon caused by ice accretion on the leading edge of the vertical stabilizer.

The rudder hinge moment reversal phenomenon occurs when changes in the aerodynamic characteristics of a control surface, resulting, for example, from airflow disturbances caused by ice accretion, significantly alter the aerodynamic hinge moment acting on the movable surface. Under such conditions, the aerodynamic force that normally opposes the movement of the control surface (restoring force) may be substantially reduced or even reverse its direction, thereby acting in the same direction as the deflection of the movable surface. Consequently, instead of restoring the control surface toward its neutral position, the aerodynamic force contributes to the movement induced by the applied control inputs. As a result, significant loads may be transmitted through the flight control system, promoting rapid control surface movement. This mechanism constitutes a second physically plausible explanation for the abrupt rudder deflection observed during the occurrence.

It is important to note that the aircraft was operating under severe icing conditions well beyond its certified operational envelope. By definition, aircraft certification demonstrates compliance only within the approved operational envelope. Therefore, the aerodynamic characteristics demonstrated during certification cannot necessarily be extrapolated to the extreme icing conditions encountered during the accident flight. For this reason, the SIPAER Investigation Commission considered that the possibility of an aerodynamic phenomenon affecting the rudder hinge moment should also be evaluated.

Since the rudder horn was protected by the anti-icing system, no ice accretion was expected in that region. However, prolonged exposure to severe icing conditions outside the approved operational envelope may have resulted in ice accretion on the unprotected portions of the vertical stabilizer. Such ice accretion could have disturbed the airflow impinging on the rudder, thereby reducing the magnitude of the restoring force.

Under this hypothesis, the aerodynamic loads acting on the rudder could have been progressively modified as a result of the altered airflow around the vertical stabilizer. Under these conditions, the aerodynamic moment generated by the airflow acting on the rudder horn may have overcome both the rudder restoring moment and the YD command, causing the rudder to continue deflecting in the direction of the movement already initiated. Consequently, the rightward motion could have continued until the rudder reached approximately 8° of deflection. At that point, the imbalance of forces acting within the directional flight control system could have caused the YD to disengage automatically.

Following YD disengagement, the resistance previously imposed by the system would have been removed, allowing the rudder to move abruptly from approximately 8° to a position near its right stop within 0.5 second. The rudder then remained deflected more than 17° to the right for approximately three seconds.

To assess this second hypothesis, the SIPAER Investigation Commission reviewed the engineering analyses provided by the manufacturer regarding the rudder hinge moment reversal phenomenon.

According to ATR, flight tests conducted with representative long-exposure ice shapes installed on the vertical stabilizer did not demonstrate any reduction in rudder pedal forces or significant non-linear rudder behavior for sideslip angles of up to ±10°.

ATR further stated that, during the interval in which the rudder deflected from approximately 0° to 8° to the right, the recorded lateral acceleration indicated a right sideslip condition, under which extensive airflow separation over the right side of the vertical stabilizer would be unlikely.

In addition, the manufacturer indicated that, although sustained stall conditions may reduce the rudder hinge moment and consequently reduce the pedal forces required to move the rudder, the ATR-72-212A rudder incorporates a spring-tab configuration that tends to generate an opposing hinge moment under separated-flow conditions, thereby reducing the aerodynamic tendency for further rudder deflection.

Consequently, although the rudder hinge moment reversal phenomenon remains a physically plausible explanation, the available evidence does not allow this hypothesis to be conclusively demonstrated.

It was not possible to determine which hypothesis occurred during the accident flight, nor whether both mechanisms acted simultaneously during the sequence of events.

Nevertheless, regardless of the mechanism responsible for the abrupt rudder deflection, the recorded flight data demonstrate that the rudder movement resulted in an abrupt yaw of approximately 110° to the right, as evidenced by the recorded heading change and lateral acceleration values. Through lateral-directional coupling, this directional motion immediately induced a right rolling response, which developed into a right wing drop at a rate of approximately 40°/s.

In response to the rapid right roll rate, the pilots applied left control wheel input to nearly its mechanical stop, commanding left aileron deflection together with the retraction of the right spoiler and the deployment of the left spoiler. During this period, the aircraft remained in a cross-controlled condition for approximately three seconds, with the rudder near its right mechanical stop (as explained by the previously discussed hypotheses) while the pilots maintained the control wheel near its left mechanical stop.

As a consequence of the sudden right yaw and the associated sideslip, the aircraft experienced a rapid increase in angle of attack (AOA) to approximately 30°, followed by a dramatic reduction in airspeed, eventually reaching 0 kt, despite the aircraft remaining in a nose-down pitch attitude.

With the high AOA, aerodynamic stall of the horizontal stabilizer and elevator occurred. As a consequence, the elevators moved abruptly from the NOSE DOWN position to a NOSE UP position, near the stop, due to the upward airflow. This condition led to a rapid increase in AOA to approximately 60°. With this AOA magnitude, recorded at 16:21:22 (UTC), recovery of the aircraft was no longer possible and, from that moment on, the loss of control of the aircraft became irreversible.

Figure 192 - Illustration demonstrating the point of irreversibility of the accident.

Subsequently, the aircraft entered a dive with a pitch attitude of -43°. The maximum bank angle to the right reached 94°. The rudder presented values close to a centered (neutral) position, and the AOA reached values close to 63°. At that moment, all APM alerts were deactivated.

The control column force parameter recorded a period during which the PIC attempted to push the control column forward. However, no significant change occurred in the position of the left elevator, demonstrating that the force applied by the pilot was insufficient to overcome the impact force generated by the airflow acting on the surface in the direction of positioning the elevator nose-up.

During the loss of control, the FDR data recorded a tendency for altitude gain. However, after analyzing the aircraft attitudes and flight condition, the SIPAER Investigation Commission concluded that the rate-of-climb values were not reliable due to disturbances affecting the aircraft pressure sensing ports.

As a result of the left aileron input and the return of the rudder to a near-neutral condition, the aircraft reversed the direction of rotation, beginning to yaw in the counterclockwise direction. From that point onward, the aircraft motion was characterized by entry into a spin to the left, with an AOA greater than 60° and continuous yaw maintained by the aerodynamic conditions themselves (Figure 193).

Figure 193 - Illustration demonstrating the entry into a spin with counterclockwise rotation.

During the uncontrolled descent, forces in both the NOSE-UP and NOSE-DOWN directions were recorded on both control columns. Since the elevators were disconnected, the pilots' inputs were neither simultaneous nor mechanically linked. Furthermore, due to the elevated AOA and high rate of descent of the aircraft, the left elevator indicated a position close to the nose-up stop during the incipient phase of the spin, remaining near that position throughout the entire descent.

The divergence between the AOA sensors greater than 4° for more than five seconds, culminated in the inhibition of the stick shaker and stick pusher activation, with the illumination of the FAULT light on the STICK PUSHER/SHAKER button, in addition to the triggering of a MASTER CAUTION alert.

Subsequently, the pitch and roll oscillations were damped, characterizing the development of a flat spin, with an AOA close to 70° (mechanical stop) and a rotation rate of approximately 45°/s. From that moment onward, with the stabilization of the rotation, no further discrepancy between the AOA sensors was identified. As a result, the stick pusher became available again until the aircraft reached 500 ft RALT, when it was once again inhibited.

Throughout the spin, rudder surface movement of approximately 15° to the right was recorded, in a behavior compatible with pilot input aimed at stopping the rotation to the left. Despite this control input, no tendency of the aircraft to reduce the rotation rate was observed, since the aerodynamic effectiveness of the vertical stabilizer and rudder was highly compromised due to the elevated AOA.

Eight seconds before impact, the ITT of engine No. 1 exceeded 840°C for three seconds as a result of the reduction in relative airflow and, consequently, the mass airflow to the engines during the flat spin condition to which the aircraft was subjected. Despite the exceedance, all collected data were consistent with normal engine operation, as the power plants presented parameters within expected limits and responded adequately to the flight crew inputs up to the moment of impact.

The maximum peak vertical acceleration reached values around 1.8 positive G at the onset of the loss of control, followed by fluctuations between 1.2 and 1.6 positive G from the aircraft descent until impact with the ground.

The aircraft established an almost constant rate of descent of approximately 14,000 feet per minute, completing five turns in a spin to the left over an interval of 68 seconds, with pitch variations between + 10° and -62° and left bank angles between 75° and 10° until impact with the ground (Figure 194).

Figure 194 - Illustration demonstrating the aircraft in a flat spin.

The aircraft impacted the ground with high vertical speed and low horizontal speed, resulting in a concentrated wreckage site within an area approximately 30 meters in diameter.

The aircraft was destroyed, with crushing damage and fractures throughout its entire structure due to the high-energy impact with the ground. Following the collision, a fire occurred, increasing the degree of destruction of the aircraft.

During the accident flight, several advisories/alerts issued by the APM were recorded, comprising eight CRUISE SPEED LOW advisories, one DEGRADED PERFORMANCE alert, and one INCREASE SPEED alert.

For the CRUISE SPEED LOW advisories, all activations observed during the accident flight occurred in a manner technically consistent with the APM system algorithm established by the manufacturer, indicating that the system correctly identified the performance degradation under the cruise condition in which the aircraft was operating.

Based on the data presented in Table 4 (Conditions for activation of the APM CRUISE SPEED LOW), the plots (red dots in Figure 195) corresponding to the indicated airspeed differences (IAS-Delta_Speed) during cruise and the percentage increase in drag (Delta_Drag) for each of the eight CRUISE SPEED LOW ADVISORIES triggered during the accident flight were highlighted. These plots showed that those advisories were issued within their design range and in accordance with the behavior expected by the APM system.

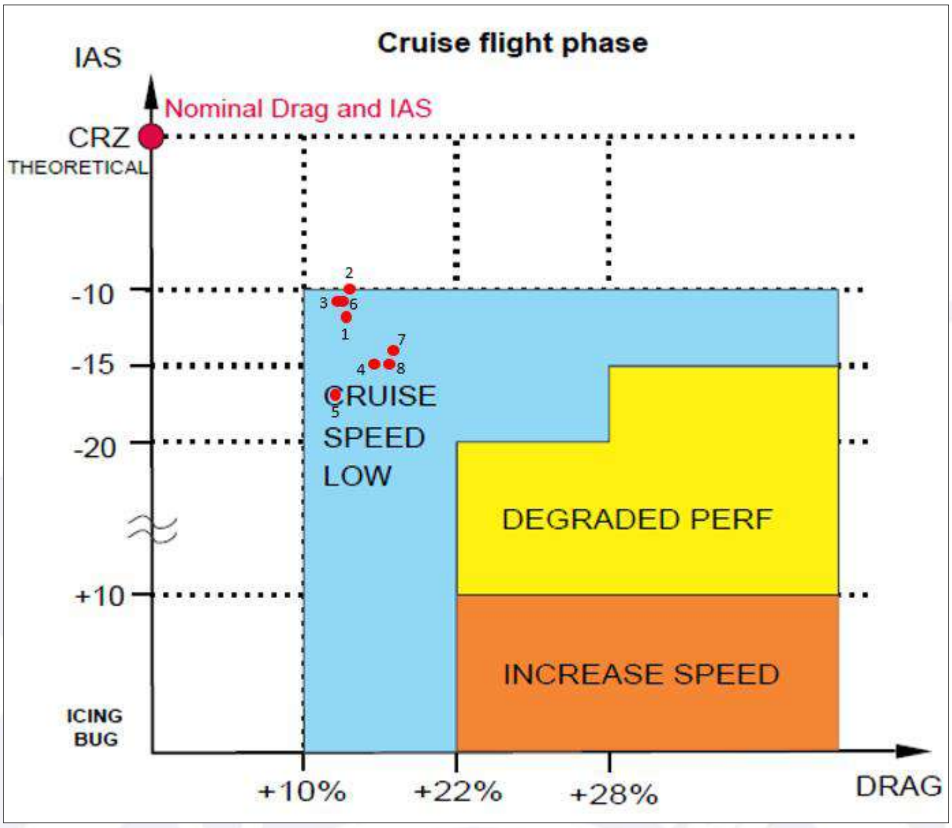


Figure 195 - Plots of the eight CRUISE SPEED LOW advisories during the accident flight, showing airspeed differences (IAS - vertical axis) and drag percentage (DRAG - horizontal axis).

As previously highlighted in this Final Report, the analysis of the data volumes related to flights conducted by the operator, as well as by other ATR-72 operators, revealed a higher percentage of APM system advisories/alerts activations within the operator company.

The high rate of occurrence of the CRUISE SPEED LOW advisory allowed to identify an operational characteristic in which the aircraft were cruising at indicated airspeeds considerably lower than those prescribed for the maximum cruise level under icing conditions. This behavior indicated that the flights were being conducted at altitudes higher than those at which the aircraft had sufficient performance to maintain the theoretical cruise speed.

The Commission concluded that the high frequency of the CRUISE SPEED LOW advisory led the operator's flight crews to normalize that condition, such that it was no longer recognized as an initial indication of performance degradation due to ice accretion. Since the advisory was classified as Level 0 (informational, displayed in blue), and the procedure prescribed in the QRH merely instructed the crew to monitor airspeed and icing conditions, those factors may also have contributed to the observed trivialization of the advisory.

This operational pattern of frequently conducting flights at altitudes above those at which the aircraft had sufficient performance to maintain the speeds recommended by the manufacturer contributed to the high recurrence of CRUISE SPEED LOW alerts, since the APM algorithm used the theoretical cruise speed (IAS_TH or APMIASTH), corresponding to the altitude being flown, as the reference for comparison with the aircraft's actual speed.

Thus, the aircraft cruise speed could reach a value 10 kt below the preselected cruise speed, causing Condition 2 (reduction of indicated airspeed by 10 kt, that is, APMIAS < APMIASTH -10 kt) for the triggering of the CRUISE SPEED LOW advisory to be met shortly after the beginning of the cruise phase.

Drag fluctuations, such as those caused by wind waves or the onset of ice accretion not yet affecting indicated airspeed, could then activate Condition 1 (10% increase in drag), that is, APMCXAC > 1.1 × APMCXTH, such that both conditions were satisfied and the advisory was triggered, since Condition 2 had already been present since the beginning of the cruise phase.

The flight presented in Figure 130 (FDM of the ATR-72-500 and ATR-72-600 Models) evidenced one of the cases in which the aircraft remained in cruise with indicated airspeed below the reference speed, recording multiple CRUISE SPEED LOW advisories issued by the APM, in addition to the DEGRADED PERFORMANCE and INCREASE SPEED alerts.

The graph containing the data from that flight highlighted a value approximately 20 kt below the reference speed (IAS_TH) throughout the entire cruise phase, with the CRUISE SPEED LOW advisory being triggered 6 times (Figure 196). At a certain point, there was a rapid and significant degradation of IAS, consistent with a severe ice accretion condition, reaching a minimum value of 163 kt, that is, 1 kt above VmLB0icing and 41 kt below IAS Theoretical (IAS th).

Figure 196 – Graphs reproduced from Figure 130 of this Report. Indication of Delta_Speed around 20 kt throughout the entire cruise phase, with 6 activations of the CRUISE SPEED LOW advisory.

At the moment the DEGRADED PERFORMANCE alert was triggered during the accident flight, the reference speed value (IAS_TH or APMIASTH) was 205.8 kt, while the indicated airspeed (APMIAS) was 185.3 kt. The alert was triggered when the drag difference reached 27% and the speed difference reached 20.5 kt (red arrow in Figure 197).

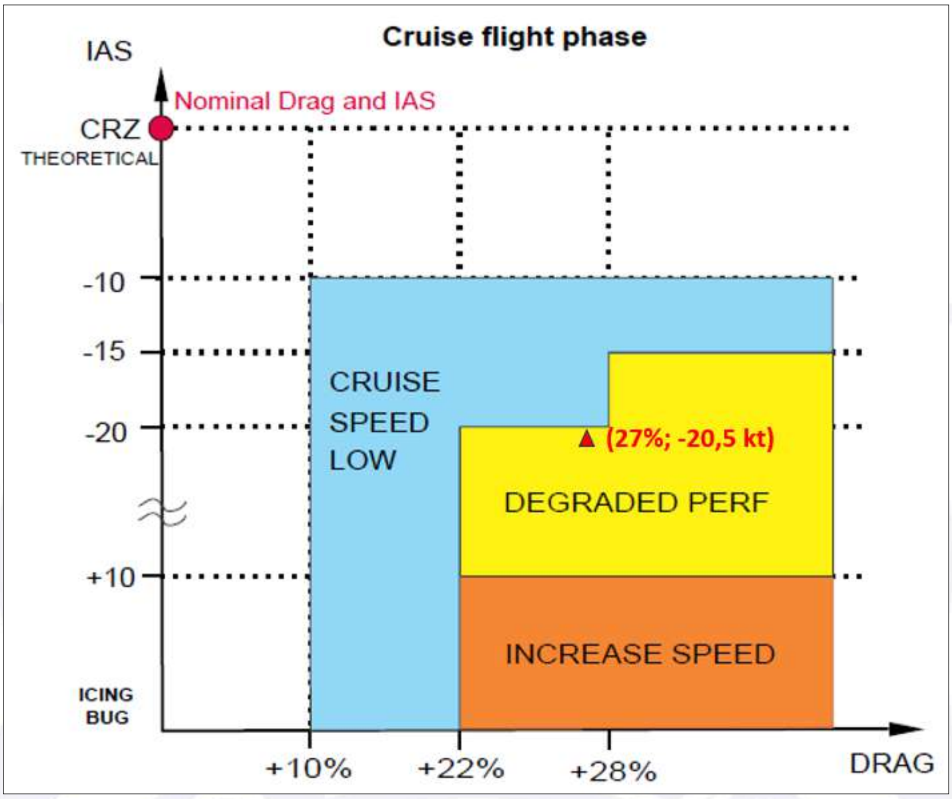


Figure 197 - Plot of the DEGRADED PERFORMANCE alert during the accident flight, showing speed differences (IAS - vertical axis) and drag percentage (DRAG - horizontal axis).

The SIPAER Investigation Commission identified that the 22% drag (reference drag value) was reached 28 seconds before the indicated airspeed decreased below 20 kt (reference IAS value) in relation to the drag and speed computed by the APM. The alert occurred 1 minute and 42 seconds before the stall warning and the automatic disengagement of the AP.

At the moment the INCREASE SPEED alert was triggered during the accident flight, the aircraft weight considered by the APM was 20,989 kg, corresponding to a VmLB0icing of 161.1 kt. Therefore, the MSIS value was 171.1 kt (VmLB0icing + 10 kt).

However, it should be emphasized that the reference value for VmLB0icing used by the pilots was the ICING BUG, which was defined and set on the airspeed indicators (RED BUG) at the beginning of the flight, based on the takeoff weight, and was always conservative. In the case of the accident, this value was 165 kt.

The Increase Speed alert was triggered when the increase in drag (Delta_Drag) reached 44%, satisfying Condition 1 (increase in drag of at least 22% - APMCXAC > 1.22 × APMCXTH), while the indicated airspeed was 171 kt, satisfying Condition 2 (reduction of indicated airspeed to the value known as MSIS). Thus, the alert occurred within the parameters established by the manufacturer (blue triangle in Figure 197). The alert was triggered 13 seconds before the stall warning and the automatic disengagement of the AP.

It should be emphasized that the procedure defined in the QRH for the INCREASE SPEED alert was classified as Level 2 (CAUTION) and included a memory item, that is, it required immediate pilot action without consultation of the QRH. The memory action established an increase in airspeed to at least 30 kt above the ICING BUG (165 + 30 kt).

The Commission considered that the INCREASE SPEED alert was triggered in a situation requiring immediate corrective action by the flight crew, in which the aircraft indicated airspeed was close to the VmLB0icing speed, thus representing an operating condition near the minimum control limit, consistent with the criteria established by the manufacturer for the definition of a level 3 alert message (WARNING).

Considering the history of events related to icing on the ATR design and the need to prevent new events of this nature, the SIPAER Investigation Commission concluded that a thorough evaluation by the manufacturer and the primary certification authority (EASA) was necessary, with a view to upgrading the alert level of the INCREASE SPEED message to WARNING.

Another condition observed by the Commission was the simultaneous activation of the DEGRADED PERFORMANCE and INCREASE SPEED alerts, both classified as CAUTION level. This situation was evidenced during “flight -1” (item 1.18.1.3) and illustrated in Figure 152, as well as in other flights presented in item 1.17.8.1, whose graphs are shown in Figures 129, 131, and 132.

For those cases, the Commission identified that the aircraft entered and remained in cruise with indicated airspeeds significantly below the theoretical reference value (IAS_TH or APMIASTH), thereby satisfying the airspeed conditions (delta_speed) for the triggering of both alerts.

During cruise flight, the APM system algorithm used the same drag difference criterion (delta_drag) for both alerts (22% increase). Since the airspeed difference criterion (delta_speed) was already satisfied for both alerts, an increase in drag caused by ice accretion was sufficient to satisfy the remaining conditions, resulting in the simultaneous activation of both alerts.

Figure 198 reproduces, as an example, the flight data graphs obtained from the operator’s FDM, evidencing how the airspeed difference (delta_speed) remained below the reference speed (IAS_TH) throughout the entire cruise phase, and how the performance degradation conditions associated with the APM algorithm logic allowed the simultaneous activation of the DEGRADED PERFORMANCE and INCREASE SPEED alerts.

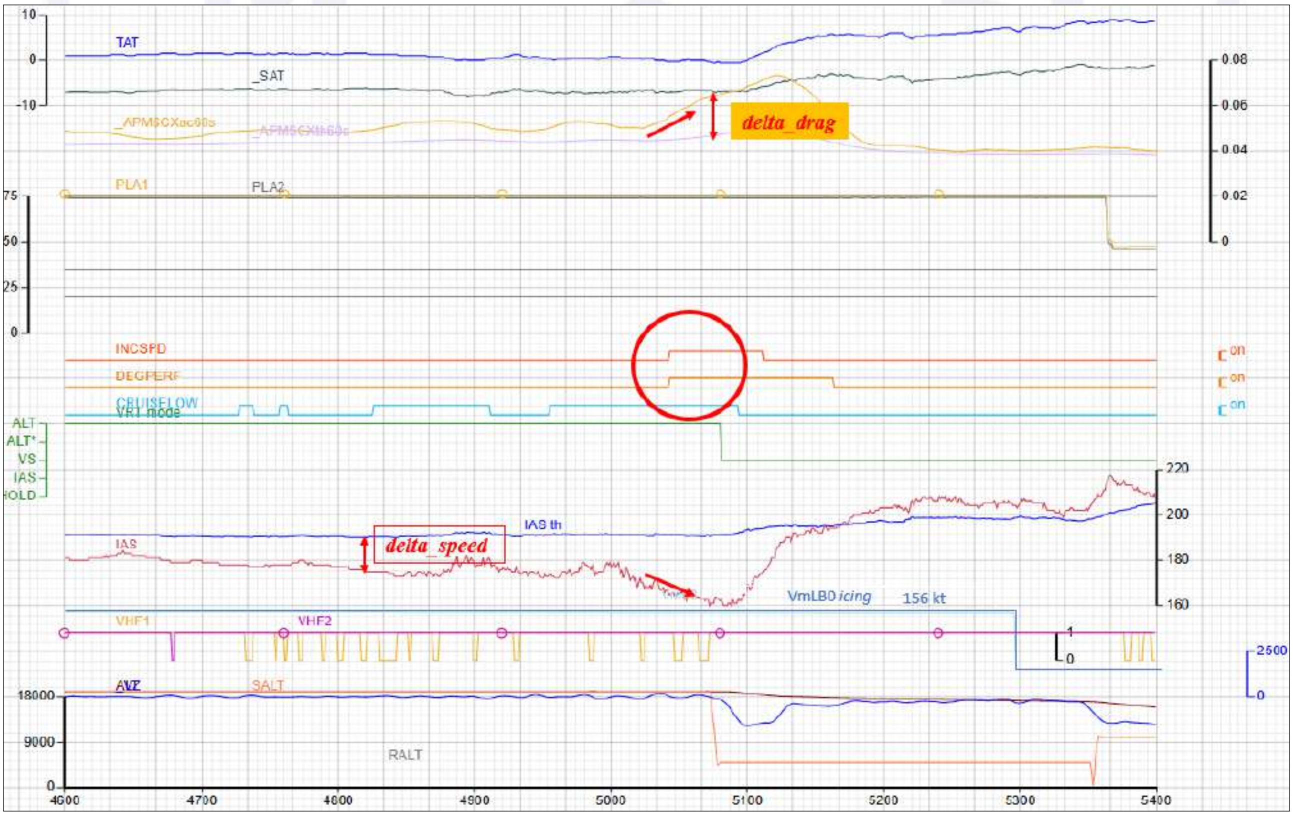


Figure 198 - Flight data graphs reproduced from Figure 131 of this Report, showing delta_speed during the cruise phase and the simultaneous activation of the DEGRADED PERFORMANCE and INCREASE SPEED alerts following the increase in delta_drag.

This simultaneous occurrence of the alerts could generate confusion in the flight crews' response, since both had the same classification level (Level 2 - CAUTION), despite one of them being more critical than the other from the standpoint of system design and the actions required to maintain safe flight.

In the case of simultaneous alert activation, as evidenced in the examples presented in this Report, the FCOM did not address the prioritization criteria to be adopted for the execution of the prescribed procedures.

Thus, the Commission concluded that a thorough evaluation by the manufacturer and the primary certification authority (EASA) was necessary in order to reassess the activation conditions of the APM alerts, so as to establish an appropriate alert hierarchy and prevent simultaneous activation.

3. CONCLUSIONS

3.1. Findings.

a) the crew members held valid CMAs (Aeronautical Medical Certificates);

b) the crew members held valid AT-47 type aircraft and IFRA ratings;

c) the crew members were qualified and had experience in the type of flight conducted;

d) the aircraft held a valid Certificate of Airworthiness;

e) the operator had an organizational context with multiple vulnerabilities in its safety culture;

f) ANAC's risk management process was not sufficient to support the strategic decision-making necessary for the mitigation and control of risks in the operational environment it regulated and oversaw;

g) although the operator had the infrastructure and data necessary to identify hazards based on actual flight parameters, there was no evidence that this information had been systematically converted into corrective, doctrinal, or procedural actions;

h) there was a culture of absence of formal recording in the TLB, which prevented the company's technical and operational departments from applying corrective maintenance to aircraft systems;

i) the aircraft was within the weight and balance limits specified by the manufacturer;

j) the aircraft had no record of an Airframe De-Icing system malfunction in the TLB;

k) despite the Airframe De-Icing system malfunction, the aircraft was dispatched without the restrictions imposed by the MEL being recorded;

l) the aircraft was dispatched with a failure in the wiper F/O system despite the meteorological forecast;

m) the meteorological conditions at the planned flight level constituted an environment conducive to SEV ICE and were below the minima for conducting the flight;

n) the meteorological conditions forecast for the route, prior to aircraft dispatch, were not adequately evaluated by the CCO, DOV, and PIC;

o) the aircraft departed SBCA, bound for SBGR, in order to conduct scheduled public air transport, with 4 crew members and 58 passengers on board;

p) during the climb, upon crossing approximately FL130, the Electronic Ice Detector indicated ice accumulation;

q) during the accident flight, the aircraft experienced a failure of the Airframe De-Icing system, still during the climb;

r) the Airframe De-Icing system failure was associated with the operation of the right wing boots;

s) the procedures prescribed in the checklist for the Airframe De-Icing system failure were not performed;

t) the Airframe De-Icing system was turned on and off multiple times during the flight;

u) after leveling off at FL170, the Electronic Ice Detector indicated ice accumulation on several occasions and remained activated for a significant portion of the flight;

v) the aircraft experienced a performance degradation due to ice accumulation on its surfaces;

w) the CRUISE SPEED LOW advisory was triggered 8 times during the accident flight;

x) the procedures prescribed for the triggering of the CRUISE SPEED LOW advisory were not executed;

y) the DEGRADED PERFORMANCE alert was triggered once during the flight and occurred 1 minute and 42 seconds before the activation of the Stall Warning System;

z) the procedures prescribed for the triggering of the DEGRADED PERFORMANCE alert were not executed;

aa) the INCREASE SPEED alert was triggered during the turn to the SANPA position and occurred 13 seconds before the activation of the Stall Warning System;

bb) no actions by the flight crew were identified that indicated recognition, awareness, or processing of the APM system advisories/alerts;

cc) the procedures prescribed for the triggering of the INCREASE SPEED alert were not executed;

dd) the AOA values reached the stall warning activation threshold for icing conditions during cruise flight;

ee) the procedures prescribed for stall recovery were not executed;

ff) the AOA values reached the stick pusher activation threshold for icing conditions during cruise flight;

gg) during stick pusher activation, a force in excess of 10 daN was applied to the right control column, in opposition to the stick pusher activation;

hh) the opposing action against the stick pusher direction produced a differential force capable of activating the pitch uncoupling mechanism;

ii) loss of control of the aircraft occurred;

jj) the aircraft entered a flat spin, completing 5 left turns over a period of 68 seconds;

kk) the aircraft exhibited a rate of descent of approximately 14,000 ft/min until it collided with the ground;

ll) the aircraft was destroyed; and

mm) all 4 crew members and 58 passengers sustained fatal injuries.

3.2. Contributing factors.

- **Handling of aircraft flight controls – a contributor.**

The pilots' pitch control inputs in the nose-up direction during the activation of the stall warning, contrary to the procedures prescribed in the QRH and in UPRT training, contributed to the increase in AOA and to the aggravation of the stall condition.

- **Attention – a contributor.**

During a significant portion of the flight, the pilots remained engaged in informal conversations unrelated to the technical and operational conduct of the aircraft, which reduced the flight crew's attentional focus both on monitoring the external environment, characterized by the presence of conditions conducive to severe ice formation, and on observing the indications and alerts activated in the cockpit. This state of distraction favored the onset of inattentional blindness and inattentional deafness.

- **Attitude – a contributor.**

Despite prior awareness of the failure in the Airframe De-Icing system and the forecast of conditions conducive to severe ice formation along the route, the flight crew chose to proceed with the flight as planned, without adopting mitigating measures intended to reduce the risk inherent to operations under such atmospheric conditions. This conduct evidenced an attitude characterized by disregard for applicable operational aspects and procedures, contributing to the aircraft's exposure to a high-risk scenario.

Additionally, the pilots failed to execute operational procedures prescribed in the QRH throughout the flight, such as the DE ICING AIRFRAME FAULT procedure, still during the climb to cruise level, as well as those related to the APM system advisories/alerts (CRUISE SPEED LOW, DEGRADED PERFORMANCE, and INCREASE SPEED). This conduct reflected an inadequate posture on the part of the flight crew, suggesting tacit acceptance of deviations from established operational standards, contributing to the escalation of operational risk throughout the flight and, consequently, to the chain of events that culminated in the accident.

- **Qualification and Training – undetermined.**

Although the pilots had completed the training required by the regulatory requirements related to operations under conditions conducive to severe ice formation and upset prevention and recovery training (UPRT), the actions observed during the accident flight were not consistent with the theoretical and practical knowledge expected from such training.

Within this context, the pilots did not recognize in a timely manner the severity of the condition being faced, did not respond adequately to the risks associated with the recurrent alerts, and ultimately acted on the flight controls in a manner divergent from that prescribed in training.

- **Adverse meteorological conditions – a contributor.**

The meteorological conditions contributed to the configuration of the occurrence scenario, creating an environment unfavorable to the safe operation of the aircraft. Prolonged exposure to severe icing conditions (SEV ICE) resulted in a significant increase in aerodynamic drag and degradation of aircraft performance, with a direct impact on cruise speed and on the ability to maintain the desired flight regime.

- **Crew Resource Management – a contributor.**

The inadequate management of the tasks assigned to each crew member, the failure in communication, and the noncompliance with operational standards characterized inefficiency in cockpit coordination, in which threat management was not jointly mitigated, thereby favoring the continuation of the flight in an environment of increasing risk, even in the presence of successive aircraft performance degradation alerts issued by the APM, contributing to the accident.

- **Work-group culture – a contributor.**

The frequent occurrence of advisories and alerts, especially those related to the APM system, generated complacency within the company's pilot group, culminating in reduced vigilance, and relaxation in the face of their high repetitiveness. Within this context, the company's pilot group tended to underestimate the APM system advisories/alerts, supported by a false sense of safety justified by previous experience in which no consequences had been associated with such actions.

- **Organizational culture – a contributor.**

The company's organizational culture of failing to properly address the information made available through the PAADV, as well as failing to use it in risk management and in the adoption of mitigating actions, influenced the behavior of the flight crews with regard to the importance attributed to the aircraft alerts.

Thus, the pilots' decisions during the accident flight were influenced by an organizational context marked by multiple vulnerabilities in the safety culture, in which the acceptance of deviations had become normalized and the aircraft alerts had become trivialized, reducing risk perception.

- **Emotional state – undetermined.**

According to the CVR recordings and the accounts obtained throughout the investigation, the PIC was facing, at the time of the accident, personal problems that were negatively affecting his operational performance. This emotional state may have influenced his behavior during the flight, reducing his engagement in the critical decisions of the operation and diverted his attentional focus from the stimuli relevant to the safe conduct of the aircraft.

- **External influences – undetermined.**

The personal problems faced by the PIC at the time of the occurrence, which became the subject of informal conversations between him and the SIC during the flight, diverted his attentional focus from stimuli related to the operation and reduced his risk perception, given that such dialogues occurred even during critical moments of the operation, such as during or immediately after the onset of the performance loss advisories/alerts, thereby influencing his operational performance.

- **Piloting judgment – a contributor.**

At no point during the flight did the pilots request an immediate descent or declare an emergency situation due to the ice accumulation and performance degradation condition. This omission, combined with the non-execution of the actions prescribed in the operational procedures in response to the performance degradation advisories/alerts issued by the aircraft, indicated that the flight crew performed an inadequate assessment of parameters related to the safe operation of the aircraft, which resulted in the absence of the necessary actions to manage the conditions encountered.

Furthermore, the acceptance of conducting the flight in known icing conditions in an aircraft that was knowingly operating with the Airframe De-Icing system inoperative, as well as the non-execution of the procedures prescribed for the triggering of the various APM advisories, revealed an inadequate assessment of parameters related to the operation of the aircraft, despite the crew's qualifications to operate it.

- **Aircraft maintenance – a contributor.**

The absence of formal recording in the TLB following the onset of in-flight failures, especially with regard to the malfunction of the Airframe De-Icing system on the flights preceding the accident, prevented the company's technical and operational sectors from implementing mitigating measures, such as dispatch under the MEL, aircraft substitution, route replanning, or even corrective maintenance to resolve the malfunction, thereby contributing to the aircraft operating under meteorological conditions conducive to ice formation with the Airframe De-Icing system inoperative.

- **Perception – a contributor.**

Impairments were identified in the flight crew's ability to recognize, comprehend, and project the sensations arising from internal and external stimuli within the operational environment, such as meteorological information related to severe ice formation, indications of performance loss, and advisories/alerts issued by the APM, which led to reduced situational awareness and delayed perception of the risk to which they were exposed, thereby impairing the issuance of responses compatible with the severity of the situation.

- **Flight planning – a contributor.**

The flight planning process did not involve effective integration among the responsible sectors, nor did it include continuous and proactive support from the CCO, failing to mitigate foreseeable risks arising from documented hazards. This gap constituted a contributing factor in maintaining the aircraft at a flight level susceptible to ice accretion, culminating in the progressive degradation of performance and in the development of the occurrence scenario.

- **Decision-making process – a contributor.**

The decision to conduct cruise flight at FL170, a flight level at which severe ice formation had been forecast, without questioning or adapting the planning to the identified meteorological scenario, evidenced difficulties in the flight crew's process of analyzing and selecting alternatives.

This condition manifested itself even more critically during the cruise phase, when, despite the successive performance degradation advisories/alerts issued by the APM, including the DEGRADED PERFORMANCE and INCREASE SPEED alerts, the pilots did not adopt any structured action prescribed in the operational procedures, nor did they request an immediate descent or declare an emergency situation.

Such conditions indicated that the flight crew experienced difficulties in adequately analyzing the ongoing situation, selecting the available alternatives, and acting in a timely manner, characterizing inadequate decision-making in the face of a progressively increasing risk scenario, which contributed to the evolution of the events leading to the loss of control of the aircraft.

- **Organizational processes – a contributor.**

The underutilization of the information made available through the PAADV, which was frequently neither analyzed nor incorporated into risk management, especially information related to performance degradation due to ice accretion, combined with the absence of real-time support from the CCO to the pilots regarding meteorological conditions along the route, demonstrated that the organizational processes were not consolidated as effective risk mitigation instruments.

This set of weaknesses favored the adoption of a passive posture in response to the alerts and inhibited the structured actions prescribed in the operational procedures.

- **Design – undetermined.**

The INCREASE SPEED alert was activated in a situation requiring immediate corrective action by the flight crew, in which the aircraft indicated airspeed was close to the VmLB0icing, thus representing an operating condition near the minimum controllable limit, consistent with the criteria established by the manufacturer for a level 3 alert message (WARNING).

The fact that the INCREASE SPEED alert was categorized as a level 2 alert (CAUTION) by the manufacturer may have led flight crews to underestimate the severity of the condition to be managed.

- **Managerial oversight – a contributor.**

The absence of effective managerial oversight regarding the use of the information made available through the PAADV, which was not adequately analyzed nor incorporated into risk management and the adoption of mitigating actions, especially those related to performance degradation due to ice accretion, evidenced inadequate oversight by the organization's management of operational planning and execution activities. As a result, more robust preventive measures were not adopted prior to the occurrence, allowing the escalation of risks, contributing to the flight crew adopting a passive posture in response to the alerts, thereby delaying the structured actions prescribed in the operational procedures.

- **Other / ANAC Actions – a contributor.**

The audits and inspections conducted by ANAC on the operator prior to the accident revealed several technical and procedural nonconformities related to aircraft maintenance, component traceability, noncompliance with MEL conditions, and the recurrent practice of informal reporting or non-reporting of malfunctions.

The findings of the SIPAER Investigation Commission indicated that the signs identifying hazards, degradation of technical conditions, and latent conditions prior to the accident were not capable, when analyzed within the scope of ANAC's risk management process, of supporting the strategic decision-making necessary for the mitigation and control of risks in the operational environment regulated and overseen by the Agency.

Thus, it is possible to conclude that the means for recording, processing, and monitoring data and information related to hazards for the purpose of risk management were still in a maturation phase, allowing the continuity of the company's operations despite degradation of the safety levels.

4. SAFETY RECOMMENDATIONS

A safety recommendation is a proposal issued by an accident investigation authority on the basis of information derived from an investigation, made with the sole objective of preventing future accidents or incidents. Under no circumstances shall it create a presumption of blame or liability for an accident or incident. In accordance with Brazilian Law No. 7,565/1986, safety recommendations are issued exclusively in the interest of aviation safety and shall be treated in conformity with the provision set forth in NSCA 3-13, which governs the investigation of civil aviation aeronautical occurrences conducted by the Brazilian State.

Recommendations issued at the publication of this report:

To the *European Union Aviation Safety Agency* (EASA), it is recommended:

A-116/CENIPA/2024 – 01 **Issued on: 07/23/2026**

To engage with the aircraft manufacturer with a view to evaluating the possibility of revising and enhancing the DEGRADED PERFORMANCE procedure, requiring an immediate action from the flight crew to restore aircraft performance (ICING BUG + 30 kt), so as to prevent the approach of the limit condition defined by VmLB0Icing.

A-116/CENIPA/2024 – 02 Issued on: 07/23/2026

To engage with the aircraft manufacturer with a view to evaluating the possibility of enhancing the procedures related to flight in icing conditions, in particular regarding the use of LOW BANK mode, with the purpose of preventing the increase in stall speed due to aircraft bank angle under performance degradation conditions.

A-116/CENIPA/2024 – 03 Issued on: 07/23/2026

To engage with the aircraft manufacturer with a view to evaluating the feasibility of including FDR recording of the following parameters for all ATR aircraft in operation, with the purpose of preventing the possible loss of relevant data.

Parameters: Airframe De-Icing system failure; stick pusher system activation; right elevator position; rudder pedal and control column position of each pilot; pitch uncoupling mechanism activation; active AFCS lateral modes (LOW BANK or HIGH BANK); and CAUTION message indications activated by the CCAS.

A-116/CENIPA/2024 – 04 Issued on: 07/23/2026

To engage with the aircraft manufacturer with a view to reassessing the alert levels of the APM system, with the objective of enhancing flight crew situational awareness regarding the severity of the condition encountered and the need to execute the prescribed procedures in a timely manner, considering the possibility of upgrading the INCREASE SPEED alert level of the APM system from CAUTION to WARNING.

To the National Civil Aviation Agency (ANAC), it is recommended:

A-116/CENIPA/2024 – 05 Issued on: 07/23/2026

To engage with ATR aircraft operators with a view to verifying whether the checklists actually used by their pilots, similar to the Normal Checklist used by Passaredo Linhas Aéreas S.A., include the SPEED BUGS adjustment procedure for the cruise phase of flight, as prescribed in the FCOM.

A-116/CENIPA/2024 – 06 Issued on 07/23/2026

To review the process of Topic 18 of the 2023-2024 Regulatory Agenda, concerning the bilateral air-ground communications of operations governed by RBAC 121, so that the lessons gathered in this investigation, together with new contributions from airlines, may support the decision regarding the amendment of the requirement established in paragraph (c) of section 121.601.

A-116/CENIPA/2024 – 07 Issued on: 07/23/2026

To revise and update its internal risk management processes prescribed in the PSOE-ANAC, in particular those arising from continuous surveillance activities, so that they are capable of supporting the strategic decision-making necessary for the mitigation and control of risks in the operational environment regulated and overseen by the Agency.

A-116/CENIPA/2024 – 08 Issued on: 07/23/2026

To disseminate the lessons learned from the present investigation to airlines governed by RBAC 121, highlighting the contributing factors present in this accident, with the purpose of increasing the level of situational awareness of flight crews.

A-116/CENIPA/2024 – 09 Issued on: 07/23/2026

To monitor, in coordination with the primary certification authority of the aircraft, the implementation process of the safety recommendations issued in this Final Report to EASA, with the purpose of adopting such mitigating actions as it deems appropriate, within the regulatory scope under its responsibility, with regard to recommendations that have not been complied with, have been partially adopted, or have been adopted in an alternative manner.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

MANUFACTURER – ATR:

01 – Introduction to Version 2.0 (V2) of the APM software*:*

The findings obtained by the SIPAER Investigation Commission, specifically regarding the operating modes of the APM system algorithm, were communicated to the manufacturer from the beginning of the analyses conducted during the investigation process.

Several interactions were conducted between the SIPAER Investigation Commission and the ATR engineering team, such that, by the date of issuance of this Final Report, a new version of the APM system software (APM Version 2.0) had already been certified by EASA for incorporation into the fleets through compliance with Service Bulletin (SB) ATR-72-31-1137, dated 26JUN2025.

This SB was applicable to ATR-72-212A model aircraft and contained instructions for the loading (upload) of new software which, among other functions, incorporated operational safety improvements related to enhancements to the APM algorithm, updated to Version 2.0 (V2), as described in ATR technical documentation.

This version sought to incorporate the improvements suggested by the SIPAER Investigation Commission and identified by ATR engineering teams, promoting adjustments to the system calculation and monitoring methods, as well as to the alert activation conditions, with the objective of increasing the robustness of the APM system.

Without seeking to exhaustively address the technical changes, which, for full understanding, should be consulted directly in the manufacturer's technical documentation, it is worth mentioning some of the modifications incorporated into V2, as established in Flight Operations Information Message (FOIM) 2025/08, Issue 1:

- extension of the monitoring envelope

  APM V2 began performing continuous monitoring and issuing alerts throughout the entire flight, regardless of the aircraft's identification of icing conditions.

- adjustment of speed threshold values

  The activation conditions for the APM V2 speed alerts became based exclusively on the airspeed margins relative to VmLB0icing (ICING BUG), rather than on the theoretical airspeed values (IAS_TH), which had been used for the CRUISE SPEED LOW advisory and the DEGRADED PERFORMANCE alert in APM V1.

- 60-second delay before disappearance of an issued advisory/alert:

  V2 established a 60-second delay before cancellation of the CRUISE SPEED LOW advisory and the DEGRADED PERFORMANCE alert after the conditions that triggered them ceased to exist. This improvement addressed two main purposes:

  1) to reduce intermittent alert appearances (flickering), especially of the CRUISE SPEED LOW advisory, preventing messages from repeatedly appearing and disappearing and becoming trivialized by flight crews; and

  2) to allow adequate time for procedure execution, ensuring that the flight crew would have sufficient time to complete the required actions.

Figure 199 illustrates one of the adjustments incorporated into the V2 algorithm, indicating the elimination of the theoretical speed criterion for advisory and alert activation, such that all of them came to use VmLB0icing (ICING BUG) as the reference basis.

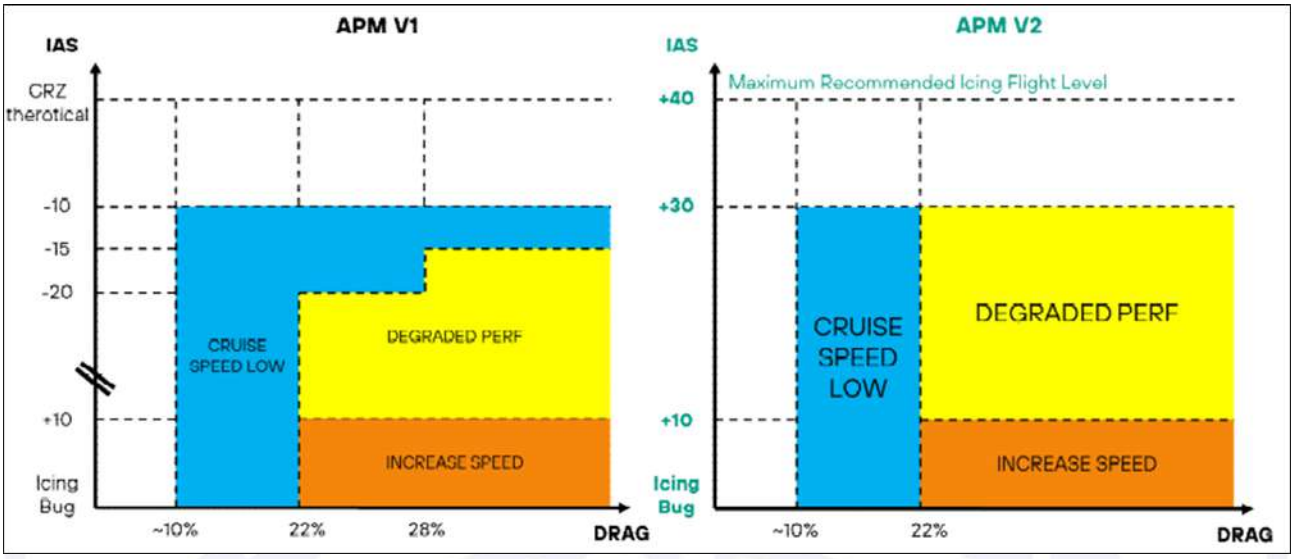


Figure 199 - Comparative illustration of the APM warning/alert activation regions between Versions 1 and 2.
Source: 2025/08 Issue 1.

The accident flight was simulated by the ATR engineering team using the algorithm of the new APM V2 version. The simulation with APM V2 resulted in a reduction in the number of CRUISE SPEED LOW advisories and additionally generated the activation of a new DEGRADED PERFORMANCE alert, recorded approximately 27 minutes before the moment at which the same alert was activated during the actual flight. Furthermore, in the V2 simulation, the last DEGRADED PERFORMANCE alert was activated 31 seconds earlier than in the accident flight.

APM Alertas V1	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	CRUISE SPEED LOW	DEGRADED PERF	INCREASE SPEED
Horário de ativação	15:24:57	15:25:49	15:34:46	15:51:58	15:54:12	16:00:12	16:01:42	16:18:42	16:19:28	
Horário de desativação	15:25:02	15:26:24	15:36:14	15:53:10	15:54:44	16:00:46	16:02:04	----		16:20:57
Intervalo	00:00:05	00:00:35	00:01:28	00:01:12	00:00:32	00:00:34	00:00:22	----	----	----

APM Alertas V2			CRUISE SPEED LOW	CRUISE SPEED LOW / DEGRADED PERF	CRUISE SPEED LOW			CRUISE SPEED LOW	DEGRADED PERF	INCREASE SPEED
Horário de ativação			15:34:54	15:51:54 15:52:25	15:54:16			16:18:43	16:18:57	16:20:54
Horário de desativação			15:36:19	15:54:03 15:53:40	15:55:33			----	----	----
Intervalo			00:01:25	00:02:09 00:01:15	00:01:17			----	----	----

Figure 200 – Illustration showing the comparison between the APM advisories/alerts issued during the accident flight and the flight simulation performed using the updated ATR V2 software.

The APM software update was characterized as an evolution resulting from the identification of opportunities for improvement, rather than as a replacement motivated by noncompliance with the system's original design and operational requirements.

It is important to highlight that, despite the changes already implemented in V2, the alert level of the INCREASE SPEED alert had still not been upgraded to WARNING by the time this Final Report was published.

02 - Update of the Aircraft Maintenance Manual (AMM) regarding the removal and installation procedure for the left elevator position sensor (Synchro Transmitter).

Although the incorrect installation of this sensor did not exert any influence on the chain of events of the accident, this inadequacy prompted action by the ATR manufacturer, which indicated the revision of the AMM or the issuance of a Service Bulletin (SB), with the objective of alerting all operators to the possibility of incorrect installation of the synchro transmitter.

ANAC:

01 - Study on UPRT, particularly regarding the startle effect.

ANAC was aware that several accidents had as a contributing factor the inadequate application by pilots of the knowledge associated with UPRT training.

Within this context, beginning in 2024, the Agency started participating in and promoting technical events involving manufacturers, other civil aviation authorities, specialists, and operators, with the objective of discussing recurrent vulnerabilities and enhancing the effectiveness of the training.

As of the date of issuance of this Final Report, there was within the Agency a study group dedicated to the UPRT topic, focused on the improvement of instructional methods, scenarios, and techniques, with emphasis on the effects of the startle effect and its impacts on decision-making and aircraft control.

As a product of these discussions, in January 2026 an Operational Safety Bulletin was issued within the scope of the Brazilian Commercial Aviation Operational Safety Group (BCAST), containing recommendations to operators governed by RBAC 121 aimed at strengthening the application of UPRT concepts, including the proposal of studies and practices focused on mitigating the startle effect.

02 - Study regarding the mandatory implementation of FDM for all RBAC 121 operators, regardless of aircraft MTOW.

RBAC 121 established the mandatory implementation of the PAADV for aircraft with an approved Maximum Takeoff Weight (MTOW) exceeding 27,000 kg. For aircraft below this threshold, the program could be adopted on a voluntary basis and, in any case, should comply with the guidelines set forth in IS 119-008 as the reference document.

However, in August 2025, ANAC approved Amendment No. 22 to RBAC 121, which expanded the applicability of the PAADV to aircraft with an approved Maximum Takeoff Weight (MTOW) exceeding 15,000 kg. With this amendment, the PAADV became mandatory for all aircraft models currently employed in operations governed by RBAC 121, including the entire ATR fleet in service in Brazil.

03 - Intensification of ANAC's continued surveillance activities.

Following the accident, ANAC intensified its oversight activities and implemented an assisted operation regime, consisting of a continuous on-site supervision model, in order to monitor the company's operations and maintenance activities in greater detail.

The first phase (August/September 2024) found that the accident had degraded the company's ability to respond to technical failures, leading to measures such as: reduction of the route network, prohibition on expanding maintenance privileges, removal of mechanics from duty, and the requirement to maintain two spare aircraft in order to increase the time available for maintenance activities.

During the second phase (February 2025), ANAC identified further deterioration, including recurrent failures in areas that had already been addressed, noncompliance with the requirement to maintain spare aircraft, and worsening operational performance.

In view of this scenario, on March 11, 2025, the Agency precautionarily suspended the company's Air Operator Certificate (COA) and Maintenance Organization Certificate (COM), under RBAC Nos. 121 and 145, respectively. Following an administrative proceeding, on June 24, 2025, ANAC determined the revocation of the COA and COM, as well as the imposition of pecuniary sanctions.

On July 23th, 2026.