COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
A-135/CENIPA/2022

OCCURRENCE:	**ACCIDENT**
AIRCRAFT:	**PR-AIY**
MODEL:	**A330-243**
DATE:	**28NOV2022**

NOTICE

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

The elaboration of this Final Report was conducted 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 nº 21713, dated 27 August 1946.

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

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

N.B.: This English version of the report has been written and published by the CENIPA with the intention of making it easier to be read by English speaking people. 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 concerns the accident involving aircraft PR-AIY, an Airbus A330-243, which occurred on 28 November 2022 and was classified as "[TURB] – Turbulence".

During the cruise phase, the aircraft entered an area of turbulence. One passenger was displaced from their seat and sustained serious injuries, while three other passengers sustained minor injuries. The remaining occupants were uninjured.

The aircraft was not damaged.

An Accredited Representative from the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) of France, the State of Manufacture of the aircraft, was designated.

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GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

AC	Advisory Circular
ACARS	ARINC Communication Addressing and Reporting System
ACAS	Airborne Collision Reporting System
ACC	Area Control Center
AFM	Aircraft Flight Manual
AGL	Above Ground Level
AIREP	Air-Report
AISWEB	Brazil’s official web-based Aeronautical Information Service portal
ANAC	Brazil’s National Civil Aviation Agency
AP	Auto Pilot
ATC	Air Traffic Control
BCAST	Brazilian Commercial Aviation Safety Team
CVA	Airworthiness Verification Certificate
CFR	Code of Federal Regulations
CB	Cumulonimbus Cloud
CCO	Operational Control Center
CENIPA	Center for the Investigation and Prevention of Aeronautical Accidents
CIMAER	Integrated Aeronautical Meteorological Center
CIV	Digital Pilot-Logbook
CMA	Aeronautical Medical Certificate
COL	Chief Flight Attendant
CVR	Cockpit Voice Recorder
DECEA	Airspace Control Department
EDR	Eddy Dissipation Rate
EFIS	Electronic Flight Instrument System
EWINS	Enhanced Weather Information Systems
FAA	Federal Aviation Administration
FCOM	Flight Crew Operating Manual
FDR	Flight Data Recorder
FIR	Flight Information Region
FL	Flight Level
FOQA	Flight Operational Quality Assurance
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules

IFRA	Airplane Flight Instrument
KMCO	ICAO location designator – Orlando International Aerodrome, FL, USA
LABDATA	Flight Recorders Data Readout and Analysis Laboratory
MCMSV	Flight Attendants' Manual
MGO	General Operations Manual
ND	Navigation Display
NWS	National Weather Service
NTSB	National Transportation Safety Board
PA	Public Address
PCM	Airplane Commercial Pilot License
PF	Pilot Flying
PIC	Pilot in Command
PIREP	Pilot Weather Reports
PLA	Airplane Airline Transport Pilot License
PM	Pilot Monitoring
PPR	Airplane Private Pilot License
PSO-BR	Brazilian Program for Civil Aviation Safety
PWS	Predictive Windshear System
RBAC	Brazilian Civil Aviation Regulations
REDEMET	Brazilian Air Force Meteorology Network
SBCC	ICAO location designator – *Campo de Provas Brigadeiro Veloso* Aerodrome, *Guarantã do Norte*, state of *Mato Grosso*
SBKP	ICAO location designator – *Viracopos* International Aerodrome, *Campinas*, state of *São Paulo*
SBMN	ICAO location designator – *Campo Ponta Pelada* Aerodrome, *Manaus*, state of *Amazonas*
SBNF	ICAO location designator – *Ministro Victor Konder* International Aerodrome, *Navegantes*, state of *Santa Catarina*
SIC	Second in Command
SIGMET	Significant Meteorological Information
SIGWX	Significant Weather Chart
SIPAER	Aeronautical Accidents Investigation and Prevention System
SN	Serial Number
TCU	Towering Cumulus
TPR	Scheduled Public Air Transport Registration Category
UTC	Coordinated Universal Time
VCSH	Vicinity Shower
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions
WRCU	Weather Radar Control Unit
WX/T	Precipitation and Turbulence
WXR	Weather Radar

1. FACTUAL INFORMATION.

Aircraft	**Model:** A330-243 **Registration:** PR-AIY **Manufacturer:** Airbus S.A.S.	**Operator:** Azul Linhas Aéreas Brasileiras S.A.
Occurrence	**Date/time**: 28NOV2022 - 15:47 (UTC) **Location:** *Amazônica* FIR airspace. **Lat.** 03°02'18"S **Long.** 060°02'57"W **Municipality – State:** Not applicable.	**Type(s):** [TURB] Turbulence encounter

1.1. History of the flight.

The aircraft departed from *Viracopos* International Airport (SBKP), *Campinas*, state of *São Paulo*, bound for Orlando International Airport (KMCO), Florida, United States of America, on a scheduled commercial air transport flight, with 14 crewmembers and 197 passengers on board.

During the cruise phase at FL380, at a distance of 215 NM away from the city of Manaus, the aircraft entered an area of turbulence, at which time one passenger was displaced from their seat and sustained fractures to the right wrist and to a lumbar vertebra. Three other passengers sustained minor injuries. The remaining passengers and crewmembers were uninjured.

1.2. Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	-	1	-
Minor	-	3	-
None	14	193	-

1.3. Damage to the aircraft.

NIL.

1.4. Other damage.

NIL.

1.5. Personnel information.

1.5.1. Crew's flight experience.

Flight Experience		
	PIC	SIC
Total	9,857:30	3,564:55
Total in the last 30 days	32:05	47:45
Total in the last 24 hours	01:25	01:25
In this type of aircraft	2,767:05	857:30
In this type in the last 30 days	32:05	47:45
In this type in the last 24 hours	01:25	01:25

Note: The flight time data were obtained from information provided by the aircraft operator.

1.5.2. Personnel training.

The Pilot in Command (PIC) completed the PPR course (Airplane Private Pilot) in 1985, at *Aeroclube de Bauru*, state of *São Paulo*.

The Second in Command (SIC) completed the PPR course (Airplane Private Pilot) in 2016, at *Aeroclube de São José do Rio Preto*, state of *São Paulo*.

1.5.3. Category of licenses and validity of certificates and ratings.

The PIC held a PLA license (Airplane Airline Transport Pilot) and valid ratings for A330/A350 aircraft and IFRA (Airplane Instrument Flight). The A330/A350 type rating included the A330-243 model.

The SIC held a PCM license (Airplane Commercial Pilot) and held valid ratings for A330/A350 type and IFRA.

1.5.4. Qualification and flight experience.

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

1.5.5. Validity of medical certificate.

The pilot held valid CMAs (Aeronautical Medical Certificates).

1.6. Aircraft information.

The aircraft, SN 365, was manufactured by Airbus SAS in 2000 and was registered in the Scheduled Public Air Transport (TPR) category.

At the time of the occurrence, the aircraft had accumulated 27,345 hours and 15 minutes of total flight time.

The Certificate of Airworthiness Verification (CVA) was valid, and the aircraft maintenance records were up to date.

1.6.1. Weather Radar System (WXR).

The aircraft was equipped with the Honeywell RDR-4000 weather radar, a fully automated X-band Doppler system integrated with the Predictive Wind Shear (PWS) system. The system was designed to detect, process, and graphically display atmospheric disturbances within the area scanned by the antenna, including precipitation, associated turbulence, and microscale convective phenomena, thereby assisting the flight crew in avoiding adverse weather conditions

The information processed by the RDR-4000 contributed significantly to the flight crew's situational awareness, as the symbology displayed on the Navigational Display (ND), together with the system's automatic scanning functions, enabled the identification of areas of significant convective activity, the anticipation of deviation routes based on the structure of weather formations, the detection of turbulence associated with precipitation within its detection range, and the provision of predictive wind shear alerts during critical phases of flight, such as takeoff and approach.

According to the RDR-4000 3D Weather Radar Systems Technical White Paper, the system performed the following primary functions: precipitation detection, automated scanning and management, terrain mapping, and PWS (Predictive Wind Shear).

The weather radar featured the following operating modes:

Mode	Description
OFF	Radar inactive, with no transmission.
WX	Displays precipitation echoes only.
WX/T	Combined display of precipitation and detected wet turbulence (magenta).
MAP	Displays terrain and ground returns, with no weather Information.
TILT (manual)	Allows manual vertical adjustment of the antenna to optimize the scan.

Table 1 – Weather radar operation modes.
Source: Honeywell.

The presentation of radar echoes on the Navigation Display (ND) (Figure 1) followed the scheme described in Table 2.

Color	Intensity	Operational Interpretation
Black		No precipitation.
Green	Light	Light precipitation.
Yellow	Moderate	Moderate convective activity; possible turbulence.
Red	Heavy	Heavy precipitation; high risk.
Magenta	Very Heavy	Indicative of hail or severe turbulence.
Solid Magenta		Wet turbulence detected within an area of precipitation (WX/T).
Cyan / Light Blue		Ground return or interference (*ground clutter*).

Table 2 – Colors, intensities and operational interpretations of weather radar echoes.
Source: Honeywell.

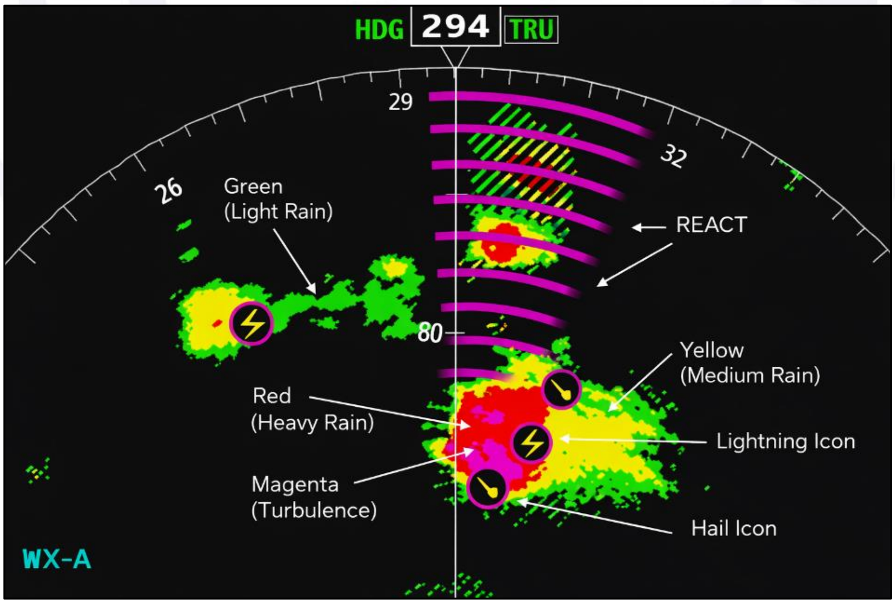


Figure 1 – Example of Weather Radar Echo Display on the Navigation Display (ND).
Source: Honeywell.

1.7. Meteorological information.

The analysis of the satellite imagery over the northern region of Brazil revealed an environment of high atmospheric instability, characterized by the widespread presence of deep convective cells across the Amazon region.

The areas highlighted by more intense colors indicated very cold cloud tops, consistent with well-developed cumulonimbus (CB) clouds, suggesting that those formations reached high levels of the troposphere, possibly near or above the tropical tropopause.

Some of these convective cells exhibited organized spatial structure and significant horizontal extent, a characteristic typical of Mesoscale Convective Systems (MCSs), with multiple embedded cells and intense convective activity, in a pattern consistent with the tropical convection of the region, favored by the high moisture content at low and middle levels, daytime heating, and convergence associated with the regional atmospheric circulation.

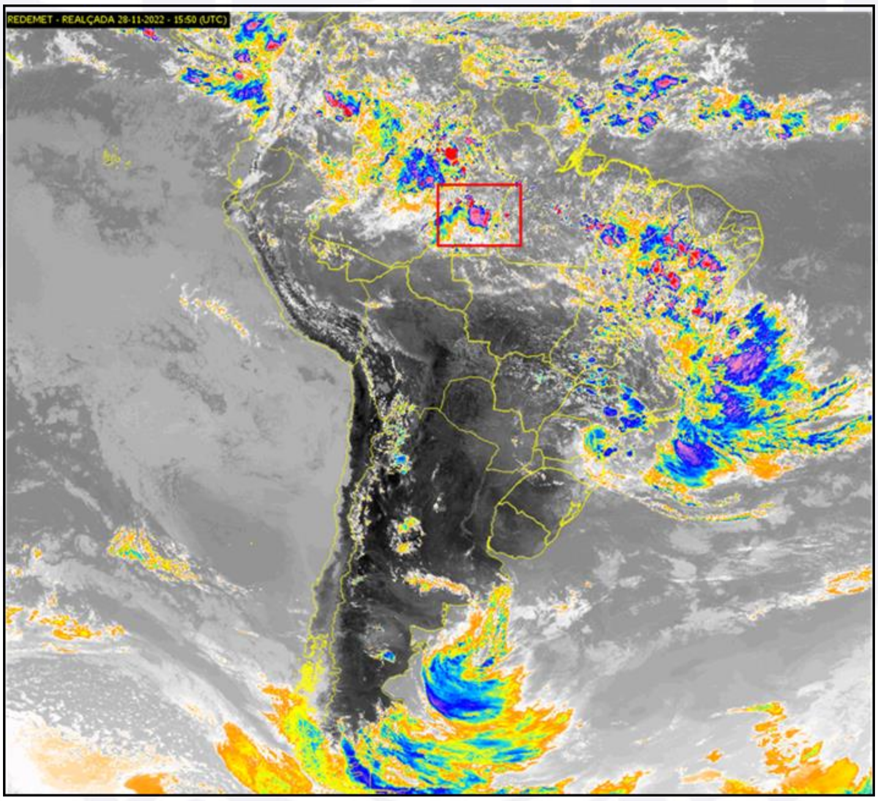


Figure 2 – Satellite image at 15:50 UTC on 28NOV2022, highlighting the location of the occurrence.
Source: REDEMET

The areas adjacent to the most intense convective cells, depicted in shades of gray, indicated less developed cloudiness, possibly consisting of middle- and high-level clouds associated with upper-level outflow from the convective cells.

From an operational standpoint, this combination of conditions characterized an adverse meteorological environment, with the potential for moderated to severe turbulence at altitude, strong vertical currents, intense electrical activity, and conditions favorable to icing at higher flight levels, as well as requiring lateral deviations from the planned route, particularly at typical cruise altitudes.

Along airway UM417, on the segment between *Campo de Provas Brigadeiro Velloso* Airport (SBCC), *Guarantã do Norte*, state of *Mato Grosso*, and *Ponta Pelada* Airport (SBMN), *Manaus*, state of *Amazonas*, a high-intensity convective system was observed along and in the vicinity of the route.

The satellite image showed an extensive convective cluster with well-defined cells and very cold cloud tops, consistent with deeply developed cumulonimbus (CB) clouds, exhibiting significant horizontal extent and internal organization, suggesting an advanced stage of convective maturity.

This configuration indicated the presence of strong updrafts and downdrafts, as well as intense convective activity at higher altitudes. The peripheral areas, depicted in lighter yellow and blue shades, represented regions of less intense convection, by were still associated with significant atmospheric instability and the occurrence of precipitation.

In this context, the meteorological conditions along the segment between SBC and SBMN were particularly challenging for air navigation, with a high potential for moderate to severe turbulence, especially in the vicinity of the most intense convective cells.

Additionally, the predominance of ice at higher altitudes, associated with the elevated cloud tops, could reduce the onboard weather radar's detection capability in certain sectors, partially masking the system's actual severity and making the flight crew's technical assessment more difficult, thereby reinforcing the need for significant lateral deviations and continuous monitoring of the weather conditions along the route.

The analysis of the Significant Meteorological Information (SIGMET) messages issued for the *Amazônica* Flight Information Region (FIR) corroborated the conditions observed in the satellite imagery, indicating the widespread presence of embedded thunderstorms throughout virtually the entire area of responsibility, characterizing an intense, deep, and persistent convective environment.

The SIGMET messages issued throughout 28 November and during the early hours of 29 November repeatedly indicated the occurrence or forecast of embedded thunderstorms in multiple sectors, with convective cells reaching tops up to FL480, a characteristic typical of storms with significant vertical development. In all advisories, the movement of the convective formations was reported as stationary, and the trend was consistently reported as no change, indicating a stable atmospheric pattern and the absence of significant displacement of the convective systems.

At times close to the occurrence, SIGMETs 13, 14, 15, 16, and 17 expanded upon the conditions described in the earlier series, indicating the persistence and expansion of areas of embedded thunderstorms over virtually the entire central portion of the FIR.

The messages covered regions extending from northern Amazonas to areas as far south as 11°S in the southern sector of the FIR, also including portions of northwestern Pará, eastern Amazonas, and the vicinity of Amapá. The polygons described in the advisories showed that the thunderstorms maintained significant vertical extent and remained organized into clusters of considerable horizontal extent, reinforcing the widespread nature of the atmospheric instability.

SIGMET 13
Validity: 28 1530 – 28 1930 UTC.
Indicated embedded thunderstorms over a broad portion of the central-western Amazon region, including the area bounded by 10°S–00° and 66°W–54°W.
Tops: FL480.
Movement: Stationary.
Trend: No change.

SIGMET 14
Validity: 28 1530 – 28 1930 UTC.
Covered an extensive area from the far north of Brazil to the central-eastern Amazon region, with embedded thunderstorms forecast within a complex polygonal area extending from 03°S/53°W to 11°S/42°W.
Tops: FL480.
Movement: Stationary.
Trend: No change.

SIGMET 15
Validity: 28 1635 – 28 1930 UTC.
Reported embedded thunderstorms forecast within an extensive and irregular area, extending across sectors from 10°S/55°W to 02°N/41°W, and subsequently returning to 10°S/54°W.
Tops: FL480.
Movement: Stationary.
Trend: No change.

SIGMET 16
Validity: 28 1708 – 28 1930 UTC.
Indicated a large area of embedded thunderstorms extending from northwestern Amazonas to the border with Pará and Amapá, from 03°N/65°W to 05°N/60°W, and then southward to the vicinity of 06°S/53°W.
Tops: FL480.
Movement: Stationary.
Trend: No change.

SIGMET 17
Validity: 28 1708 – 28 1930 UTC.
Covered forecast embedded thunderstorms extending from the southwestern Amazon region to the central portion of the FIR, from approximately 11°S/65°W to 10°S/55°W.
Tops: FL480.
Movement: Stationary.
Trend: No change.

Between 11:30 UTC and 15:30 UTC, the initial SIGMETs delineated adjacent areas of embedded thunderstorms extending from northwestern *Amazonas* to the coast of *Amapá* and northern *Pará*, covering extensive sectors and characterizing convective clusters with significant vertical development, embedded within extensive cloud layers, thereby making visual detection by the pilots more difficult.

Between 15:30 UTC and 19:30 UTC, the subsequent SIGMETs expanded upon this scenario, indicating the persistence and expansion of areas of embedded thunderstorms over virtually the entire central portion of the FIR, extending from northern *Amazonas* to areas near 11°S in the southern sector, including northwestern *Pará*, eastern *Amazonas*, and regions adjacent to *Amapá*. The areas described in these advisories showed that the thunderstorms maintained significant vertical extent and remained organized into clusters of considerable horizontal extent, reinforcing the widespread nature of the atmospheric instability.

The evaluation of the Significant Weather Chart (SIGWX), focusing on the corridor between SBCC and SBMN, revealed embedded convection distributed within an extensive layer of stratiform cloud, a configuration consistent with an environment of deep atmospheric instability that was difficult to detect tactically.

The convective cells were not isolated but rather embedded within the cloud mass, a condition that reduced both the ability to detect them visually and the effectiveness of the onboard weather radar. This scenario was consistent with the sequence of SIGMETs issued for the *Amazônica* FIR, which continuously reported the occurrence of embedded thunderstorms with high tops and stationary movement over the sector encompassing SBCC and SBMN, indicating the presence of a broad, persistent, and slow-moving convective system.

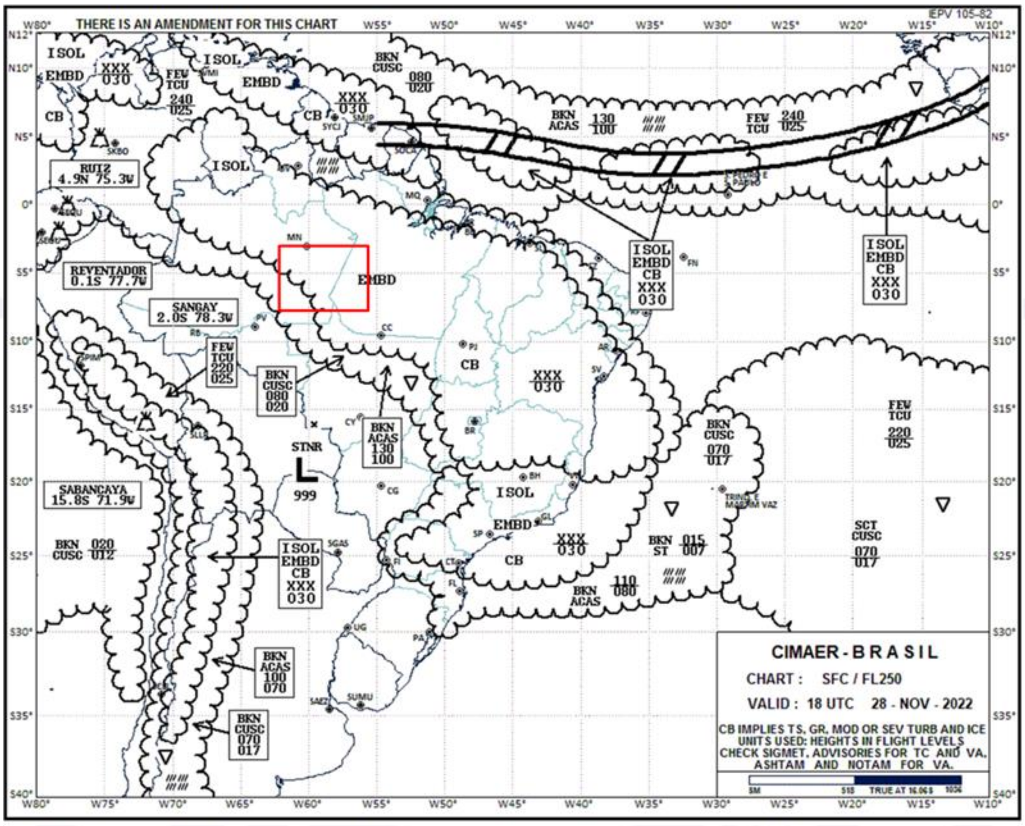


Figure 3 – SIGWX Chart valid until 18:00 UTC on 28NOV2022, highlighting the location of the occurrence
Source: REDEMET.

Along the specific segment between these aerodromes, the SIGWX chart already indicated the presence of towering cumulus (TCU) clouds and CB cells associated with convective development at multiple levels, which was subsequently confirmed by the SIGMETs.

This combination of conditions characterized a hazardous en-route operating environment, with the potential for moderate to severe turbulence, strong updrafts, icing at altitude, and abrupt wind variations associated with wind shear. Furthermore, the cloud pattern suggested relatively low cloud bases and significantly elevated tops, favoring the occurrence of thunderstorms that were difficult to detect at a distance, thereby making it more difficult for the pilots to anticipate route deviations, particularly during flights conducted under Instrument Flight Rules (IFR).

In summary, the integration of the SIGWX chart, the satellite imagery, and the successive SIGMETs demonstrated that the sector between SBCC and SBMN was under the influence of a broad, persistent embedded thunderstorm system with significant vertical development.

Such conditions represented an operational hazard requiring thorough weather planning, continuous coordination with ATC units, and the judicious use of onboard weather sensors in order to mitigate exposure to the associated turbulence.

1.8. Aids to navigation.

NIL.

1.9. Communications.

NIL.

1.10. Aerodrome information.

The occurrence was outside of aerodrome area.

1.11. Flight recorders.

The aircraft was equipped with a Cockpit Voice Recorder (CVR), Part Number 16-05-01-00, Serial Number 1138, manufactured by Universal Avionics, and a digital Flight Data Recorder (FDR), FA-2100 FDRL-3, Model 2100-2/4043, Part Number 7598-443-00, Serial Number 000-5854-79.

Both recorders were sent to the Flight Recorder Data Readout and Analysis Laboratory (LABDATA) of the Aeronautical Accidents Investigation and Prevention Center (CENIPA), where the data were successfully downloaded.

The recorders operated normally throughout the flight. The FDR data analyzed by the SIPAER Investigation Commission contained relevant information on the flight parameters recorded at the time of the occurrence, contributing to the characterization of the operational conditions encountered by the aircraft. However, it was found that the CVR data had been overwritten.

To facilitate the understanding of the operational context of the occurrence, the relevant portions of the flight data recorded by the FDR are presented in Section 1.18, Operational Information, as they are directly related to the aircraft's operating parameters and contribute to the understanding of the dynamics of the occurrence.

1.12. Wreckage and impact information.

NIL.

1.13. Medical and pathological information.

1.13.1. Medical aspects.

As a result of the pronounced variation in vertical acceleration recorded at the time of the occurrence, four passengers who were not wearing their seat belts were thrown from their seats, sustaining injuries of varying severity.

The passenger occupying seat 25D sustained trauma to the right wrist and right elbow, with a suspected fracture. The other injured passengers, seated in 26G, 28D, and 35C, sustained minor contusions that did not require specialized medical treatment.

Table 3 and Figure 4 present the seating locations of the injured passengers, the injuries identified immediately after the occurrence, and other relevant information.

Seat	Reported Injuries	Remarks
25D	Suspected fracture of the wrist and contusion to the right elbow.	The most serious injury recorded in the occurrence. The passenger was thrown upward, struck the armrest of the seat, fell into the aisle, and injured the wrist.
35C	Contusion to the inguinal and perineal region.	The injury occurred when the passenger was thrown upward and returned to the seat. Following an assessment by a flight attendant, a small superficial laceration was identified in the inguinal and perineal region, with no need for medical intervention.
26G	Contusion to the head.	The passenger struck the head against the ceiling, causing the partial detachment of the overhead panel, which, according to the passenger, helped cushion the impact. No significant injuries were reported.
28D	Contusion to the head.	The passenger struck the head during the event and was treated with ice and medication for nausea and dizziness.

Table 3 – Injured passengers, injuries reported immediately after the occurrence, and additional remarks

With regard to the most seriously injured passenger, the post-occurrence interview revealed that the passenger had fastened the seat belt at the beginning of the flight but removed it during the meal service. After finishing the meal, the passenger did not fasten it again and put on headphones to watch a movie, and therefore did not hear the announcement made by the flight crew instructing passengers to remain seated with their seat belts fastened.

During the turbulence, the passenger was thrown upward, struck the armrest of the seat, fell into the aisle, and injured the wrist. The other injured passengers were either asleep or wearing headphones, circumstances that prevented them from noticing the visual and aural seat belt warning.

Approximately one minute after the turbulence ended, the seat belt sign was switched off. Once the aircraft had stabilized, the cabin crew requested medical assistance from among the passengers, and an orthopedic physician on board provided first aid, including temporary immobilization of the injured passenger.

The flight continued normally to its final destination, where the passenger with the most serious injuries was transferred to a hospital for further evaluation and treatment.

According to the medical report issued by the hospital on the day of the occurrence, the patient presented with traumatic injuries to the lumbar spine and the upper limb. A wrist fracture and a compression fracture of the L2 lumbar vertebra, characterized by the partial collapse of the vertebral body, were identified, along with severe pain in the lumbar region associated with the injuries described. The findings were consistent with significant orthopedic injuries, requiring appropriate immobilization and targeted pain management.

The interviews conducted with the flight crew after the occurrence indicated a low risk of fatigue at the time of the event, with no evidence of sleep deprivation.

1.13.2. Ergonomic information.

NIL.

1.13.3. Psychological aspects.

There was no evidence that psychological factors affected the flight crew's performance.

1.14. Fire.

There was no fire.

1.15. Survival aspects.

NIL.

1.16. Examinations, Tests, and Research.

On the day following the occurrence, the components of the weather radar system, located both in the flight deck and in the nose section of the aircraft, were subjected to ground testing, and no discrepancies were observed in their operation.

1.17. Organizational and management information.

NIL.

1.18. Operational information.

The flight was conducted under the requirements of the Brazilian Civil Aviation Regulation (RBAC) No. 121, Amendment No. 14, Public Air Transport Operations with airplanes having a maximum seating configuration of more than 19 passenger seats or a maximum certificated payload capacity exceeding 3,400 kg, operating between SBKP and KMCO, with 14 crewmembers and 197 passengers on board.

The operational analysis of the entire flight, from engine start to engine shutdown, did not identify any non-compliance by the flight crew with the operator's or the manufacturer's procedures, nor with the requirements established by the Brazilian National Civil Aviation Agency (ANAC) and the Airspace Control Department (DECEA).

The aircraft was within the prescribed weight and balance limits, and no pre-existing technical conditions that could have contributed to the occurrence were identified.

Based on the evidence gathered, all operational procedures were carried out in accordance with the applicable requirements. From the pre-flight safety briefing to the in-flight announcements, the cabin crew consistently emphasized the importance of keeping seat belts fastened whenever passengers were seated.

According to the flight crew, the weather radar operated normally, accurately displaying the surrounding weather formations under visual flight conditions. Functional tests performed on the equipment confirmed its proper operation.

According to the data obtained from the FDR, at the time of the occurrence the weather radar was configured in WX/T mode, intended for the detection of wind shear and turbulence, and the radar range and antenna tilt were set in accordance with the parameters established by the operator and the manufacturer.

At the time the aircraft encountered the turbulence, the PIC was acting as the Pilot Flying (PF), while the SIC was acting as the Pilot Monitoring (PM).

During the cruise phase at FL380, within the *Amazônica* FIR, after approximately 2 hours and 45 minutes of flight, the aircraft encountered heavy weather formations consisting of cumulonimbus (CB) and cumulus congestus (TCU) clouds, displayed in magenta on the onboard weather radar.

As a result, the pilots stabilized the aircraft at the recommended turbulence penetration speed (Mach 0.80) and coordinated a right lateral deviation with the *Amazônica* Area Control Center (ACC). The deviation began while the aircraft was on airway UM417, approximately 215 nautical miles from the vertical of the city of *Manaus*, state of *Amazonas*, and reached a maximum displacement of 10 nautical miles from the original track (Figure 4).

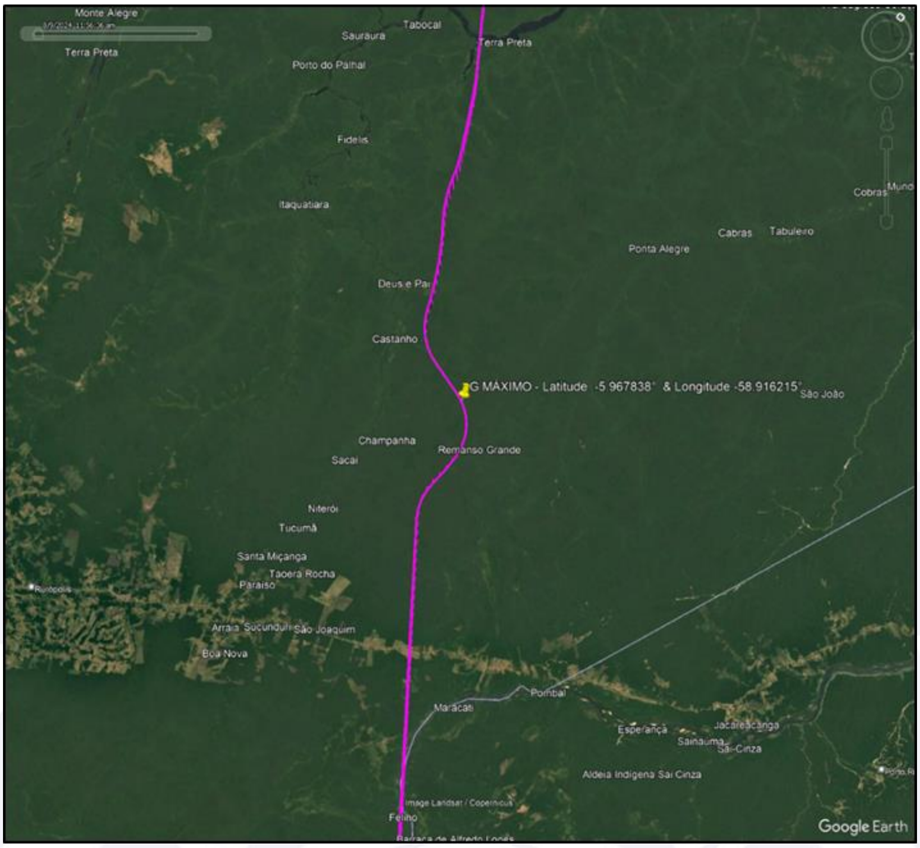


Figure 4 – Aircraft trajectory recorded by the FDR. Highlighted is the point at which the maximum vertical acceleration (maximum G) occurred.
Source: FDR/Google Earth.

According to the interviews conducted by the SIPAER Investigation Commission, while returning to the airway track, the pilots identified that the aircraft would pass through an area of possible convective activity, indicated by green and yellow returns on the weather radar, and switched on the FASTEN SEAT BELTS sign.

The cabin crew subsequently instructed the passengers, through the PA[1] system, to return to their seats and fasten their seat belts due to the proximity of an area of atmospheric instability. Approximately 40 seconds later, the aircraft abruptly encountered a region of severe, short-duration turbulence, recording peaks of vertical acceleration of +1.78 G and −0.35 G.

The aircraft trajectory, shown in Figure 5 and overlaid on the satellite image provided by the Aeronautics Command Meteorological Network (REDEMET), was found to be consistent with the prescribed operational procedures.

[1] Passenger Address (PA) refers to the onboard communication system used by the crew to make announcements to passengers. This system enables pilots and flight attendants to communicate with passengers by providing important information, such as safety instructions, flight updates, weather conditions, and turbulence advisories. The PA system is an essential component of an aircraft's communication equipment, ensuring that all passengers receive clear and timely messages directly from the crew.

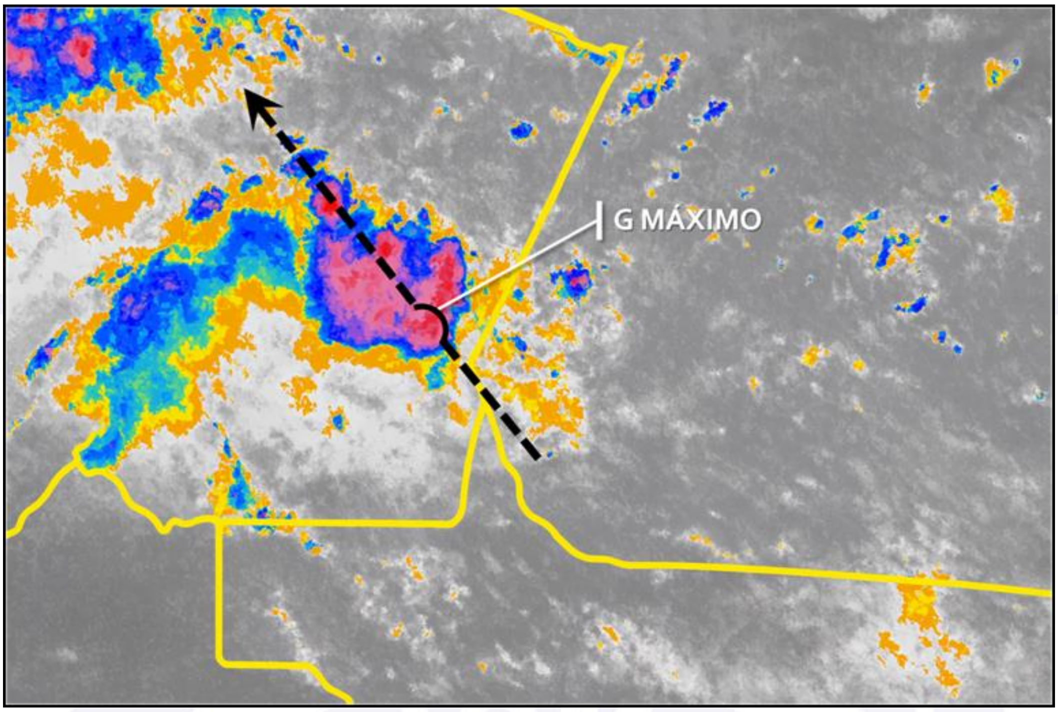


Figure 5 – Aircraft trajectory recorded by the FDR overlaid on the satellite image of the occurrence area. Highlighted is the point at which the maximum vertical acceleration occurred.
Source: FDR/REDEMET.

In the sequence of events related to the encounter with the turbulence, 2 seconds after the peak load factor, the Autopilot (AP) disengaged, and the indication "AP OFF INVOLUNTARY" was recorded, characterizing an involuntary disengagement of the system. The AP disengagement indicated that the atmospheric disturbances had exceeded the automatic system's operational limits, resulting in its disconnection as a protective measure provided for in the aircraft design.

The AP remained disengaged for approximately 45 seconds and was re-engaged by the PF shortly after the aircraft had passed through the most critical phase of the turbulence. During this period, significant variations in vertical acceleration were recorded (Figure 6).

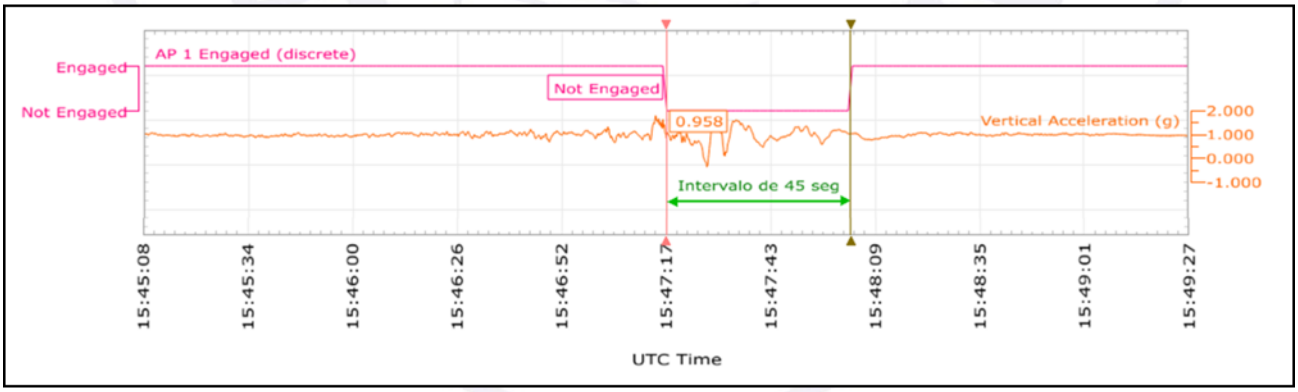


Figure 6 – Vertical acceleration (G) profile and autopilot status during the encounter with turbulence in cruise flight.
Source: FDR.

According to the FDR, the turbulence lasted approximately 55 seconds, with the peak intensity concentrated within a period of approximately 6 seconds.

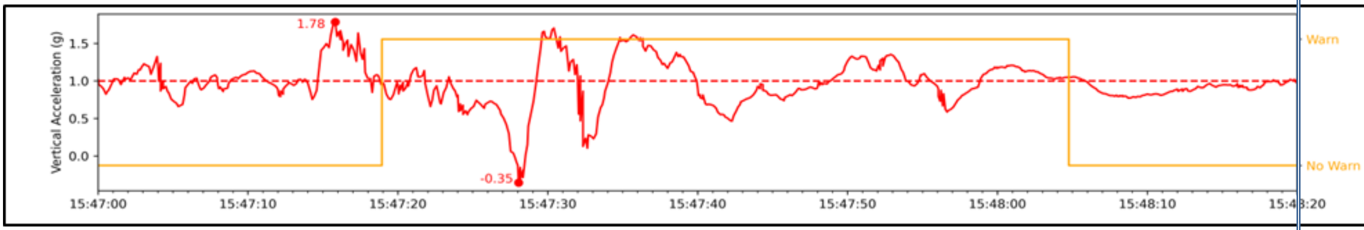


Figure 7 – Vertical acceleration (G) variation during the encounter with turbulence.
Source: FDR.

The detailed vertical acceleration profile during the encounter with the turbulence, presented in Figure 7, made it possible to identify three distinct phases of the event.

During the initial period, the vertical acceleration remained predominantly close to the nominal value of 1 G, with moderate oscillations generally ranging between 0.8 G and 1.2 G. The observed variations were irregular and of small amplitude, consistent with the effects of light to moderate turbulence. No abrupt peaks or progressive increases in load factor were identified, indicating that the aircraft remained relatively stable, with no evidence of intentional pitch maneuvers or significant structural loading.

Subsequently, a marked intensification of the vertical acceleration oscillations was observed, characterized by rapid, large-amplitude variations. Notably, a maximum positive peak of approximately +1.78 G was recorded, followed shortly thereafter by an abrupt reduction to values significantly below 1 G, reaching a maximum negative peak of −0.35 G. This sequence evidenced the action of severe vertical currents, with a rapid alternation between strong updrafts and pronounced downdrafts, typical of strong to severe turbulence. The temporal pattern indicated an abrupt atmospheric variation, a condition that is particularly critical for occupants who are not adequately restrained.

Following the critical period, the vertical acceleration gradually returned to values closer to 1 G, although smaller irregular oscillations were still observed. The variations remained greater than those recorded during the initial phase, indicating the persistence of an unstable atmospheric environment, but without the recurrence of extreme vertical load peaks. This behavior suggested that the aircraft had exited the most intense core of the turbulence, with a progressive attenuation of the severe vertical currents.

Additionally, Figure 8 presents three graphs illustrating the temporal evolution of three other aerodynamic parameters during the aircraft's penetration into the turbulence, demonstrating the effects of the unstable atmospheric environment on the flight.

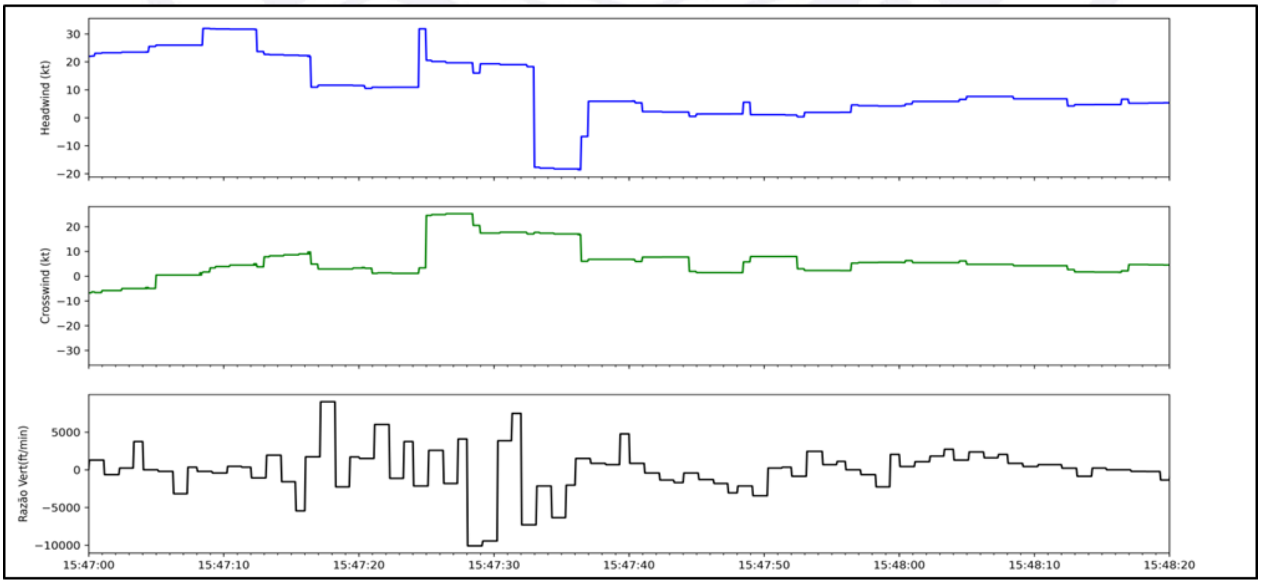


Figure 8 – Temporal evolution of the flight parameters during the turbulence.
Source: FDR.

The first graph shows significant variations in the headwind component, with rapid oscillations and abrupt changes in intensity. Marked reductions were observed, followed by sudden increases, with peaks ranging from approximately 11 kt to values exceeding 30 kt over short periods of time. This behavior is consistent with the presence of wind gradients associated with turbulent cells, resulting in instantaneous variations in the available aerodynamic energy and directly affecting the aircraft's lift and indicated airspeed.

The second graph presents significant variations in the crosswind component, with alternating direction and magnitude between negative and positive values, reaching pronounced peaks. Notably, toward the end of the event, this component underwent an abrupt change, increasing from approximately 2 kt to values exceeding 25 kt within a short period of time, indicating a rapid shift in wind direction and requiring continuous lateral corrections, with a direct impact on the aircraft's lateral and directional stability.

The third graph shows extreme fluctuations in the vertical speed, characterized by rapid transitions between strong updrafts and downdrafts, with climb rates approaching 10,000 ft/min and descent rates on the order of 5,000 ft/min over short periods of time. This behavior is indicative of the presence of severe vertical currents associated with intense turbulence, which may have momentarily exceeded the response capability of the flight control systems, resulting in abrupt variations in the aircraft's vertical flight path.

Taken together, the parameters analyzed indicated that the aircraft was subjected to an environment of strong turbulence, with simultaneous effects on its longitudinal, lateral, and vertical stability. These effects resulted in a significant increase in structural loads, a temporary degradation of flight quality, an increased flight crew workload, and a potential risk to occupants who were not adequately restrained.

At the time of the turbulence encounter, the cabin service had already been completed, and no passengers or crewmembers were in the aisles, galleys, or lavatories. The flight crew and cabin crew were seated with their seat belts fastened and did not sustain any injuries.

1.19. Additional information.

In 2021, the National Transportation Safety Board (NTSB) published a comprehensive study entitled Safety Research Report: Preventing Turbulence-Related Injuries in Air Carrier Operations Conducted Under Title 14 CFR Part 121, which found that turbulence-related accidents were the most frequent type of occurrence involving scheduled air carriers in the United States. According to the study, between 2009 and 2018, the NTSB identified that these events accounted for more than one-third of the occurrences recorded in that sector, resulting predominantly in serious injuries to occupants.

During the period analyzed, the NTSB determined the probable causes of the various turbulence-related occurrences and issued recommendations aimed at improving the forecasting, dissemination, and operational use of meteorological information, as well as enhancing air traffic management practices.

According to the study, although the overall accident rate in scheduled air carrier operations showed a downward trend, turbulence remained one of the leading causes of in-flight injury events, particularly among cabin crewmembers.

The study analyzed 111 turbulence-related accidents investigated by the NTSB and concluded that the use of the seat belt was a critical factor in preventing serious injuries. Among the 123 occupants who sustained serious injuries in those accidents, only one passenger was wearing a seat belt at the time of the turbulence encounter. Figure 9 shows that 83.5% of the cabin crewmembers who sustained injuries were not wearing a seat belt at the time of the event. The NTSB concluded that the continuous use of the seat belt significantly reduces the risk of serious injuries for all occupants involved in turbulence events.

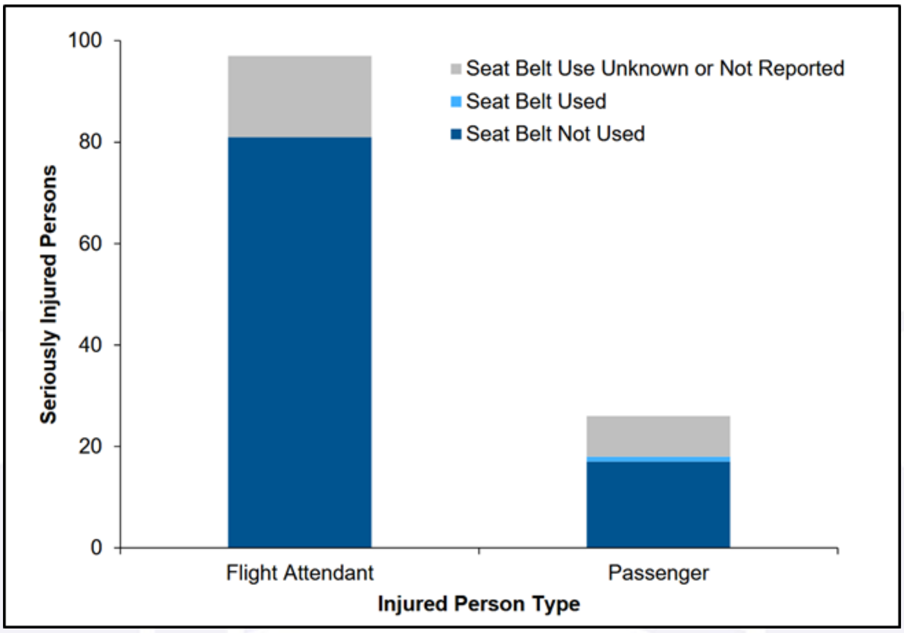


Figure 9 – Seat belt use by occupants seriously injured in turbulence-related accidents during scheduled air carrier operations.
Source: NTSB.

Over the past 15 years, the CENIPA database identified three accidents, two serious incidents, and sixteen incidents involving RBAC 121 operators that were caused by turbulence.

With regard to turbulence, the Brazilian Commercial Aviation Safety Team (BCAST) published Safety Bulletin No. 02/2024 in June 2024 for the purpose of disseminating operational safety guidance aimed at preventing accidents and serious incidents associated with this type of occurrence, targeting air operators, flight dispatchers, pilots, and cabin crews.

The document was based on international operational safety data, regulations, and tools to raise awareness among its target audience of the importance of the subject, demonstrating that turbulence remains one of the most frequent causes of occurrences involving injuries on board, with a particularly significant impact on cabin crewmembers.

In this context, the bulletin presented operational, meteorological, technological, and training measures that Brazilian air operators could adopt to reduce the risk of turbulence encounters, including improvements in weather planning, the strengthening of flight dispatch policies, the use of turbulence detection technologies, enhanced crew training, and revisions to seat belt use policies.

The bulletin also emphasized the need for integration among operational sectors, highlighting the importance of effective communication between the aircraft, the Operational Control Center (OCC), flight dispatchers, and Flight Operations Quality Assurance (FOQA) teams, with particular emphasis on the use of turbulence monitoring dashboards to enable the continuous monitoring of risk conditions.

The guidance presented was supported by standards and technical documents published by the ICAO, FAA, NTSB, and CENIPA, thereby providing a consolidated technical foundation for the bulletin.

1.19.1 Principle of weather radar operation.

The onboard weather radar is an active remote sensing system that operates by transmitting pulses of electromagnetic waves, typically in the X-band, and analyzing the energy reflected (echo) by hydrometeors present in the atmosphere. Its operational purpose is to detect areas of precipitation and, indirectly, identify regions potentially associated with convective turbulence, thereby supporting the pilots' decision-making with respect to deviations around adverse weather phenomena.

The fundamental physical principle of weather radar is based on the reflectivity of atmospheric particles, which varies according to their nature, size, and physical state. Liquid water droplets exhibit a high capacity to reflect radar pulses, whereas solid particles, such as ice crystals and dry snow, have significantly lower reflectivity. Accordingly, weather radar is inherently optimized for the detection of precipitation rather than turbulence itself. It is therefore not a direct turbulence sensor, but rather a sensor of precipitation associated with convective structures that frequently produce severe turbulence (Figure 10).

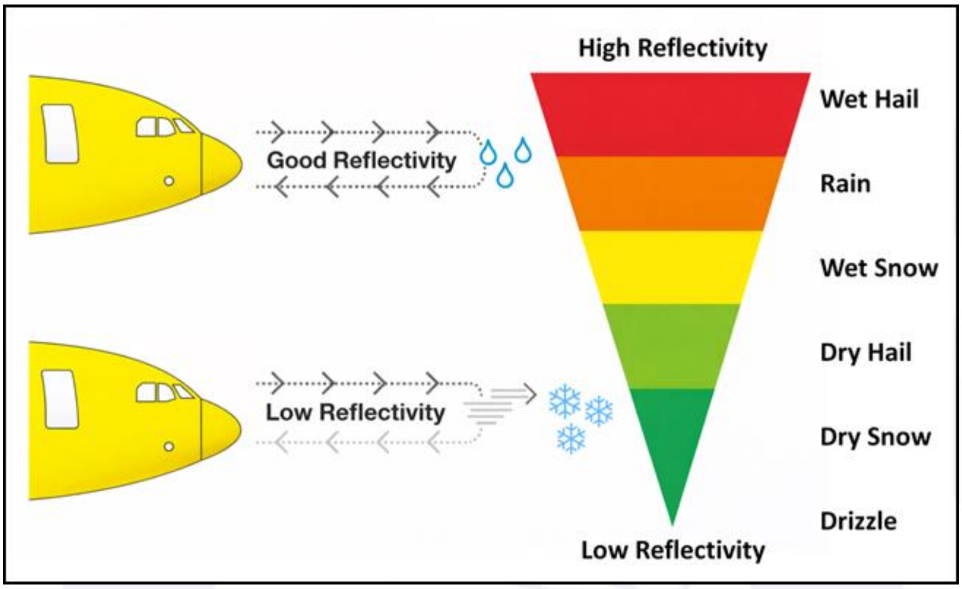


Figure 10 – Reflectivity of different types of precipitation.
Source: Airbus.

In convective storms, reflectivity is not distributed uniformly throughout the storm's vertical structure. The lower portion of the cell, located below the freezing level, consists predominantly of heavy rain and constitutes the region of highest reflectivity, returning a significant portion of the energy transmitted by the radar. Immediately above lies an intermediate layer, extending from the freezing level to the altitude corresponding to approximately −40°C, where ice crystals and supercooled water coexist. In this region, the liquid water contributes to the partial reflection of the radar pulse, whereas the ice crystals tend to absorb or scatter the energy, resulting in intermediate reflectivity.

The upper portion of the storm, above the −40°C isotherm, is composed predominantly of ice crystals. Because of its low reflectivity, this region may not be detected by the weather radar, even though it is often visible to the naked eye through the aircraft windshield.

Above this layer, in developing thunderstorms, the so-called turbulence dome may form, characterized by extremely strong updrafts and very severe turbulence. This feature may extend several thousand feet above the visible cloud top and remain completely undetectable by the weather radar due to the absence of liquid water.

The maximum vertical extent detectable by the weather radar is known as the radar top, or wet top, and corresponds to the highest altitude within the storm where sufficient liquid or supercooled water remains to produce detectable radar echoes. This level separates the intermediate portion of the convective cell from its upper portion. Above the radar top, despite the continued vertical development of the cloud, the reflectivity becomes insufficient to produce a significant radar return (Figure 11).

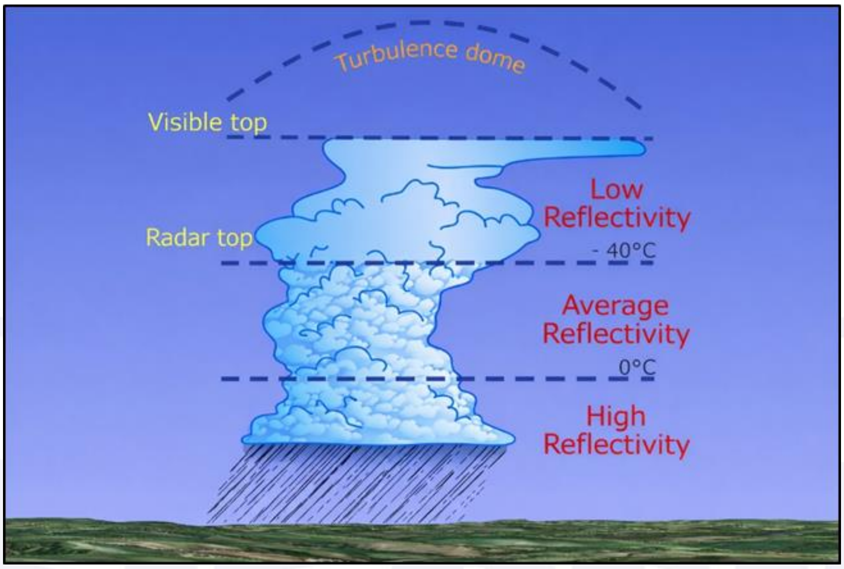


Figure 11 – Structure of a convective cell (CB) and its corresponding reflectivity regions.
Source: Airbus.

Certain phenomena may also produce attenuation and masking effects. Wet hail, for example, exhibits higher reflectivity than heavy rain due to the large size of the hailstones combined with the presence of liquid water on their surface. Under these conditions, the radar pulse may be strongly reflected or attenuated, preventing it from penetrating the convective cell, so that meteorological structures located behind that region become obscured on the radar display. A similar phenomenon occurs within the melting layer, in the vicinity of the freezing level, where partially melted ice crystals become coated with liquid water, artificially increasing their reflectivity.

Accordingly, the proper interpretation of weather radar imagery requires an understanding that the intensity of radar echoes is directly related to the presence of liquid water, and not necessarily to the storm's total vertical extent or the severity of the associated turbulence. An understanding of the system's limitations, together with the proper selection of operational parameters, such as the antenna tilt angle and range, is essential for the flight crew to correctly assess the meteorological risk and adopt effective weather avoidance strategies, thereby contributing to the maintenance of operational safety.

1.19.2 Differences between satellite imagery and onboard weather radar displays

Meteorological images obtained from satellites and those generated by the onboard weather radar differ fundamentally with respect to their sensing method and the observation plane of atmospheric formations. These differences determine the type of information available and the manner in which meteorological phenomena are interpreted in the operational context.

Satellite observation systems analyze the atmosphere from a downward-looking vertical perspective, that is, they observe clouds from above. The sensors carried on board the satellites detect the radiation emitted or reflected by the cloud tops, making it possible to estimate parameters such as cloud-top temperature, approximate altitude, horizontal extent, and the degree of organization of meteorological systems.

Because of these characteristics, satellite imagery is particularly effective for identifying areas of active convection, assessing the stage of thunderstorm development, and monitoring large-scale weather systems. However, this type of imagery does not directly depict the internal structure of clouds, nor does it provide a precise indication of precipitation intensity or the vertical distribution of hydrometeors in the lower levels of the atmosphere.

In contrast, the onboard weather radar operates by transmitting electromagnetic pulses ahead of the aircraft, performing a volumetric scan in the horizontal and oblique planes, depending on the selected tilt setting.

The returned echoes result from the reflection of these pulses by hydrometeors, such as rain, hail, and supercooled water, providing a representation of the intensity and distribution of precipitation within meteorological formations. This capability allows the flight crew to assess the internal structure of convective cells, identify high-reflectivity cores, significant reflectivity gradients, and areas potentially associated with severe turbulence, making the onboard weather radar an essential tool for tactical decision-making during flight.

Conversely, the onboard weather radar has limitations inherent to its operating principle, including the reduced detection capability for clouds containing little or no precipitation, signal attenuation in areas of heavy rainfall, the masking of regions located behind highly reflective cores, and its dependence on the correct selection of operational parameters.

Accordingly, while satellite imagery provides a broad, strategic, and predominantly top-down view of meteorological formations, the onboard weather radar offers a forward-looking, detailed perspective of the internal structure of weather systems along the aircraft's flight path.

These perspectives are complementary and, when analyzed in an integrated manner, contribute to enhanced pilot situational awareness and to the mitigation of risks associated with adverse weather conditions, in accordance with the principles of operational safety.

1.19.3. Established Operational Procedures of the Scheduled Air Transport Operator

Chapter 2 – Operational Procedures, under the Seat Belts and Turbulence sections of the Flight Attendants Manual (MCMSV), contained the following information

> 2.23. SEAT BELTS
>
> [Ref.: IOSA]
>
> During taxi, takeoff, and landing, or whenever instructed by the Captain, flight attendants shall remain at their assigned stations with their seat belts and shoulder harnesses securely fastened, except when performing duties related to the safety of the aircraft and its occupants.
>
> When occupying a seat in the flight deck, the flight attendant shall wear the shoulder harness, which shall be fastened:
>
> • before the commencement of pushback and kept fastened until the transition altitude (or 10,000 feet, whichever occurs first);
>
> • before the commencement of the descent and kept fastened until the aircraft is parked; and
>
> • during moderate to severe turbulence.
>
> Passengers shall receive pre-flight instructions on the use of seat belts, as set forth in the Cabin Announcement Manual. Passengers traveling with lap infants shall be instructed to fasten their own seat belt and secure the lap infant in the safest manner possible. Passengers requiring a seat belt extension shall be provided with a seat belt extender and instructed on its proper use. The use of a seat belt extender is prohibited in emergency exit seats, as its full length, when combined with the length of the seat belt, may hinder an evacuation through that exit. If a passenger seated in an emergency exit seat requests a seat belt extender, the flight attendant shall inform the passenger of this restriction and arrange for the passenger to be relocated to another seat, providing the necessary seat belt extender to ensure the passenger's safety throughout the flight.
>
> The FASTEN SEAT BELTS sign shall be illuminated before the aircraft begins surface movement and shall remain illuminated during each takeoff and landing, and at any other time deemed necessary by the Captain.

Immediately before or after the FASTEN SEAT BELTS sign is switched off, passengers shall be advised that, whenever seated, they should keep their seat belts fastened even when the sign is not illuminated.

After the STERILE COCKPIT or NO DEVICE sign has been activated, the Flight Attendant shall make the announcement restricting the use of electronic devices and deactivate the power outlets (if applicable). Flight attendants may, however, perform brief tasks, such as carrying out or concluding the cabin service, optimizing cabin preparation for takeoff or landing, and other activities necessary during the flight. After the FASTEN SEAT BELTS sign has been illuminated, if any passenger fails to comply with the instruction, the Captain shall be notified.

At any time, the Captain may illuminate the FASTEN SEAT BELTS sign whenever turbulence is anticipated, in coordination with the Lead Flight Attendant.

If turbulence is expected to be of such intensity that it may pose a risk of physical injury to persons on board, the FASTEN SEAT BELTS sign may be accompanied by a public address (PA) announcement made by the Captain.

With the FASTEN SEAT BELTS sign illuminated, all Crewmembers and Passengers shall remain seated with their seat belts fastened. Cabin service and any other activities not related to the safety of the aircraft occupants shall be suspended until the Captain switches off the sign. For this reason, and to preserve the credibility of the illuminated sign, Captains should avoid activating it unnecessarily.

In the event of moderate or severe turbulence encountered unexpectedly (e.g., CAT), the cabin crew shall take emergency measures, such as occupying the nearest available passenger seats, with the primary objective of preserving their own safety.

2.23.2. Cabin Check During Cruise with Forecast Turbulence

Whenever it is possible and appropriate to anticipate that the aircraft will pass through an area of moderate or severe turbulence, as well as to estimate when the FASTEN SEAT BELTS sign will be illuminated, the Captain shall inform the Lead Flight Attendant.

The Lead Flight Attendant shall make the prescribed announcement if the Captain has not already provided a PA announcement containing this information.

Flight attendants shall verify that the aircraft occupants have complied with the instruction to fasten their seat belts.

As soon as the FASTEN SEAT BELTS sign is illuminated, flight attendants shall return to their assigned seats and fasten their seat belts as well.

NOTE

This procedure shall be applied only when moderate or severe turbulence can reasonably be anticipated.

...

2.42 TURBULENCE

[Ref.: IOSA]

Turbulence is the movement of air that causes changes in an aircraft's altitude and attitude during flight. These changes may be slight and almost imperceptible. However, turbulence may be severe and result in physical injury to the occupants and damage to the aircraft.

Factors such as warm and cold air masses and fronts, atmospheric pressure, certain types of clouds, jet streams (high-altitude winds), airflow near mountains or structures, and thunderstorms may produce turbulence. According to its intensity, turbulence may be classified as:

• Light;

• Moderate

• Severe

• Extreme.

Light turbulence still permits the continuation of activities such as cabin service. Slight aircraft movements may be experienced, and there is no significant risk to the occupants.

Moderate and severe turbulence are characterized by varying degrees of changes in the aircraft's attitude or altitude. During moderate turbulence, occupants experience discomfort, walking becomes very difficult, and increased pressure is felt from the fastened seat belt. During severe turbulence, walking is virtually impossible, and unsecured persons and loose objects may be thrown about the cabin.

Although rare, extreme turbulence is a real phenomenon. Under such conditions, the aircraft is violently tossed, control of the aircraft becomes virtually impossible, and structural damage may occur.

Moderate or severe turbulence prevent the performance of cabin service and routine duties. They present a significant risk of injury to the aircraft occupants. To reduce the risk of such injuries, the Company's seat belt policy shall be followed. Remember to keep your seat belt fastened whenever:

• the FASTEN SEAT BELTS sign is illuminated

• moderate, severe (or extreme) turbulence is encountered; or

• you are seated.

Whenever turbulence is forecast, the flight crew shall contact the cabin crew and may provide information regarding its expected intensity, duration, and any additional precautions to be taken. Cabin announcements concerning turbulence shall be made in order to enhance the safety of all persons on board.

There is one type of turbulence that is unpredictable and deserves special attention: Clear Air Turbulence (CAT). It cannot be detected by the aircraft's weather radar and may occur at various altitudes, with intensities ranging from light to extreme. To minimize the risk of injury during this type of turbulence:

• always be prepared;

• keep the galley compartments and passenger cabin stowage compartments closed;

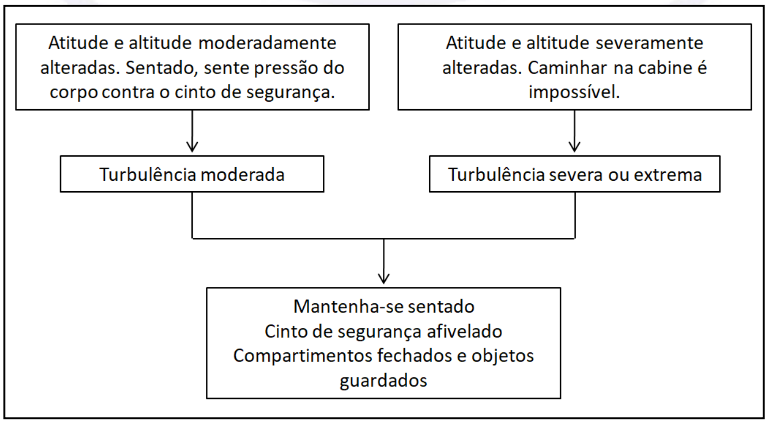
• keep your seat belt fastened whenever seated;

• pay close attention to passengers who are not wearing their seat belts;

• avoid leaving loose objects in the passenger cabin and galley; and

• pay special attention to unaccompanied minors to ensure that their seat belts are fastened.

Compliance with the Company's seat belt policy is an ongoing safety campaign. As a safety measure, keeping seat belts fastened should be regarded as a good habit and practiced consistently. Flight attendants shall check the condition of the passengers and the cabin as soon as the aircraft has exited the area of turbulence and the FASTEN SEAT BELTS sign has been switched off. Depending on the severity of the turbulence and whether seat belts were being worn, first aid may be required.



Algorithm 2-1 – Turbulence Algorithm.

In this situation, Flight Attendants shall consider two factors: the FASTEN SEAT BELTS sign and their own assessment of whether the turbulence is light, moderate, or severe.

If the FASTEN SEAT BELTS sign is illuminated and the turbulence is perceived to be light, establish communication with the flight deck. A passenger with a disability or special need may genuinely need to use the lavatory. Open communication is essential so that the flight attendant can exercise sound judgment in determining how best to ensure the safety of both themselves and the aircraft occupants. Remember that, in this situation, you are not an enforcer. Your objective is to ensure the safety of everyone on board, including your own. Under the Brazilian Aeronautical Code and the Brazilian Aeronaut Law, flight attendants are responsible for the safety of the passengers. This responsibility cannot be delegated or transferred. There is no such concept as, "You may get up during turbulence at your own risk." Whenever in doubt, establish communication to make the safest possible decision.

The Chapter 2 – Operational Procedures, under the Basic Operational Routines and Concepts and Operations in Turbulence Conditions sections of the General Operations Manual (MGO), contained the following information.

B. BASIC OPERATIONAL ROUTINES AND CONCEPTS

FASTEN SEAT BELTS Sign – the sign shall be illuminated before the aircraft begins surface movement, shall remain illuminated during each takeoff and landing, and at any other time deemed necessary by the Captain.

Departure – the FASTEN SEAT BELTS sign shall be illuminated before the takeoff briefing begins, during the final phase of passenger boarding, and shall be switched off upon passing FL100 (10,000 ft) during the climb (or upon leveling off, if the cruise flight level is below FL100 (10,000 ft)).

*At the Captain's discretion, on short flight sectors, the FASTEN SEAT BELTS sign may be switched off after passing the transition altitude in order to facilitate the provision of cabin service.

Immediately before or after the FASTEN SEAT BELTS sign is switched off, passengers shall be advised that, whenever seated, they should keep their seat belts fastened and properly adjusted, even when the sign is not illuminated.

Arrival – the FASTEN SEAT BELTS sign shall be illuminated upon passing the Transition Level during the descent and shall be switched off after engine shutdown.

At any time – the Captain may illuminate the FASTEN SEAT BELTS sign whenever turbulence is anticipated, in coordination with the Lead Flight Attendant. Whenever turbulence is expected to be of such intensity that it may pose a risk of physical injury to persons on board, the FASTEN SEAT BELTS sign shall be accompanied by a public address (PA) announcement made by the Captain:

- “Crew, please remain seated with your seat belts fastened.”

With the FASTEN SEAT BELTS sign illuminated, all crewmembers and passengers shall remain seated with their seat belts fastened. Cabin service and any other activities not related to the safety of the aircraft occupants shall be suspended until the Captain switches off the sign. For this reason, and to preserve the credibility of the illuminated sign, Captains should avoid activating it unnecessarily.

Whenever it is possible to anticipate that the aircraft will pass through an area of moderate or severe turbulence, the Captain shall inform the Lead Flight Attendant of the estimated duration of that condition. The Lead Flight Attendant shall, in turn, make the appropriate announcement to the passengers. Flight attendants shall verify that passengers have complied with the instruction to fasten their seat belts. As soon as the FASTEN SEAT BELTS sign is illuminated, flight attendants shall return to their assigned seats and fasten their seat belts as well.

In the event of moderate or severe turbulence encountered unexpectedly (e.g., Clear Air Turbulence (CAT)), the cabin crew shall take emergency measures, such as occupying the nearest available passenger seats, with the primary objective of preserving their own safety.

...

C.4. OPERATIONS IN TURBULENCE CONDITIONS

[Ref.: FLT 3.11.40]

The *Azul* Company seat belt policy is set forth in Chapter 6.

Turbulence is classified into four levels and four types, as follows:

• Turbulence Levels:

A. Light: conditions less severe than moderate turbulence. Changes in accelerometer readings of less than 0.5 G at the aircraft's center of gravity. Slight discomfort.

B. Moderate: conditions in which moderate changes in the aircraft's attitude and/or altitude may occur, while the aircraft remains under positive control at all times. Airspeed usually varies only slightly. Accelerometer readings change by 0.5 G to 1.0 G at the aircraft's center of gravity. Walking becomes difficult. Occupants feel pressure from their seat belts, and unsecured objects are displaced.

C. Severe: conditions in which abrupt changes in the aircraft's attitude and/or altitude occur. The aircraft may be momentarily out of positive control. Airspeed usually varies significantly. Accelerometer readings change by more than 1.0 G at the aircraft's center of gravity. Occupants experience severe pressure from their seat belts. Unsecured objects are thrown about. Walking is impossible.

D. Extreme: the aircraft is violently tossed, and control of the aircraft becomes virtually impossible. Structural damage may occur.

NOTE

Turbulência severa e extrema devem ser reportadas no TLB para ação de Manutenção. Compulsório o preenchimento do Flight Safety Report (FSR) e, se for o caso, do Cabin Safety Report (CSR). Severe and extreme turbulence shall be recorded in the Technical Logbook (TLB) for maintenance action. Completion of a Flight Safety Report (FSR) is mandatory and, when applicable, a Cabin Safety Report (CSR) shall also be completed.

• Types of Turbulence:

A. Convective: caused by thermal instability and associated with the development of cumulonimbus thunderstorm clouds.

B. Orographic: the natural airflow is disturbed as it moves horizontally over obstacles such as hills, mountains, or buildings. Under certain conditions of atmospheric instability and wind speed, the flow of an air mass across mountainous terrain creates a pattern of stationary waves on the leeward side, known as mountain waves, which may produce severe turbulence. Typical indicators of these waves include lenticular clouds, rotor clouds, and waterfall clouds. The most severe turbulence under these conditions is typically found within rotor clouds.

C. Clear Air Turbulence (CAT): characterized by rapid changes in wind direction and/or speed, producing wind shear, which generates turbulence. It is generally associated with jet streams at altitudes above 15,000 ft.

C.4.1. Turbulence Penetration

Apply the operational procedures prescribed in the AOM/SOP/FCOM for the aircraft.

• General Considerations – flight through cumulonimbus clouds or other areas of severe turbulence should be avoided whenever possible, as it not only causes discomfort to passengers but also exposes the aircraft to damage from hail, lightning, or excessive dynamic loads.

The mutual exchange of significant weather forecasts between flight crews and ATC, together with the careful monitoring of meteorological conditions and their evolution, is of paramount importance for the safe conduct of flight through turbulence-free areas.

Be alert to the presence of cirrus clouds along the route, as they may "conceal" the tops of cumulonimbus (CB) clouds and reduce the effectiveness of the weather radar.

C.4.2. Moderate to Severe Turbulence

• Recommendations: maintain an adequate margin above the stall speed and below the overspeed limit, generally achieved by flying approximately 4,000 ft below the optimum altitude. The aircraft shall initially be properly configured with respect to the turbulence penetration speed and configuration. Avoid flap extension and/or steeply banked turns. The use of the shoulder harness is recommended. Loose objects shall be secured in appropriate stowage locations. Notify the cabin crew, emphasizing the precautions to be taken in the passenger cabin. The FASTEN SEAT BELTS sign shall be illuminated, and passengers shall be instructed accordingly through a public address (PA) announcement. At night, if intense lightning activity is present, the use of white lighting in the flight deck is recommended.

• Piloting Techniques:

A. Automation: the automatic systems (A/P – A/T – F/D) should remain engaged when operating in areas of turbulence. Their proper operation shall be continuously monitored. If necessary, a reduction in the level of automation should be considered.

B. Manual flight: if manual flight becomes necessary, it should be conducted smoothly to avoid imposing additional loads on the aircraft beyond those caused by the turbulence. Select the appropriate thrust setting and maintain the desired attitude, avoiding changes to these settings unless required by significant variations. Apparent fluctuations in altitude and airspeed may be observed due to displacement of the air mass (pressure changes). Trimming during turbulence is not recommended, as the trim setting may become inappropriate.

C. Holding: if it becomes necessary to enter a holding pattern in turbulent conditions, use reduced bank angles and maintain an adequate margin above the stall speed. If moderate turbulence or greater is encountered, relocation to another holding fix is recommended.

D. Radar Use: the weather radar shall be used in all turbulence situations, particularly at night and in IMC (mandatory). Monitor the antenna tilt to ensure that it is appropriate for the phase of flight, even when operating in ACT (Altitude Compensated Tilt) mode. (E-JET).

E. Loss of Control: if the aircraft enters an unusual flight attitude, the pilot shall recover the aircraft by applying the Unusual Attitude, Wake Turbulence, and Stall Recovery procedures, while always taking terrain clearance into consideration.

F. RVSM: flight within RVSM airspace may be adversely affected during turbulence due to the inability to maintain the assigned altitude.

All pilots shall report turbulence conditions encountered, particularly below 1,000 ft above ground level (AGL). They shall also report turbulence conditions that were forecast or reported but not encountered.

1.19.4. Recommended Turbulence Penetration Speed

According to the Airplane Flight Manual (AFM), under severe turbulence conditions during cruise flight, the aircraft should be stabilized at a constant Mach number corresponding to the recommended turbulence penetration speed.

Based on Figure 12, it was found that, at FL380, a speed of Mach 0.80 provides an appropriate balance between structural protection, maintenance of control authority, and preservation of sufficient margin to absorb speed variations resulting from gusts.

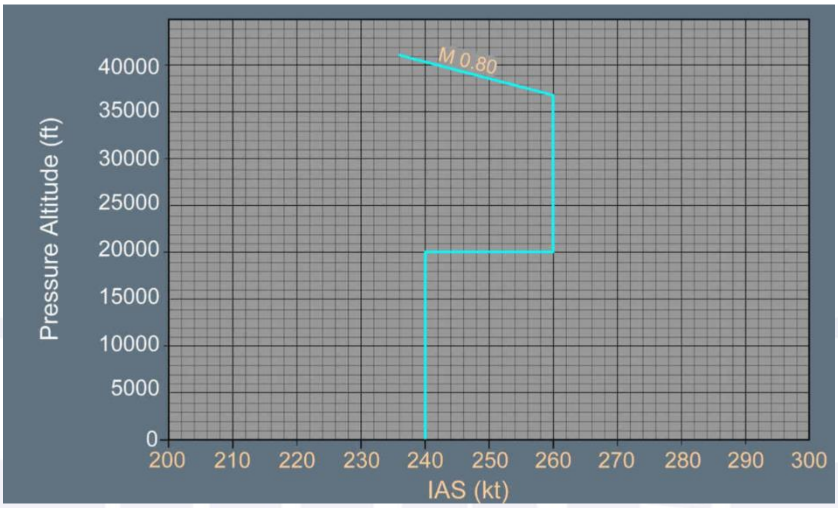


Figure 12 – Recommended Turbulence Penetration Speed.
Source: Airbus.

1.20. Application of other investigation techniques.

NIL.

2. ANALYSIS.

The flight was a scheduled passenger air transport operation conducted under the requirements of RBAC 121, between SBKP and KMCO, with 14 crewmembers and 197 passengers on board.

The SIPAER Investigation Commission found no evidence that physiological factors, incapacitation, or fatigue affected the performance of the flight crew. The post-occurrence interview indicated a low risk of fatigue at the time of the event, with no evidence of sleep deprivation. Likewise, no psychological factors related to the crewmembers that could have contributed to the occurrence were identified.

The operational requirements applicable to the flight crew and the aircraft were in accordance with the applicable regulations.

The navigation aids and communications with air traffic control operated without any abnormalities.

The aircraft was in the cruise phase at FL380, within the *Amazônica* FIR, when the flight crew identified significant weather formations displayed by the onboard weather radar, including magenta echoes consistent with Cumulonimbus and Cumulus Congestus clouds.

In response, a lateral deviation of approximately 10 NM from airway UM417 was coordinated with the *Amazônico* Area Control Center (ACC), a measure consistent with the prescribed procedures for avoiding areas of atmospheric instability. This initial deviation demonstrated that the flight crew was continuously monitoring the weather radar and adopting mitigation strategies from the earliest indications of significant convective activity.

Following the deviation, while returning to the originally planned route, the weather radar displayed areas of light to moderate convective activity, represented by green and yellow echoes. In response, the FASTEN SEAT BELTS sign was illuminated, and the cabin crew instructed the passengers to return to their seats and fasten their seat belts. However, approximately 40 seconds after the seat belt sign was activated, the aircraft abruptly encountered a region of severe turbulence, characterized by intense vertical motion and vertical acceleration peaks of +1.78 G and −0.35 G.

The event resulted in the involuntary disengagement of the autopilot and significant oscillations in vertical acceleration, typical of the strong updrafts and downdrafts associated with high-intensity convection. The analysis of the FDR parameters revealed that the abrupt load factor variations occurred within a very short time interval, consistent with an intense, localized convective phenomenon.

The short interval between the activation of the FASTEN SEAT BELTS sign and the aircraft's entry into the turbulence core indicated that the instability was either developing rapidly or was partially embedded, a condition that may limit the tactical awareness provided by the weather radar, even when the system is operating normally. This characteristic is recognized as typical of tropical convective environments, in which severe turbulence may be present even adjacent to moderate-intensity radar echoes.

Inside the passenger cabin, the sudden variation in load factor threw the occupants who were not wearing their seat belts against the ceiling, resulting in one serious injury and three minor injuries among the passengers. The flight crew, the cabin crew, and the remaining passengers who were seated with their seat belts fastened and properly adjusted remained uninjured.

The statement provided by the seriously injured passenger, who was seated in 25D, indicated that the passenger had removed the seat belt during the meal service and did not fasten it again afterward. Subsequently, the passenger did not notice either the FASTEN SEAT BELTS sign or the cabin announcement because headphones were being used. This individual behavior substantially increased the passenger's exposure to risk during the short interval between the crew's warning and the encounter with the severe turbulence.

The damage to the aircraft was limited to interior components, including the partial displacement of an overhead ceiling panel and the overturning of items in the galley, consistent with the intensity of the event and the impact of passengers being thrown from their seats. No structural damage was identified, and the aircraft remained airworthy, allowing the flight to continue to its originally planned destination.

The investigation identified no technical deficiencies in the aircraft, the weather radar, or the navigation and communication systems. The flight crew had adequate experience on the aircraft type, held valid ratings, and showed no evidence of fatigue or incapacitation. From an operational standpoint, it was verified that the procedures established by the operator were properly followed, including the execution of weather avoidance deviations, continuous weather radar monitoring, the timely activation of the FASTEN SEAT BELTS sign, and appropriate communication with the cabin crew.

Based on the evidence identified by the SIPAER Investigation Commission, it can be concluded that the determining factor in the outcome of the occurrence was the exposure of passengers who were not wearing their seat belts at the time of the abrupt variations in vertical acceleration.

The absence of individual restraint, combined with the abrupt nature of the convective turbulence, constituted the critical link that allowed the observed injuries to occur. Although the flight crew adopted conservative preventive measures consistent with the information available, the short interval between the warning and the encounter with the turbulence limited the effectiveness of those mitigating actions, particularly for passengers who had temporarily removed their seat belts.

The dynamics of the event therefore reflected the combination of three principal elements: the presence of rapidly developing convective instability; the inherent limitations of the tactical weather information provided by the onboard weather radar; and the exposure of occupants who were not wearing their seat belts.

The supplementary data on turbulence-related accidents showed that turbulence events continue to represent a significant operational safety risk in scheduled air transport operations, particularly with respect to the physical safety of aircraft occupants.

Robust statistical data from scheduled air carrier operations in the United States, consolidated by the NTSB in the *Safety Research Report: Preventing Turbulence-Related Injuries in Air Carrier Operations Conducted Under Title 14 CFR Part 121*, demonstrated that the number of turbulence-related injuries remains significant and recurrent, reinforcing the need for measures aimed at mitigating the risk, both by preventing turbulence encounters and by reducing the severity of their consequences.

The importance of the continuous use of seat belts was clearly demonstrated by the data presented. Among the 123 occupants who sustained serious injuries in the turbulence events analyzed, only one was wearing a seat belt at the time of the event.

Additionally, it was found that 83.5% of the injured cabin crewmembers were not wearing their seat belts at the time they sustained their injuries. These findings corroborated the conclusion previously established by the NTSB, namely that keeping the seat belt fastened throughout the entire period in which an occupant remains seated is the most effective measure for mitigating serious injuries in scheduled air transport operations.

In this context, it is essential to increase passenger awareness of the need to comply with the FASTEN SEAT BELTS sign and of the importance of keeping their seat belts fastened whenever they are seated, as well as ensuring the proper stowage of loose items, remaining seated during periods of atmospheric instability, and strictly complying with the instructions provided by the crewmembers.

Another relevant aspect concerns the difficulties associated with the early identification of phenomena such as embedded convection, which cannot always be detected in a timely manner by either onboard or ground-based weather radar systems, despite ongoing improvements in forecasting procedures and detection technologies. In such situations, where the risk is neither predictable nor avoidable, reducing occupants' exposure remains the most effective means of mitigating injuries.

In light of these findings, it is reaffirmed that increasing passenger awareness of the continuous use of seat belts, adopting conservative operational procedures, and improving turbulence detection and warning capabilities constitute key elements in mitigating turbulence-related injuries, as well as in reducing the residual risks inherent in scheduled air transport operations conducted in regions subject to significant convective activity.

3. CONCLUSIONS.

3.1. Findings.

a) the pilots held valid CMAs (Aeronautical Medical Certificates);

b) the pilots held valid A330/A350 type aircraft ratings and instrument ratings (IFRA);

c) the pilots were qualified and had experience compatible with the type of flight conducted;

d) no evidence of fatigue, incapacitation, or physiological factors that could have affected the pilots' performance was identified;

e) the aircraft held a valid Airworthiness Verification Certificate (CVA);

f) the aircraft was within the prescribed weight and balance limits;

g) the maintenance records were up to date;

h) the taxi, takeoff, and climb phases were completed without abnormalities;

i) during the cruise phase of the flight, the pilots coordinated with the *Amazônico* Area Control Center (ACC *Amazônico*) for a right lateral deviation, which was initiated over airway UM417, 215 nautical miles from *Manaus*, state of *Amazonas*, and reached a maximum offset of 10 nautical miles from the planned route;

j) upon returning to the airway, the flight crew identified an area of light to moderate convective activity on the airborne weather radar and illuminated the FASTEN SEAT BELTS sign;

k) the cabin crew instructed the passengers via the PA system to return to their seats and fasten their seat belts;

l) after approximately 40 seconds after the FASTEN SEAT BELTS sign was illuminated, the aircraft abruptly encountered an area of severe turbulence of short duration;

m) the FDR recorded peak positive and negative vertical accelerations of +1.78 G and -0.35 G, respectively;

n) four passengers who were not wearing their seat belts were thrown from their seats and sustained injuries of varying severity;

o) the passenger occupying seat 25D sustained injuries to the right wrist and right elbow, with a suspected fracture, and was assisted on board by an orthopedic physician, who provided temporary immobilization;

p) the passengers occupying seats 26G, 28D, and 35C sustained minor contusions;

q) the airborne weather radar was configured for wind shear and turbulence detections and operated normally, displaying surrounding weather formations consistent with visual meteorological conditions;

r) subsequent testing confirmed the proper performance of the airborne weather radar;

s) the flight continued to the final destination aerodrome, where medical assistance was provided to the passenger who had sustained the most serious injuries;

t) at the hospital, the passenger was diagnosed with a wrist fracture, a compression fracture of the L2 vertebra, and severe lower-back pain;

u) the aircraft was not damaged; and

v) the flight crew, the cabin crew, and the remaining passengers who were wearing their seat belts were uninjured.

3.2. Contributing factors.

- **Adverse meteorological conditions – a contributor.**

The occurrence was directly associated with adverse weather conditions characterized by rapidly developing convective instability at cruising altitude.

Despite the prior identification of convective formations on the weather radar and the execution of a lateral deviation in accordance with operational procedures, the aircraft abruptly encountered an area of severe turbulence, typical of tropical convection and possibly associated with embedded convection.

The short interval between the weather radar indication of moderate convective activity and the encounter with severe turbulence revealed inherent limitations in the airborne weather radar's capability to provide tactical detection in intense convective environments, where abrupt variations in load factor may occur even in areas adjacent to lower-intensity radar echoes.

4. SAFETY RECOMMENDATIONS

A proposal issued by an accident investigation authority based on information derived from an investigation, made with the intention of preventing accidents or incidents, and which in no case has the purpose of creating a presumption of blame or liability for an accident or incident.

In consonance with the Law Nº 7565/1986, recommendations are made solely for the benefit of safety, and shall be treated as established in the NSCA 3-13 "Protocols for the Investigation of Civil Aviation Aeronautical Occurrences conducted by the Brazilian State".

To Brazil's National Civil Aviation Agency (ANAC), it is recommended:

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Disseminate the safety lessons identified during this investigation to operators conducting flights under the requirements of RBAC 121 for incorporation into their operational safety promotion activities, with the objective of enhancing passenger briefings and safety awareness campaigns by emphasizing the importance of keeping seat belts fastened whenever passengers are seated, regardless of weather conditions or whether the "Fasten Seat Belts" sign is illuminated, as well as reviewing and, if necessary, revising cabin announcement procedures during periods of atmospheric instability, thereby increasing the likelihood that safety messages will be perceived by passengers, particularly those wearing headphones or sleeping.

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Disseminate the safety lessons identified during this investigation to the Brazilian Commercial Aviation Safety Team (BCAST) for incorporation into its safety promotion initiatives, with the objective of enhancing passenger briefings and safety awareness campaigns, while emphasizing the importance of keeping seat belts fastened whenever passengers are seated, regardless of weather conditions or whether the "Fasten Seat Belts" sign is illuminated, as well as reviewing and, if necessary, revising cabin announcement procedures during periods of atmospheric instability, thereby increasing the likelihood that safety messages will be perceived by passengers, particularly those wearing headphones or sleeping.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

None.

On August 21th, 2026.