COMANDO DA AERONÁUTICA

CENTRO DE INVESTIGAÇÃO E PREVENÇÃO DE ACIDENTES AERONÁUTICOS

FINAL REPORT
A - 158/CENIPA/2013

OCCURRENCE:	**ACCIDENT**
AIRCRAFT:	**PT-MVL**
MODEL:	**A330-203**
DATE:	**02SEPT2013**

NOTICE

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

The elaboration of this Final Report was conducted taking into account the contributing factors and hypotheses raised. The report is, therefore, a technical document which reflects the result obtained by SIPAER regarding the circumstances that contributed or may have contributed to triggering this occurrence.

The document does not focus on quantifying the degree of contribution of the different factors, including the individual, psychosocial or organizational variables that conditioned the human performance and interacted to create a scenario favorable to the accident.

The exclusive objective of this work is to recommend the study and the adoption of provisions of preventative nature, and the decision as to whether they should be applied belongs to the President, Director, Chief or the one corresponding to the highest level in the hierarchy of the organization to which they are being forwarded.

This Report does not resort to any proof production procedure for the determination of civil or criminal liability, and is in accordance with Appendix 2, Annex 13 to the 1944 Chicago Convention, which was incorporated in the Brazilian legal system by virtue of the Decree nº 21713, dated 27 August 1946.

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

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

N.B.: This English version of the report has been written and published by the CENIPA with the intention of making it easier to be read by English speaking people. Taking into account the nuances of a foreign language, no matter how accurate this translation may be, readers are advised that the original Portuguese version is the work of reference.

SYNOPSIS

This is the Final Report of the 02SEPT2013 accident with the A330-203 aircraft, registration PT-MVL. The accident was classified as "Caused by Meteorological Phenomenon in Flight”.

During the cruise phase over the Atlantic, maintaining the FL400, the aircraft, coming from Madrid, Spain (LEMD) going to Guarulhos, São Paulo (SBGR), entered a severe turbulence area.

Twelve passengers and three crew members were injured, with one flight attendant and two passengers suffering serious injuries.

The aircraft had minor damage.

An Accredited Representative of the NTSB - National Transportation Safety Board, USA, and an Accredited Representative of the BEA - *Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile*, France (State where the aircraft was manufactured) were designated for participation in the investigation.

CONTENTS

GLOSSARY OF TECHNICAL TERMS AND ABBREVIATIONS

ACARS	ARINC Communication Addressing and Reporting System
ACC	Area Control Center
ANAC	(Brazil's) National Civil Aviation Agency
AP	Autopilot
ATS	Air Traffic Services
CA	Airworthiness Certificate
CAT	Clear Air Turbulence
CB	Cumulonimbus
CM	Registration Certificate
CPDL-C	Controller-pilot data link communications
CPTEC	Center for Weather Forecasting and Climate Studies
CRM	Crew Resource Management
DFDR	Digital Flight Data Recorder
DVOLMET	Data link VOLMET
ETOPS	Extended Twin Engine Operations
FIR	Flight Information Region
IFR	Instrument Flight Rules
INFRAERO	Brazilian Airport Infrastructure Company
ITCZ	Intertropical Convergence Zone
LAT	Latitude
LONG	Longitude
LEMD	ICAO location designator – Madrid Aerodrome, Spain
METAR	Aerodrome Routine Weather Report
MLTE	Qualification Type – Airplane Multi-Engine Land
ND	Navigation Display
OPMET	Operational meteorological (information)
PCM	Commercial Pilot Rating - Airplane
PLA	Airline Pilot Rating - Airplane
PF	Pilot Flying
PPR	Private Pilot
PNF	Pilot Not Flying
RANGE	Range of the aircraft radar
RBHA	Brazilian Aeronautical Homologation Regulation
REDEMET	Meteorological Data Network of the Aeronautics Command
RELPREV	Prevention Report
RS	Safety Recommendation
SBGR	ICAO location designator – Guarulhos Aerodrome, SP
SIGMET	Significant Meteorological Information
SIGWX	Significant Weather
SIPAER	Aeronautical Accident Investigation and Prevention System

SPECI	Aviation Selected Special Weather Report
TILT	Inclination angle of the aircraft radar antenna
UTC	Universal Coordinated Time
VFR	Visual Flight Rules

1. FACTUAL INFORMATION.

Aircraft	**Model:** A330-203 **Registration:** PT-MVL **Manufacturer:** *AIRBUS INDUSTRIE*	**Operator:** TAM AIRLINESt
Occurrence	**Date/time:** 02SEPT2013/0254 UTC **Location:** FIR ATLANTIC, NEAR TO FIXED NANIK **Lat.** 06°42'43" N **Long.** 032°59'31" W **Municipality – State:** None	**Type(s):** Caused by Meteorological Phenomenon In Flight" **Subtype(s):** Nil.

1.1 History of the flight.

The aircraft took off from Adolfo Suarez Airport, Madrid-Barajas, Spain (LEMD), to the São Paulo / Guarulhos International Airport - Governador André Franco Montoro, SP (SBGR), in order to perform a commercial passenger transport flight, with 16 crewmembers and 168 passengers on board.

During the cruise phase over the Atlantic, at 0254 a.m. (UTC), keeping the FL400, on the UN741 airfield, near the NANIK position, the aircraft suddenly entered an area of severe turbulence, with presence of Santelmo fire and hail noise.

The crew alternated the landing to Pinto Martins International Airport, Fortaleza, CE (SBFZ), where it landed at 0433 a.m. (UTC), for medical assistance to the wounded ones.

The aircraft had minor damage. Twelve passengers and three crew members were injured, but one flight attendant and two passengers suffered serious injuries.

1.2 Injuries to persons.

Injuries	Crew	Passengers	Others
Fatal	-	-	-
Serious	1	2	-
Minor	2	10	-
None	13	156	-

1.3 Damage to the aircraft.

There were minor damage inside the aircraft, due to the impact of passengers against the top of the passengers cabin (Figure 1).

Figure 1- Damage inside the aircraft.

1.4 Other damage.

Nil.

1.5 Personnel information.

1.5.1 Crew's flight experience.

Hours Flown		
	Pilot	Copilot
Total	11.861:55	4.039:03
Total in the last 30 days	61:00	64:30
Total in the last 24 hours	14:05	14:05
In this type of aircraft	1.712:20	1.757:03
In this type in the last 30 days	61:00	64:30
In this type in the last 24 hours	14:05	14:05

N.B.: The Data on flown hours were informed by the operator.

1.5.2 Personnel training.

The operator formed the commander and the co-pilot on the aircraft.

1.5.3 Category of licenses and validity of certificates.

The commander had the Airline Pilot Rating - Airplane (PLA) and he had valid aircraft and instrument flight (IFR) qualifications.

The co-pilot had a Commercial Pilot Rating - Airplane (PCM) and he had valid aircraft and instrument flight (IFR) qualifications.

1.5.4 Qualification and flight experience.

The pilots were qualified and had experience on this kind of flight.

1.5.5 Validity of medical certificate.

The pilots had valid Aeronautical Medical Certificates (CMA).

1.6 Aircraft information.

The aircraft, serial number 0700, was manufactured by Airbus *Industrie* in 2005 and was registered in the category of Regular Public Air Transport (TPR).

The aircraft had valid Airworthiness Certificate (CA).

The airframe and engine logbooks records were up-to-date.

Maintenance records were up to date.

1.7 Meteorological information.

Due to the characteristics of the accident, it was observed the meteorological conditions prevailing in the region, more specifically the starting point (P1: 06 ° 42'43 "N - 032 ° 59'31" W) and ending (P2: 06 ° 31 ' 50 "N - 033 ° 05'22" W). Positions accurately displayed on the aircraft's flight recorders, covering the period between 02:54 (UTC) and 02:56 (UTC), on 02SET2013 (Figure 2).

According to the Significant Time Forecast Chart (SIGWX) of 0000 UTC (UTC) on 02SEPT2013, with validity from 0900 pm (UTC) from 01SEPT2013 to 0300 am (UTC) on 02SEPT2013, ranging from FL250 (25,000 feet) to FL630 (63,000 feet), an abnormal condition with cumulonimbus clouds (CB), topped in FL520 (52,000 feet) was predicted for the region. This product was updated for access at the Meteorological Data Network (REDEMET) website, at 1147 pm (UTC) on 01SEPT2013 (Figure 2).

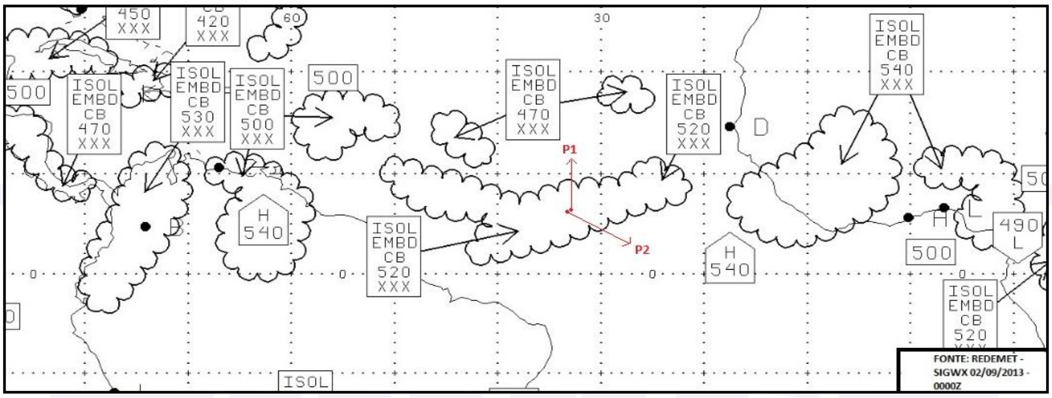


Figure 2 - SIGWX chart of 02SEPT2013, at 00h00min (UTC), where the positions P1 and P2 define the starting and ending sections of the turbulence.

The satellite image of 02SEPT2013, at 0300min (UTC), provided by the Center for Weather Forecasting and Climate Studies (CPTEC) website showed that on the route of the aircraft there were agglomerations and isolated cells of CB, appearing in the vicinity of the abnormal condition region (Figure 3).

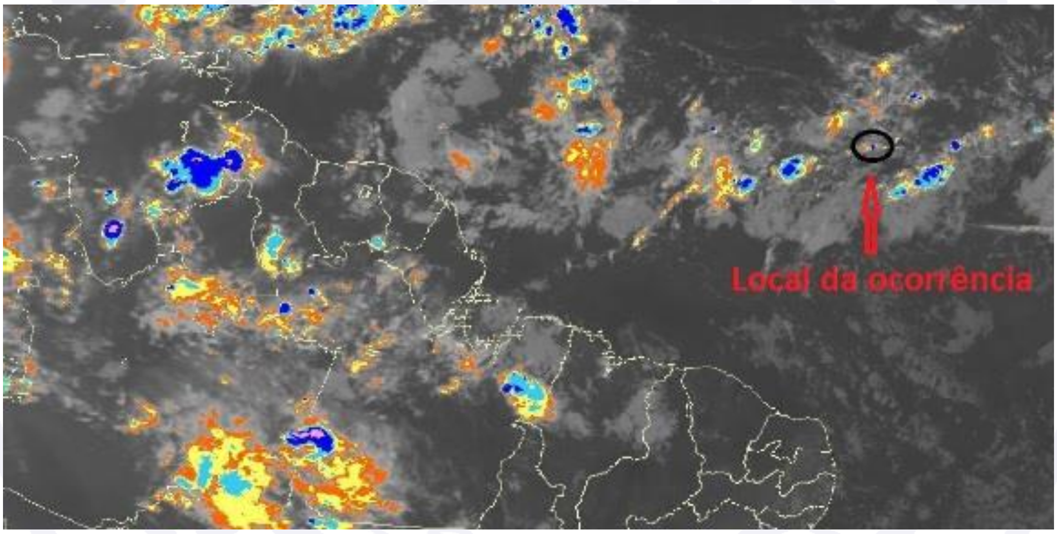
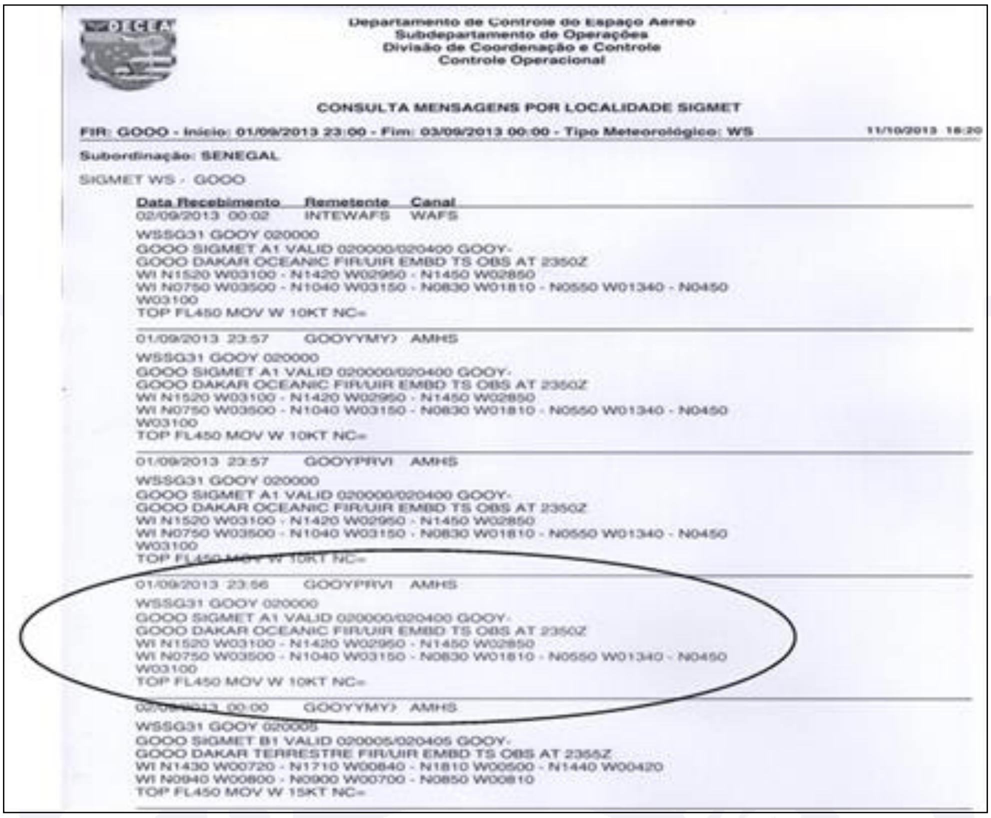


Figure 3 - Satellite image of 02SEPT13, at 0300 (UTC), highlighting the place of the occurrence.

The Meteorological Center responsible for making SIGMET messages to the DAKAR Flight Information Region (FIR) issued an alert of observed thunderstorms, topped in the FL450, valid for the 0000 (UTC) period at 0400 am (UTC) on 02SEPT2013. This alert message entered in the International Weather Data Bank (OPMET) at 1156 (UTC) on 01SEPT2013 (Figure 4).


Departamento de Controle do Espaço Aereo
Subdepartamento de Operações
Divisão de Coordenação e Controle
Controle Operacional

CONSULTA MENSAGENS POR LOCALIDADE SIGMET

FIR: GOOO - Início: 01/09/2013 23:00 - Fim: 03/09/2013 00:00 - Tipo Meteorológico: WS 11/10/2013 18:20

Subordinação: SENEGAL

SIGMET WS - GOOO

Data Recebimento	Remetente	Canal
02/09/2013 00:02	INTEWAFS	WAFS

WSSG31 GOOY 020000
GOOO SIGMET A1 VALID 020000/020400 GOOY-
GOOO DAKAR OCEANIC FIR/UIR EMBD TS OBS AT 2350Z
WI N1520 W03100 - N1420 W02950 - N1450 W02850
WI N0750 W03500 - N1040 W03150 - N0830 W01810 - N0550 W01340 - N0450
W03100
TOP FL450 MOV W 10KT NC=

01/09/2013 23:57 GOOYYMY> AMHS

WSSG31 GOOY 020000
GOOO SIGMET A1 VALID 020000/020400 GOOY-
GOOO DAKAR OCEANIC FIR/UIR EMBD TS OBS AT 2350Z
WI N1520 W03100 - N1420 W02950 - N1450 W02850
WI N0750 W03500 - N1040 W03150 - N0830 W01810 - N0550 W01340 - N0450
W03100
TOP FL450 MOV W 10KT NC=

01/09/2013 23:57 GOOYPRVI AMHS

WSSG31 GOOY 020000
GOOO SIGMET A1 VALID 020000/020400 GOOY-
GOOO DAKAR OCEANIC FIR/UIR EMBD TS OBS AT 2350Z
WI N1520 W03100 - N1420 W02950 - N1450 W02850
WI N0750 W03500 - N1040 W03150 - N0830 W01810 - N0550 W01340 - N0450
W03100
TOP FL450 MOV W 10KT NC=

01/09/2013 23:56 GOOYPRVI AMHS

WSSG31 GOOY 020000
GOOO SIGMET A1 VALID 020000/020400 GOOY-
GOOO DAKAR OCEANIC FIR/UIR EMBD TS OBS AT 2350Z
WI N1520 W03100 - N1420 W02950 - N1450 W02850
WI N0750 W03500 - N1040 W03150 - N0830 W01810 - N0550 W01340 - N0450
W03100
TOP FL450 MOV W 10KT NC=

02/09/2013 00:00 GOOYYMY> AMHS

WSSG31 GOOY 020005
GOOO SIGMET B1 VALID 020005/020405 GOOY-
GOOO DAKAR TERRESTRE FIR/UIR EMBD TS OBS AT 2355Z
WI N1430 W00720 - N1710 W00840 - N1810 W00500 - N1440 W00420
WI N0940 W00800 - N0900 W00700 - N0850 W00810
TOP FL450 MOV W 15KT NC=

Figure 4 - Extract of the inclusion in the SIGMET OPMET Bank of the FIR GOOO (DAKAR OCEANIC) valid between 0000 (UTC) and 0400 (UTC) on 02SEPT13. Focus on the information associated with the area of turbulence.

The FL390 (39,000 ft.) Wind Chart of 0000 (UTC) of 02SEPT2013, valid from 0600 p.m. on 01SEPT2013 to 0600 p.m. on 02SEPT2013, predicted northeast winds with 15 to 20kt intensity, discarding the possibility of severe turbulence in clear sky (CAT). This product was available for access on the REDEMET website at 1704 (UTC) on 01SEPT2013 (Figure 5).

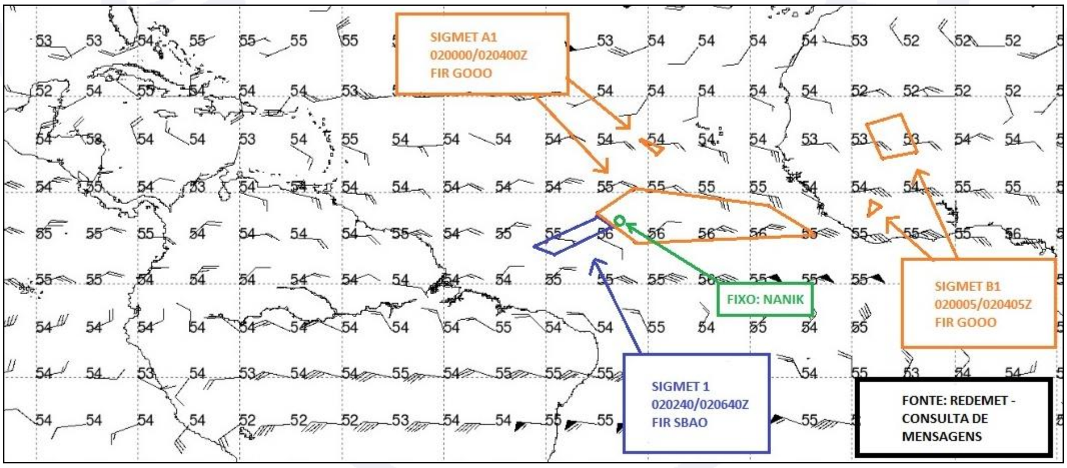


Figure 5 - Wind chart at 0000 (UTC), from FL390.

On 02SEPT2013, between 0230 (UTC) and 0300 (UTC), the ITCZ (Intertropical Convergence Zone) oscillated, in the Atlantic, between coordinates 5 ° N and 12 ° N, with moderate convective activity. The region of the abnormal condition was surrounded by cumulonimbus (CB) cells, predominantly in development / maturity phase (Figure 6).

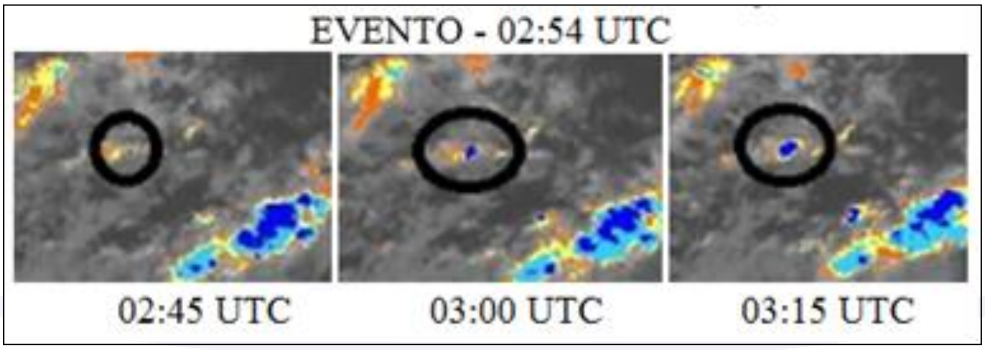


Figure 6 - Satellite images of CPTEC recording the development of cumulonimbus (CB) cells, in the region of the occurrence.

The closest image to the starting and ending time of the event, at 0300 am (UTC) on 02SEPT2013, revealed three main areas that characterized the context of the flight (Figure 7):

- plotted area S1 - an isolated CB cell in full development below the route traced by the aircraft, with tops at 0245 am (UTC), around the FL370, which probably contributed most to the occurrence of severe turbulence through intense ascending currents.
- plotted area S2 - isolated CB cells in development and dissipation in the vicinity of the abnormal condition area; and
- plotted area S3 - well developed CB agglomerations with tops around FL450 - 45,000 feet (they were west of the route but not contiguous to points P1 and P2.

The "S1" area showed considerable development between 0245 (UTC) and 0300 (UTC), that is, it was in the stage of full development, which indicated an area of intense confluence of winds.

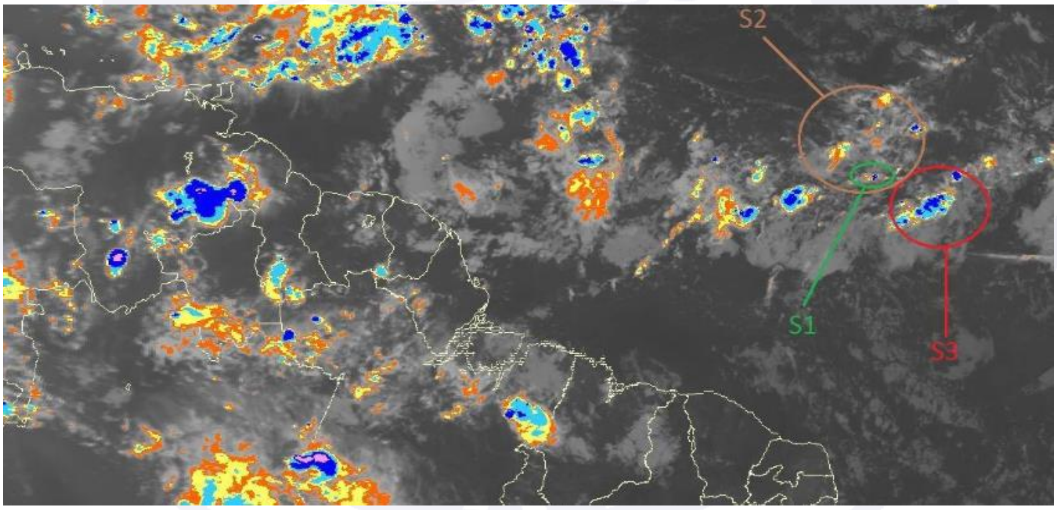


Figure 7 - Satellite Image Chart of 02SEPT2013, at 0300 am (UTC), focused on the reporting positions (S1) and adjacent sectors with CB formations (S2 and S3).

In relation to the humidity present in medium and high levels of the atmosphere, in the image of water vapor of 0300 (UTC), it can be observed that the significant humidity in the region of the abnormal condition was restricted to the CB. It suggests that the aircraft was not inserted into extensive areas of significant cloudiness at the time of the reporting of severe turbulence. This fact clarifies why the crew did not see any formation in the route, when near the place of the event (Figure 8).

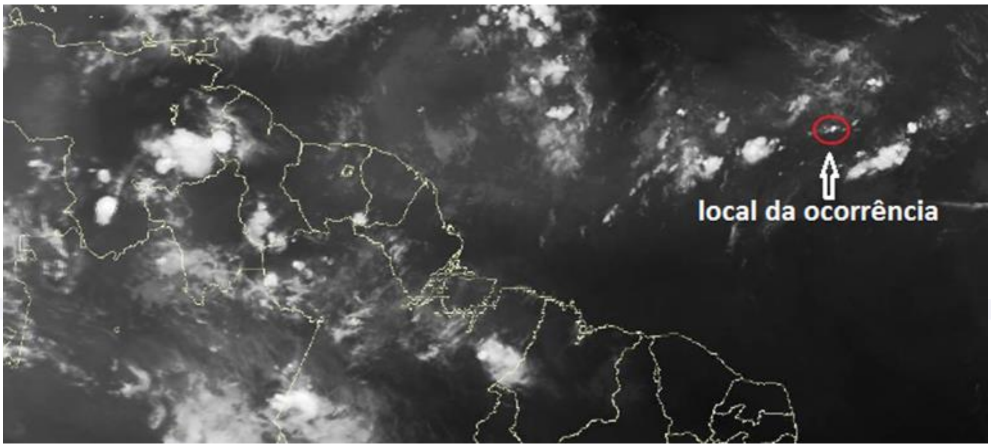


Figure 8 - Satellite image of 02SEPT2013, at 0300Z, in the water vapor image.

With the help of the enhanced image of the CPTEC and the radiosounding of Fernando de Noronha (most representative place of the abnormal condition region), it was possible to infer that its top, at 0245 am (UTC), was around FL370, that is, below (FL 400). It was evolving fast, arriving at 0300 am (UTC), as highlighted by the images shown in Figure 6, close to the flight level of the aircraft.

The data obtained by the recorder of the aircraft corroborate to the fact that the aircraft has been subjected to a rising current of air, coming from the convective movements of a CB in formation just below it. As it can be seen in Figure 9, the external temperature recorded by the aircraft, which was - 59°C, rose suddenly to an average of -52°C.

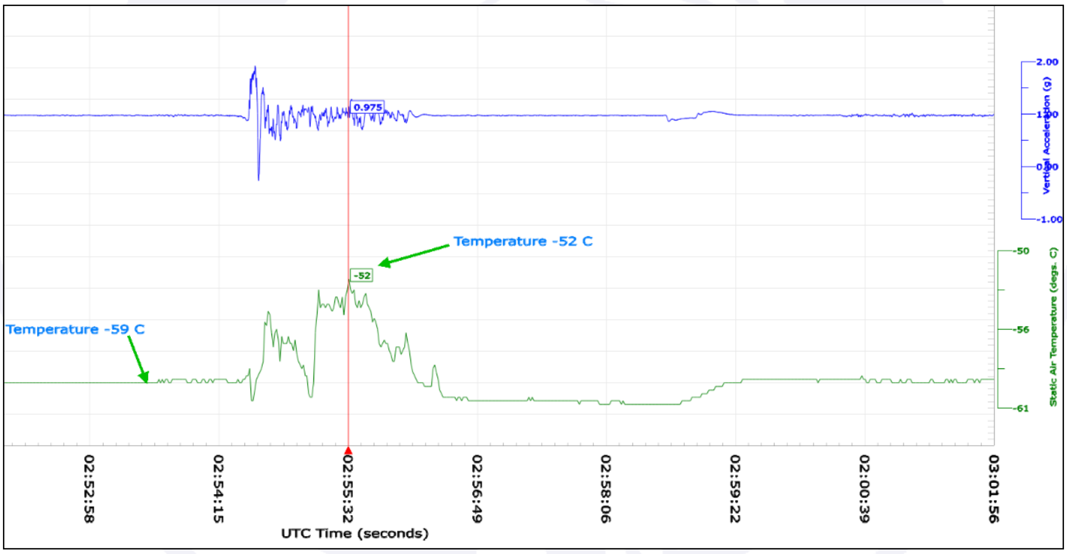


Figure 9 – Graphic of the FDR of temperature variation during turbulence.

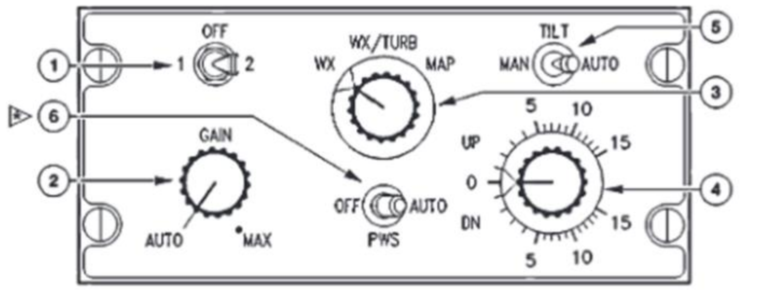
That way, it can be concluded, based on all the evidence described above, that the aircraft, at the moment of the occurrence, was in a region subject to conditions of thunderstorms, ice formation and severe turbulence from 0000 (UTC) on 02SEPT2013, but it was not inserted in extensive areas of significant cloudiness.

1.8 Aids to navigation.

On the day after the event, the antenna and the meteorological radar system of the aircraft were submitted to bench tests, and no discrepancy was observed (Figure 10).

Figure 10-Weather radar antenna scanning operational test.

The aircraft was equipped with Honeywell RDR-4B meteorological radar (Figure 11).



(1) Transceiver 1-2 switch
This switch selects one radar, or turns off both radars.

(2) GAIN knob
This knob adjusts the sensitivity of the receiver.
AUTO : Automatically adjusts the gain to the optimum setting.

(3) Mode selector
WX : Weather mode: Colors indicate the intensity of precipitation (Black indicates the lowest intensity. Green, amber, and red indicate progressively higher intensities)
WX/TURB : The screen displays turbulence areas (in precipitation areas) in magenta (within 40 nm).
MAP : The radar operates in ground mapping mode. Black indicates water. Green indicates ground. Amber indicates cities and mountains.

(4) TILT knob
This knob controls the antenna tilt.

Figure 11 - Honeywell radar control panel installed on the aircraft.

According to the information provided by the pilots, the radar control panel at the time of the accident had the following adjustments:

GAIN: AUTO

- *TILT*: -1° (manual)
- *Mode Selector*: WX
- *Range*: 80NM (*Pilot Flying* - PF) / 160NM (*Pilot Not Flying* - PNF).

However, according to the FDR, the range of the two pilots was set to 80NM.

Aiming to provide additional information on the aircraft's meteorological radar, as well as describe its capabilities and limitations in order to provide a general understanding of the system and consequently help prevent incident occurrences, Airbus issued in 2007 the Flight Operations Briefing Notes - (Adverse Weather Operations - Optimum use of the Weather Radar).

Among the aspects addressed, the publication listed a set of operational and human factors that affected the optimization of the radar use.

The document also emphasized that if the weather radar was not well used or interpreted, it could induce the crew to make a mistake when:

- An area of strong meteorological activity is hidden behind heavy rain;

- The antenna TILT is not set correctly;

- The GAIN is le

ft in the manual position;

- the range selected by the crew in the Navigation Display (ND) is small, so that it is not sufficient to determine if there are adverse formations ahead of the flown trajectory between the clouds; and

- Dry hail provides a weaker eco-radar return than water droplets.

To help optimize the use of radar, Airbus recommended the following adjustments for each flight phase (Figure 12):

Phase	Recommendations	Remarks
Taxi	Set ND to 10 NM range Tilt down, then up: Check appearance / disappearance of ground returns	*Radar check must be performed away from people*
Takeoff	Scan up to 15° UP for weather return, if significant weather is suspected Select tilt at 4° UP for takeoff	*Scan along the departure path*
Climb	Select negative tilt, maintain ground returns on top of ND as the aircraft climbs	*Change tilt according to altitude and ND range.*
Cruise	Select negative tilt and maintain ground returns on top of ND. As a rule of thumb: Range 320: tilt 1 DN Range 160: tilt 1.5 DN Range 80: tilt 3.5 DN Range 40: tilt 6 DN When approaching weather: - Decrease ND range - Tilt down - Use TURB to isolate turbulence - GAIN to AUTO	*No ground returns beyond line of sight* *FL370 => 240 NM* *FL250 => 200 NM*

Figure 12 - Flight Operations Briefing Notes - Radar adjustment recommendations for each flight phase.

In parallel, the airline provided a Supplementary Information - Use of Radar - A330 Flight Crew Training Manual, containing recommendations for the use of the radar.

In this context, the document stated that in order to ensure efficient meteorological radar monitoring, the crew should use the radar TILT effectively, taking into account the flight phase and the reach of the ND and that the TILT would provide a return of the ground at the top of ND. Unlike the manufacturer, the airline did not recommend what would be the ideal TILT to be used at the cruise level (Figure 14).

In order to assist in the selection of an ideal TILT, Airbus presented, in Chapter IV of Flight Operations Briefing Notes - (Optimum use of the Weather Radar), a formula with which the flight crew, flying towards a clouds formation, could obtain an estimate of the vertical cloud expansion above / below the altitude of the aircraft.

The TILT represented the selected inclination so that the image of the airframes would disappear from the radar display.

To illustrate, the simulation below was presented, indicating that the eco-radar would disappear at 40NM away with a TILT of -1°, with the top being located at 4,000ft below the aircraft's flight level (Figure 13).

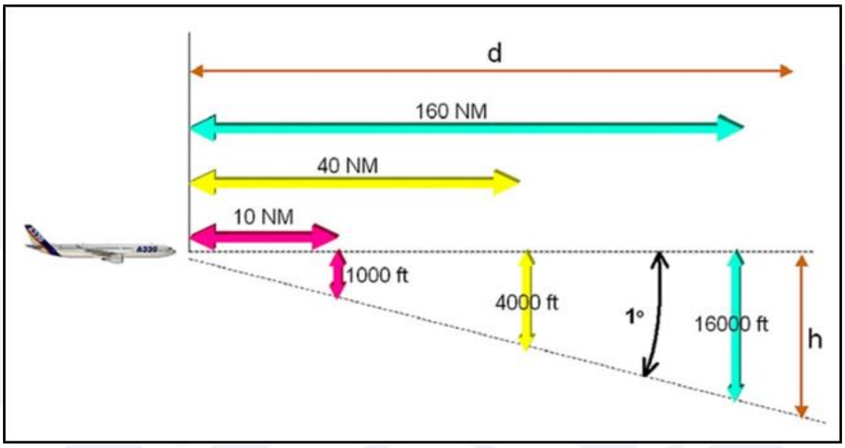


Figure 13 - Relation between distance, TILT and height.

On the other hand, the airline indicated that, for efficient tracking, pilots could select the ranges of 160NM to PNF and 80NM to FP (Figure 14), in order to allow more accurate drifts and minimize the chances of Blind Alley Effect sectors.

OPERATIONAL RECOMMENDATIONS FOR WEATHER DETECTION		
Flight Phase	**Detection and Monitoring**	**Comments**
TAXI	Clear on parking area, set ND to lowest range. Tilt down then up. Check appearance/disappearance of ground returns.	Antenna tilt check (away from people)
TAKEOFF	If weather activity is suspected: slowly scan up to detect weather (Max 15 °up), otherwise: set tilt to 4 ° up	Enables to scan along the departure path
CLIMB	Adjust the ND range as required and decrease the tilt angle as the aircraft climbs	Avoids over scanning of weather
LEVEL FLIGHT/CRUISE	Depending on FL and detection requirement, adjust ND range. Maintain the ground return on the top of the ND Regularly scan the weather vertically by modifying the tilt Once the scan is done, adjust the ground return back on the top of the ND.	In cruise, for efficient weather awareness, the following ranges can be selected: - 160 nm on the PNF ND - 80 nm on the PF ND Shorter ranges can be used to track/avoid closing weather.
DESCENT	During descent, tilt upward to maintain the ground return on the top of the ND.	-
APPROACH	Tilt 4 ° up	Avoids ground return

Figure 14 - Supplementary Information - Use of Radar from the A330 Flight Crew Training. - Airline Manual.

The document also included some recommendations to avoid adverse weather formations, such as alerts on storm height, vertical separation of 5,000ft from formations and considerations regarding airframes exceeding 35,000ft. (Figure 15).

WEATHER AVOIDANCE RECOMMENDATIONS

In the case of a detection of a significant cell or storm, the flight crew should follow the below recommendations:

- To avoid a large storm, the flight crew must make decisions while still 40 nm from it.
- The flight crew should deviate upwind instead of downwind of a cell (less probability of turbulence or hail).
- For storm avoidance planning, the flight crew should consider the height of the storm:
  - Avoid all yellow, red, or magenta areas by at least 20 nm
  - Avoid all green, yellow, red, and magenta areas of cells taller than 28 000 ft by at least 20 nm.
  - Cells exceeding 35 000 ft should be considered extremely hazardous and additional separation (in addition to the 20 nm) should be used.
- If the top of cell is at or above 25 000 ft, overflying should be avoided due to the possibility of encountering turbulence stronger than expected.
- The flight crew should not attempt to penetrate a cell or clear its top by less than 5 000 ft vertically, because otherwise the aircraft may encounter severe turbulence.
- In the same way, the flight crew should avoid flying under a thunderstorm because of possible windshear, microbursts, severe turbulence, or hail.

Figure 15 - Supplementary Information - Use of Radar do A330 Flight Crew Training - TAM Manual- Weather Avoidance Recommendations.

In the same way, the airbus publication - Flight Operations Support & Services - Getting to grips with Surveillance, in item 6.1.1.2, which talked about the reflectivity of storms, emphasized that a storm could be divided into four areas, with the reflexivity degree of each one of them (Figure 16):

- **The turbulence dome** defines an area of very severe turbulence. It can reach several thousand feet above the visible top, when the thunderstorm is growing
- **The upper part above the altitude of −40°C** (if applicable) contains ice crystals only. It reflects a very small portion of the radar pulse. This part may be invisible on the weather radar image whereas it is clearly visible through the windshield
- **The intermediate part from the freezing level up to the altitude of −40°C** contains ice crystals and super-cooled water. The super-cooled water reflects a portion of the radar pulse. Ice crystals absorb the remainder of the radar pulse
- **The lower part up to the freezing level** is the most reflective part of the thunderstorm due to the heavy rain.

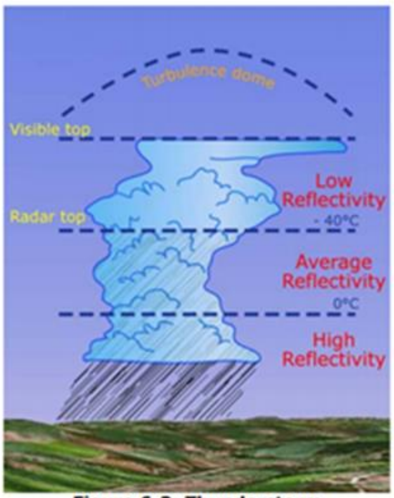


Figure 6-2: Thunderstorm

Figure 16 - Reflectivity degree of the storm.

The part called as turbulence dome defined an area of very severe turbulence. It could reach thousands of feet above the top of the least reflective part of the storm, in the development phase. It is important to note that when the storm was in the maturation phase, the aircraft would still suffer the effects of turbulence, even flying thousands of feet above the clouds.

The Honeywell Company was questioned about the simulation of possible presentations in the radar screen before the characteristics of the cloudiness associated to the event, as a function of the adjustments inserted in the equipment. In this context, the manufacturer of the radar was not able to obtain results, since the information of dimensions and relative position of the aircraft were not sufficiently precise and detailed.

1.9 Communications.

There was no technical problem of communication between the aircraft and the ATC, by the verbal communication, related to the occurrence.

Among the means of communication available to the crew was the ACARS (ARINC Communication Addressing and Reporting System), which consisted of a digital system for sending information between an aircraft and the ground stations, via radio or satellite (data link).

The system enabled the communication with both Air Traffic Control, via Controller Pilot Data Link Communications (CPDL-C) and Flight Operational Dispatcher (DOV), through the Flight Watch service (sending and receiving messages related to the on route meteorology, alternative and destination airports, clearance points, etc.).

The access to this system was unlimited, and within this scope, it was possible that the same thing occurred in several stages of the flight, especially in the transoceanic stages in Extended Twin Engine Operations (ETOPS), where pilots could receive meteorological confirmations for the entire route.

As described in item 1.7 - Meteorological information, the Meteorological Center responsible for making SIGMET messages for the DAKAR Flight Information Region (FIR) issued an alert of observed thunderstorms, topped in the FL450, valid for the period of 0000 (UTC) at 0400 am (UTC) on 02SEPT2013. This alert message entered the International Weather Data Bank (OPMET) at 1156 (UTC) on 01SEPT2013 (Figure 4).

1.10 Aerodrome information.

The occurrence took place outside the Aerodrome.

1.11 Flight recorders.

The following parameters related to the moments prior to the event were extracted from the FDR:

Parameters	Initial	Beginning of the turbulance	Moment of disengagement from AP	Summary
Flight level	FL 400	FL 400	FL 402 climbing	FL 409
Vertical Speed	- 400 ft./min	-500 ft./min	+4.600 ft.	-500 ft./min until 4.601 ft./min
Vertical “G”	+0,9/+1,2	+1,5 increasing	Descending abruptly	-0,27/+1,92
Pitch/Roll	+3,5°/0°	+4,5°/4° (right wing low)	Descending abruptly / -4° (left wing low)	-3,5°/+9°
PF/PNF Radar range	80NM/ARC	80NM/ARC	80NM/ARC	80NM/ARC
Weather Radar Mode	WX	WX	WX	WX

Table 1 - Data extracted from FDR.

In the analysis of the FDR flight data, it was possible to verify that the aircraft faced a region of turbulence, being recorded that, in a certain moment, it was submitted to a load factor that varied between +1.9 G and -0.3 G, corresponding to a variation of 2.2 G in two seconds. During this same time, an intense variation in the ascent rate of up to + 4.601 ft. / min could be observed, causing the aircraft to release FL 400 and reach FL 409 (Table 1).

This substantial variation in Vertical Acceleration, seen on board when the passengers and the flight attendant were thrown against the upper inside part of the aircraft, was the cause of serious injuries suffered by some of the occupants of the aircraft, since they were not buckled.

The FDR revealed that the turbulence lasted approximately 1 minute and 37 seconds, with a maximum intensity of 15 seconds (Figure 17).

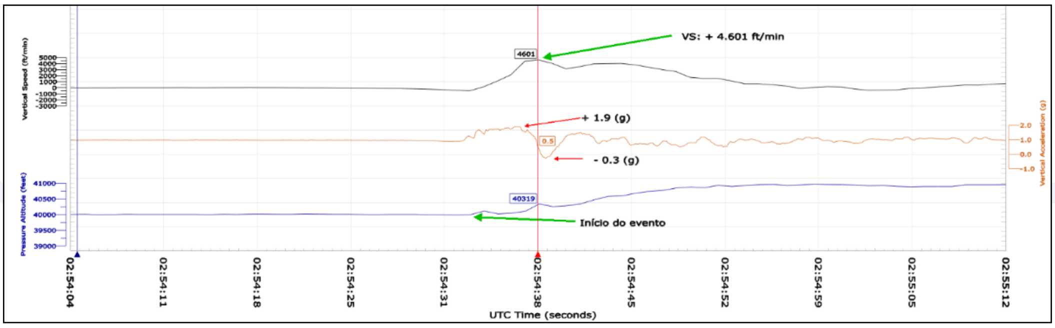


Figure 17 - Variation of the vertical acceleration, load limit, and speed during the event.

Data taken from the FDR show that the aircraft was submitted for about 5 seconds to a strong vertical air current ranging from + 2,000ft / min (down-wind) to -9,300ft / min (up-wind).

1.12 Wreckage and impact information.

There were minor damage to the aircraft due to the impact of passengers on the top of the cabin (Figure 1).

The FDR analysis showed that the structural limits of the aircraft were not exceeded, requiring no maintenance action.

1.13 Medical and pathological information.

1.13.1 Medical aspects.

A single crew member (a flight attendant) suffered serious injuries (fracture of the humerus). Throughout the turbulence, he was securing the service trolley in the rear galley, which prevented him from having time to buckle himself during the event.

In relation to the passengers, two suffered serious injuries. They were two women, who were seated but were not wearing a seat belt. One had a vertical spine fracture, in addition to a dislocation at the elbow. The second had a fractured clavicle and trauma to the spine, skull and thorax. The fracture observed on the clavicle indicated osteosynthesis requiring placement of a blocked reconstruction plaque and 10 (ten) screws.

1.13.2 Ergonomic information.

Nil.

1.13.3 Psychological aspects.

Not searched.

1.14 Fire.

There was no evidence of fire.

1.15 Survival aspects.

Nil.

1.16 Tests and research.

Nil.

1.17 Organizational and management information.

Nil.

1.18 Operational information.

The aircraft was within the weight and balance parameters specified by the manufacturer**.**

According to the FDR, there was a disengagement of the autopilot during the occurrence. This disengagement, considered as involuntary, was confirmed by the message "AP OFF". An involuntary disengagement means that there was no disconnection through the instinctive disconnect push button.

In this context, there were two possibilities that would explain the disengagement:

- Angle of Attack Protection: at the time of disengagement the AoA1 was about + 8 ° and AoA2 at + 10 °; and
- Sidestick input: At the time of disengagement, the Commander's Sidestick input had a pitch angle of 5.1°.

The limits of Sidestick input and Angle of Attack Protection were exceeded, causing the autopilot to disengage. As the disengagement possibilities were within the same time lapse of FDR data updates, it was not possible to define which parameter was first established. It should be noted that, after 6 seconds, the PF re-engaged the autopilot.

According to the crew, the meteorological radar boarded on the aircraft operated normally, so that the surrounding cloudiness presentations of the equipment were reliable under visual flight conditions, as well as the test results of the equipment. Still, according to the report of the commander and co-pilot, seconds before the turbulence, there was no indication of bad weather ahead, based on both the radar screen presentations as well as the eye contact kept with the stars.

The pilots reported that the aircraft suddenly underwent severe turbulence, with the presence of Santelmo fire and hail noise. During the occurrence, the aircraft ascended with a large ratio (4,601 ft. / min) and the pilot tried to control it by means of movements in the Sidestick (Figures 18 and 19), with command applications opposed to the changes of attitudes reflected in the aircraft.

The copilot immediately attempted to activate the "wear belts" button, which was only possible after a few seconds given the amplitude and frequency of the strong movements of the aircraft.

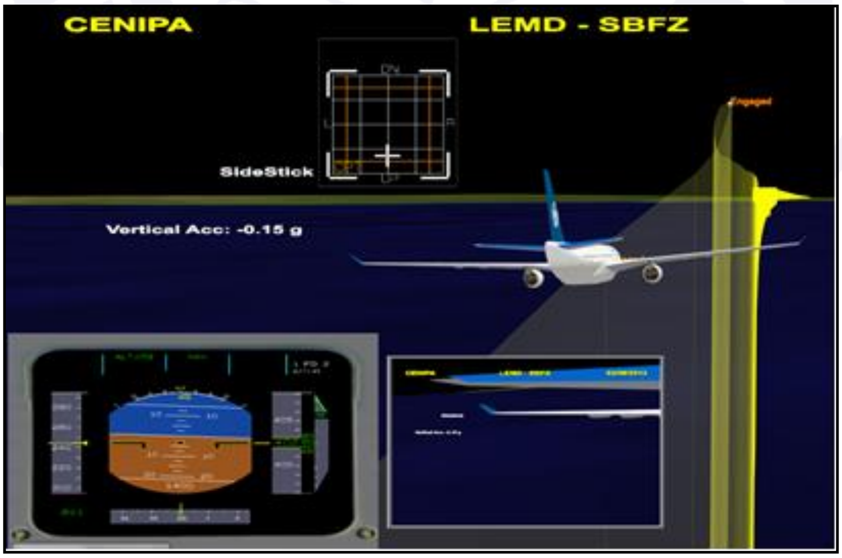


Figure 18 - Sidestick down with the aircraft pitching down.

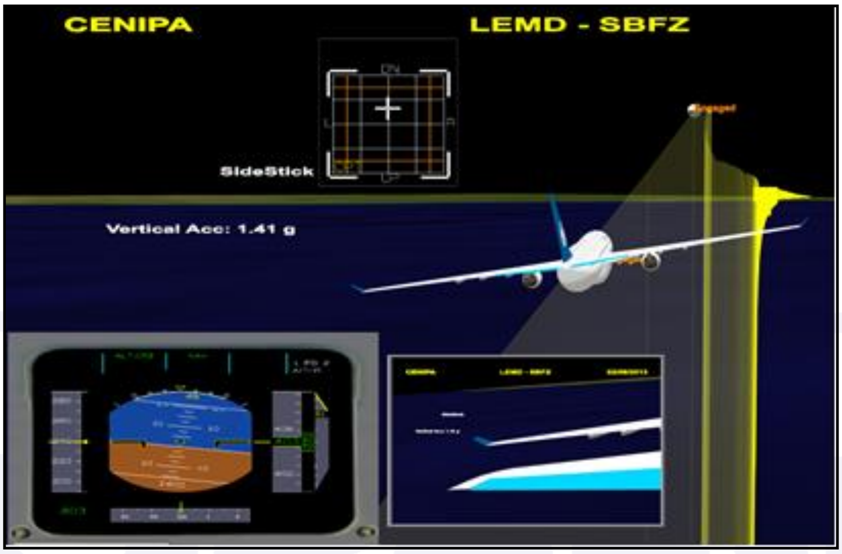


Figure 19 - Sidestick up with the aircraft pitching up.

According to the Flight Crew Operating Manual - Supplementary Procedures - ADVERSE WEATHER - SEVERE TURBULENCE (Pro_Sup 91-10 and FCTM SI-010), during severe turbulence, the autopilot should remain engaged (Figure 20).

TAM A330/A340 FLIGHT CREW OPERATING MANUAL	PROCEDURES SUPPLEMENTARY PROCEDURES ADVERSE WEATHER - SEVERE TURBULENCE

AUTOPILOT/AUTOTHRUST

Applicable to: ALL

Keep the autopilot ON.
When thrust changes are excessive : Disconnect autothrust.
For approach : Use autothrust for managed speed.

Figure 20 - Maintenance guidance of the autopilot coupling during severe turbulence (Pro-Sup-91-10 P 1/6).

However, in case of manual flight, the pilot should not be able to "pursue" the altitude in order to keep the attitude of the aircraft, allowing altitude to vary (Figure 21).

TAM A330/A340 FLIGHT CREW OPERATING MANUAL	PROCEDURES SUPPLEMENTARY PROCEDURES ADVERSE WEATHER - SEVERE TURBULENCE

ALTITUDE

Applicable to: ALL

If the flight crew manually flies the aircraft:

- They can expect large variations in altitude, but should not chase altitude.
- They should maintain attitude, and allow altitude to vary.

Figure 21 - Procedures related to attitude and altitude maintenance in case of manual flight during severe turbulence (Pro-Sup-91-10 P 1/6).

It was also pointed out in the Supplementary Information that the operating logic of aircraft control systems (Control Laws) were properly developed to operate in a turbulence area when the aircraft was piloted manually, so the pilot should avoid the temptation of "fighting" with the turbulence and not overly controlling the Sidestick.

The loading limits of the airplane have not been exceeded, and then no specific maintenance recommendations were required.

1.19 Additional information.

Nil.

1.20 Useful or effective investigation techniques.

Nil.

2. ANALYSIS.

The aircraft took off from *Adolfo Suarez* Airport, Madrid-Barajas, Spain (LEMD), to the São Paulo / Guarulhos International Airport - Governador André Franco Montoro, SP (SBGR), in order to perform a commercial passenger transport flight, with 16 crew and 168 passengers on board.

During the cruise phase over the Atlantic, at 0254 a.m. (UTC), keeping the FL400, on the UN741 airfield, near the NANIK position, suddenly the aircraft was submitted to severe turbulence, with presence of Santelmo fire and hail noise, without any indication of any adverse formation on the radar screen.

Twelve passengers and three crew members were injured, but one flight attendant and two passengers suffered serious injuries.

Both the crew member and the passengers who suffered serious injuries were not wearing seat belts. The injured crewman was standing, working in the galley area during the incident.

The "wear belts" light was not *ON* during the turbulence, since, according to the crew, at the time of the event, there was no indication of bad weather either on the radar navigation display or on the visual observation of the route.

Nevertheless, both in the initial speech of the flight attendants and in the other warnings posted during the flight, the crew warned that the belts should be buckled while the passengers were seated.

In the analysis of the FDR flight data, it was possible to verify that the aircraft faced a region of turbulence, being recorded that, in a certain moment, it was submitted to a vertical load factor that varied between +1.9 G and -0.3 G, corresponding to a variation of 2.2 G in two seconds.

In that same time, an intense variation in the climb rate of up to + 4.601 ft. / min could be observed, causing the aircraft to release the FL 400 and reach FL 409. The aircraft was also submitted, for about 5 seconds, to a strong vertical air current that varied between +2,000 ft. / min (down-wind) and - 9,300 ft. / min (up-wind).

This substantial variation in Vertical Acceleration, seen on board when the passengers and the flight attendant were thrown against the upper inside part of the aircraft, was the cause of serious injuries suffered by some of the occupants of the aircraft, since they were not buckled.

According to the FDR, there was a disengagement of the autopilot during the occurrence. This disengagement, considered as involuntary, occurred due to the overcoming of the limits established for Sidestick input and by factors related to the Angle of Attack Protection. After 6 seconds, the PF re-engaged the autopilot.

The FDR revealed that the turbulence lasted for about 1 minute and 37 seconds, with a maximum intensity in a period of 15 seconds.

In this sense, it is of fundamental importance to approach two fundamental aspects for the analysis of the occurrence. The first relates to the meteorological aspects and the second to the operation of the radar equipment on board the aircraft.

Regarding the meteorological aspects, there was a SIGMET, for the DAKAR Flight Information Region (FIR), alerting to the existence of thunderstorms, topped in the FL450, valid for the period of 0000 (UTC) at 0400 am (UTC) on 02SEPT2013. This alert message entered he International Weather Data Bank (OPMET) at 1156 (UTC) on 01SEPT2013 (Figure 4).

The SIGMET warned about the presence of en route weather phenomena that could affect the operational safety of the aircraft. The access to updates of weather information was available and could be accomplished through Flight Watch.

In fact, on 02SEPT2013, between 0230 (UTC) and 0300 (UTC), the ITCZ oscillated in the Atlantic, between coordinates 5° N and 12° N, with moderate convective activity. The region of the abnormal condition was surrounded by deep convective cells (CB), predominantly in the developmental / maturity phase, as observed in Figure 6. According to *Riehl* (1954, p.183)[1] "upward and downward currents are inherent in this stage of the life cycle of a thunderstorm cell, and in the stage of dissipation." Still, according to *Riehl* (1954, p.159)[2], "an airplane should encounter a scene of turbulence outside the cloud as the airplane approaches it."

Gavin (2008, p.51)[3] pointed out that "when several CB clouds are grouped, that is, close to each other, they resonate with an enormous system of extreme climatic conditions, which feeds itself and can increase the destruction potential of an aircraft ". This self-feeding was evident near the region of the abnormal condition. In the analysis of the satellite images, it was observed that the CB cells developed, dissipated, re-developed and dissipated again, forming a highly unstable and hostile scenario to the flight.

In this context, the prevailing and visible characteristics in the sequencing of images of the METEOSAT satellite (made available by CPTEC) between 0100 am UTC and 0300 am UTC on 02SEPT2013 indicated that the aircraft passed through a "corridor" of deep convective cells. It indicates that it is quite plausible to have been submitted to turbulent air conditions, outside the cloud, caused by the convective movements inherent to areas of instability.

Riehl (1954, p. 128)[4] said that "the growth period is fast, from 10 to 15 minutes and the dissipation lasts longer, sometimes longer than 20 minutes." The author concluded by stating, "it is for this reason that it is more difficult to identify a developing cell than a cell in its mature state or dissipation."

Thus, probably at the time of the reporting, the aircraft was under indirect influence of the systems marked by the areas "S2" and "S3" of Figure 7 and under direct influence of the developing CB cell below the region of the abnormal condition, which evidenced the presence of upward currents, predominant in the route of the aircraft. It is also inferred that the top of the CB could be very close to the level of flight of the aircraft when it suffered the turbulence.

It is important to note that Airbus warned in the publication Flight Operations Briefing Notes (FLT_OPS - ADV_WX - SEQ 07 - REV 02 - FEB 2007) that turbulence is not only associated with flight inside a CB type cloud. It is necessary to take preventive measures to avoid it, such as keeping a vertical separation of at least 5,000ft and lateral of 20 NM of the clouds formation.

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[1] *RIEHL, Herbert; Meteorologia Tropical. Rio de Janeiro: Aliança para o Progresso, 1954, p.183*

[2] *Idem - p.159*

[3] *GAVIN, Pretor-Pinney; Guia do Observador de Nuvens. Rio de Janeiro: Intrínseca, 2008, p.51.*

[4] *RIEHL, Herbert; Meteorologia Tropical. Rio de Janeiro: Aliança para o Progresso, 1954, p.128.*

Turbulence associated with a CB is not limited to inside the cloud. Weather radars cannot detect turbulence in clear air, so it is therefore necessary to take precautionary measures. A CB should be cleared by a minimum of 5.000ft vertically and 20 NM laterally, to minimize the risk of encountering severe turbulence.

According to the commander and co-pilot reports, seconds before the turbulence, there was no indication of bad weather ahead, based on both the radar screen presentations as well as the visual contact with the stars, which indicated absence of clouds. It is therefore important to clarify the reasons why the crew did not detect the presence of such a significant bad weather formation.

This fact is probably related to the use of meteorological radar aboard the aircraft. In this sense, it should be noted that both Airbus and TAM emphasized that for efficient meteorological radar monitoring, the crew should use the radar TILT correctly and effectively.

Airbus indicated that maintaining an adequate radar adjustment was associated with a negative TILT and a ground return at the top of the ND. To do so, it recommended a TILT of -3.5° for a range of 80NM and a TILT of -1.5° for a range of 160NM (Figure 12).

The airline, in turn, although it did not recommend what the ideal TILT for the selected range would be, indicated that the maintenance of an adequate radar adjustment was associated, in addition to the ground return at the top of the ND, to a permanent scanning of the meteorological conditions by means of a TILT change (Figure 14).

Considering that, according to the FDR, the range of the two pilots (PF and PNF) was set to 80NM and that the TILT selected was -1°. It could be inferred that this configuration of the on-board radar did not allow the detection of the CB cloud that was forming at the lower levels (FL 370) of the aircraft (Figure 13).

In order for the cloud to be noted at a distance that would allow the diversion, the ideal TILT, for a range of 80NM, according to the Airbus Flight Operations Briefing Notes, would be -3.5 ° (Figure 12).

At high altitudes, cloud cells may have ice crystals, which provide low reflectivity to the radar (higher reflectivities are present in the lower and middle levels, where water is present in the liquid state).

In this context, an inadequate TILT of the radar could lead to a scan only in the top position of the cloud (where ice crystals predominate), which could lead to a scan of the less reflective part of the bad weather cell, causing it to be underestimated or undetected.

In this sense, and considering that no adverse weather formations were detected or visualized on the radar screen at the time of the accident, it can be deduced that the aircraft would be flying over a cumulonimbus cloud, at FL 400. Its top was estimated in FL 370, in the development / maturity phase, as highlighted in the CPTEC satellite images (Figure 6).

From this, it can be concluded that the following factors may have contributed to the aircraft entering an area of heavy turbulence without any indication in the ND of the weather radar.

- The TILT (1° DN) was not with an ideal angle for the selected range (80NM);

- The aircraft flew over a region subjected to severe turbulence, known as turbulence dome, located above the visible top of a storm formation, of low radar reflexivity and without cloudiness;

- The aircraft did not keep a vertical separation of 5,000ft and a lateral of 20NM from a CB cloud formation, with a top above 35,000ft.

- The cloudiness with more significant humidity (with reasonable reflectivity) was approximately 3,000ft below the aircraft;

- The aircraft would be flying over a cumulonimbus cloud, at FL 400 with its top estimated in FL 370, in the development / maturity phase;

- There was no adequate use of the services provided by Flight Watch to allow the SIGMET message to be known, which alerted to the existence of thunderstorms with top at FL450.

The prevailing meteorology constituted in a critical factor for the event, with characteristics of intense vertical currents of air, great variation of intensity and direction provoked directly by the intense and fast convective process of development of the CB cell. It was located at a less than 20 NM horizontal distance and with cloud tops at approximately 3,000 ft. below the flown route.

Thus, the absence of reflectivity in the turbulence dome section, combined with the settings that were selected in the radar control panel, may have corroborated to the entry of the aircraft into a region of severe turbulence.

3. CONCLUSIONS.

3.1 Facts.

a) the pilots had valid Aeronautical Medical Certificate (CMA).

b) the pilots had valid Technical Qualification Certificate (CHT).

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

d) the aircraft had valid Airworthiness Certificate (CA).

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

f) the airframe and engine logbooks records were up-to-date.

g) near the NANIK position, the aircraft entered a sector of severe turbulence.

h) According to the commander and co-pilot's reports, seconds before the turbulence, there was no indication of bad weather ahead, based on both the radar screen presentations as well as the visual contact with the stars, which indicated absence of clouds;

i) There was an alert of observed thunderstorms, topped in the FL450, valid for the 0000 (UTC) period at 0400 am (UTC) on 02SEPT2013;

j) the region of the abnormal condition was surrounded by deep convective cells (CB), predominantly in the development / maturity phase;

k) The aircraft was in a region subject to conditions of thunderstorms, ice formation and severe turbulence, since 0000 UTC (02SEPT2013), but it was not located in extensive areas of significant cloudiness;

l) the "Wear Belts" light was not *ON* at the beginning of the turbulence;

m)- at the beginning of the severe turbulence, several injured passengers and flight attendants were not with their seat belts fastened;

n) Both, in the initial speech of the Flight attendants and in other notices posted during the flight, the crew reported that the belts should be fastened while the passengers were seated;

o) there was an attempt to control the aircraft through the Sidestick.

p) there was involuntary decoupling of the autopilot;

q) the period of instability lasted about 1 minute and 37 seconds, with a maximum intensity of 15 seconds.

r) the radar control panel, at the time of the accident, was set to a range of 80 NM (PF / PNF), with a TILT of -1°;

s) there was no evidence of a weather radar malfunction;

t) the aircraft had minor damage inside; and;

u) one flight attendant and two passengers suffered serious injuries, as well as two flight attendants and ten passengers suffered minor injuries.

3.2 Contributing factors.

- **Control skills – undetermined.**

The limits of the device entry and the Attack Protection Angle have been exceeded, causing the autopilot to disengage. According to FDR data, the pilot attempted to counteract the effects of the turbulence, with Sidestick applications opposed to the aircraft's attitude changes, which may have contributed to increase the effects caused by turbulence.

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

The prevailing meteorology constituted a critical factor for the event, with characteristics of intense vertical currents of air, great variation of intensity and direction that were provoked directly by the intense and fast convective process of development of the CB cell. It was located at a horizontal distance, less than 20 NM and with cloud tops at approximately 3,000 ft. below the flown route.

- **Other – undetermined.**

- **Radar TILT Adjustment - undetermined.**

The adjustment of the radar control panel to a range of 80 NM (PF / PNF) with a TILT of -1° and the absence of reflectivity in the upper section of the turbulence dome at the time of the accident may have corroborated for the entry of the aircraft into a region of severe turbulence.

4. SAFETY RECOMMENDATION.

A measure of preventative/corrective nature issued by a SIPAER Investigation Authority or by a SIPAER-Link within respective area of jurisdiction, aimed at eliminating or mitigating the risk brought about by either a latent condition or an active failure. It results from the investigation of an aeronautical occurrence or from a preventative action, and shall never be used for purposes of blame presumption or apportion of civil, criminal, or administrative liability.

In consonance with the Law n°7565/1986, recommendations are made solely for the benefit of the air activity operational safety, and shall be treated as established in the NSCA 3-13 "Protocols for the Investigation of Civil Aviation Aeronautical Occurrences conducted by the Brazilian State".

Recommendations issued at the publication of this report:

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

A-158/CENIPA/2013 - 01 **Issued on 10/05/2018**

To disseminate the lessons learned in this report in order to raise the situational awareness of pilots, especially with regard to the identification of areas with adverse weather conditions, as well as the procedures to be adopted to mitigate the risks caused by meteorological phenomena.

Work with the operator to reinforce the appropriate technical procedures for the use of radar and aircraft control in the company's Training Program to avoid areas of severe turbulence.

5. CORRECTIVE OR PREVENTATIVE ACTION ALREADY TAKEN.

None.

On May 10th, 2018.