BEA
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pour la sécurité de l'aviation civile

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REPORT
SERIOUS INCIDENT

Strong turbulence in cruise, momentary loss of control of the flight path by the crew

Aircraft	Airbus A330-200 registered F-GZCG
Date and time	27 February 2012 at 00 h 48[1]
Operator	Air France
Place	In cruise at FL360 over Tanzania
Type of flight	Public transport Scheduled international passenger service
Persons on board	Captain (PF); Co-pilot (PNF)
Consequences and damage	A passenger and a cabin crew member sustained minor injuries

[1] Unless otherwise specified, the times in this report are expressed in Universal Time Coordinated (UTC).

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation. As accurate as the translation may be, the original text in French is the work of reference.

HISTORY OF FLIGHT

Note: The following elements are based on data recorded on the FDR and the Direct Access Recorder (DAR) as well as testimony. The Cockpit Voice Recorder (CVR) recording of the event was not available.

The crew took off from Antananarivo airport (Madagascar) at 22 h 45 bound for Paris Charles de Gaulle.

At 23 h 10, they received an ACARS message describing the 22 h 30 satellite images. They concluded that they would encounter highly convective zones up to parallel 12°30 'S, and that these zones would be more isolated up to DV point (see Figures 1 and 2 below) and, after this point, that they would not encounter any turbulence until parallel 2°30 'S.

Several avoidance manoeuvres were performed when crossing highly convective zones.

Ten minutes after passing parallel 12°30 'S, the pilot flying (PF) changed the range of his navigation display (ND) from 40 NM to 160 NM: the ranges of the two NDs were then set to 160 NM. The crew indicated that the sky was clear with stars visible. They stated that they adjusted the tilt (the angle between the horizontal and the middle of the radar beam) on the weather radar to -1.5° and that they regularly changed this setting as well as the gain[2] setting in order to monitor the cells.

[2] The tilt and gain settings are not parameters that are recorded on the FDR.

While the aeroplane was cruising at FL360, the Dar es Salaam controller asked the crew twice to climb to FL380. The crew refused in order to maintain a sufficient margin in relation to the recommended maximum flight level (REC MAX). Autopilot and autothrust were connected. The flight directors (FD) were displayed. ALT and NAV modes were active and autothrust was in SPEED mode.

Approximately six minutes after passing DV point, the Mach was 0.81 and began to increase. The PF changed the range of the ND from 160 NM to 80 NM and said he selected a -1.5° tilt. He saw a flash and then a cloud on the right side of the aeroplane. He did not see any return on the weather radar screen.

The Mach reached 0.83. The crew selected Mach 0.8 and then 0.78 and extended the speedbrakes for about fifteen seconds. The Mach went down 0.79 and then went back up to about 0.82.

After that the crew saw a flash ahead and then felt strong turbulence. The PNF indicated he was turning on the seat-belt signs requiring the passengers to fasten their seatbelts.

In the turbulence, the angle of attack increased until it led to autopilot disconnection. The PF called out *"AP OFF"* and took over the controls. While passing through the convective zone, the aircraft climbed despite the PF's mainly nose-down inputs.

The autopilot was re-engaged but disconnected automatically. The autothrust disconnected automatically. The PNF, seeing that the PF was very busy maintaining the flight path, decided to disconnect autothrust and selected an N1 value of 90%. He was not aware that the device was already disconnected.

The crew stabilized the aeroplane at FL380, the maximum level reached during the turbulence and began to descend 10 seconds later. The PF re-engaged the autopilot and the rest of the flight was uneventful.

During the severe turbulence, which lasted about forty seconds:

- the pitch attitude varied between -6° and +11°;
- the Mach varied between 0.77 and 0.83;
- the angle of attack was between -0.7 ° and +10.2 °;
- the roll angle was between -16° and +31°;
- the vertical speed reached a maximum value of about +8,500 ft/min;
- the vertical load factor was between +0.02 g and +2.28 g;
- the lateral load factor was between -0.16 g and +0.17 g;
- the flight director cross bars disappeared and reappeared several times;
- the PF mainly applied nose-down inputs (especially for 10 consecutive seconds after the autopilot disconnection).

The manufacturer stated that the aeroplane remained within its flight envelope throughout the entire event.

ADDITIONAL INFORMATION

Meteorological conditions

It was pitch dark and there was no moon.

The weather information available to the crew initially showed the presence of isolated cumulonimbus in the region where the turbulence occurred.

The 00 h 00 SIGWX chart was available in the flight dossier; the flight path specified in the flight plan was indicated on it.

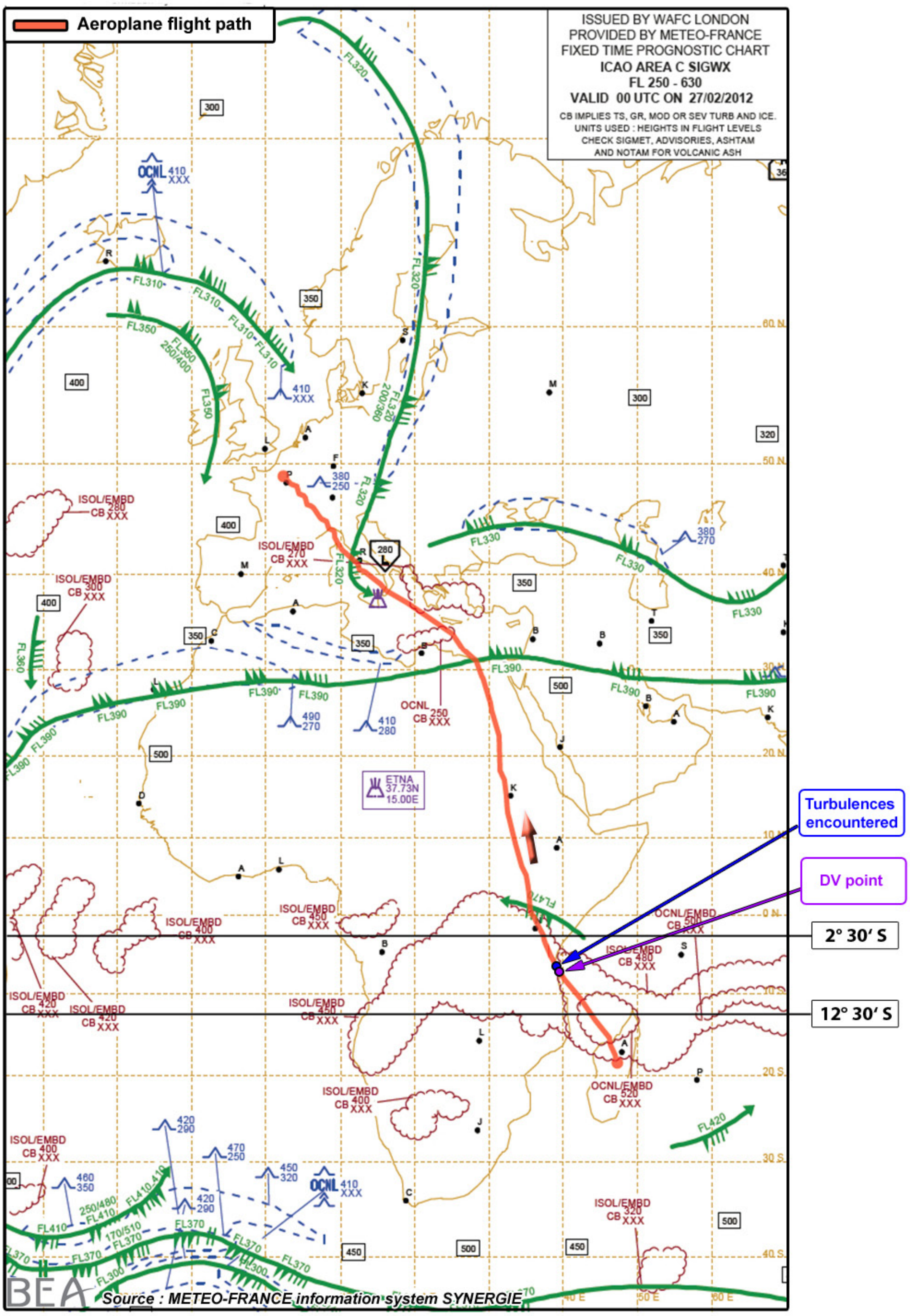


Figure 1: SIGWX chart of 00 h 00

The flight dossier reproduced the information in this chart in the form of text.

Air France flight monitoring

Monitoring of all long-haul flights is ensured by the OCC (Operations Control Centre), in accordance with the *"dispatch reference document"* procedure. This specifically states that *"the dispatcher ensures a continuous watch of the changing aeronautical environment for his entire sector (infrastructure and weather). For each new piece of information, a search for all flights affected is performed. Communications with flight crews are made preferably with ACARS. In addition, messages indicating significant weather phenomena that are sent by crews are analysed and where necessary re-transmitted to the flights likely to be affected."*

The current practice is that the dispatcher also carries out a weather review in the hour after takeoff. This point is not clearly mentioned in the procedures. This is in fact a first contact between the dispatcher and the crews.

Analysis of the weather situation

Phenomenology

The vertical development of a cumulonimbus is generally limited by the tropopause, whose altitude is between the FL500 and FL600 in the inter-tropical convergence zone. When the top of a cumulonimbus in its maturity phase reaches the altitude of the tropopause, the upper part of the cloud extends horizontally to form *"anvils"*.

The air that feeds a cumulonimbus spreads and cools when climbing. When the top approaches the tropopause, it becomes colder than its environment, which stops its vertical development. Through inertia, the most powerful clouds penetrate beyond the tropopause and their tops are then much colder than their environment: this *"overshoot"* phenomenon is visible on infrared images, and it makes it possible to characterise the most powerful clouds.

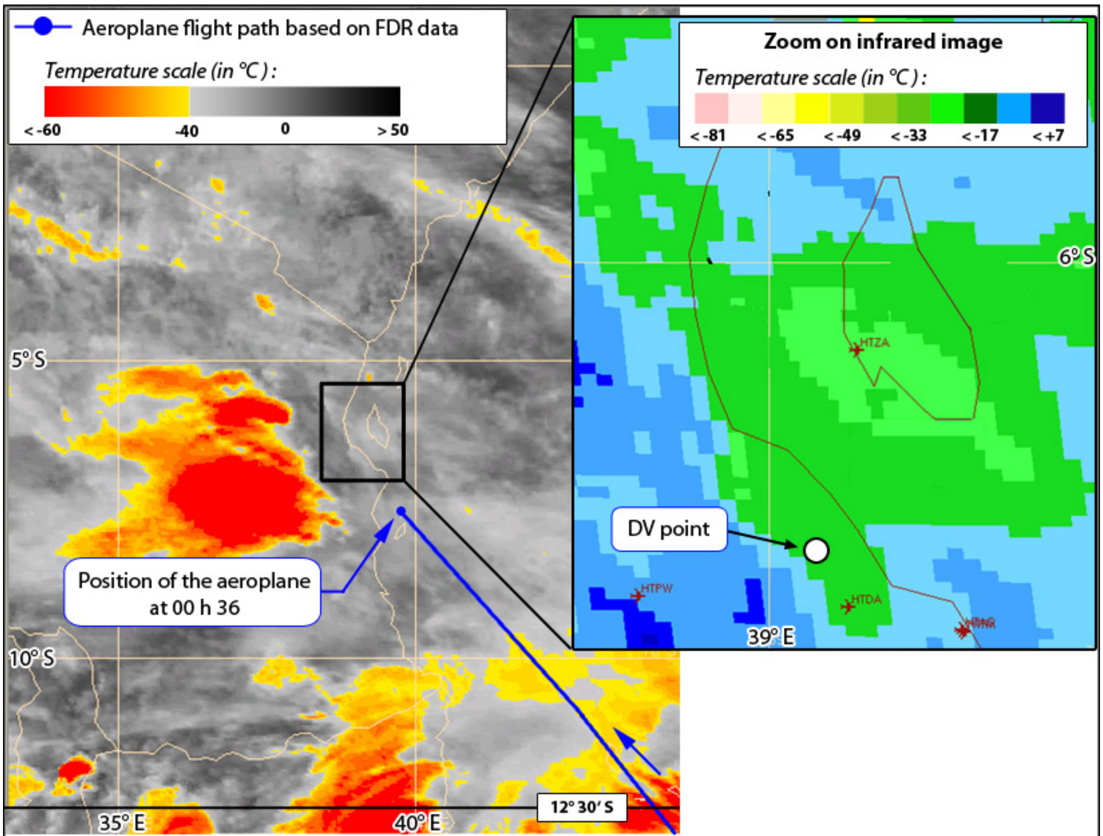
The strongest vertical movements are observed in the *"tower"* of the cumulonimbus in its phase of rapid growth, i.e. before the top reaches the tropopause and the anvil is formed. Upward speeds can then reach 110 km/h and downward speeds 50 km/h. The vertical speed can thus vary very rapidly inside the cumulonimbus while crossing its cloud tower.

Electrical activity can be strong, with the possibility of the appearance of lightning in the phases of growth or maturity of a cumulonimbus, at any altitude. Lightning can appear between the cloud and the ground, within a cloud or between two clouds.

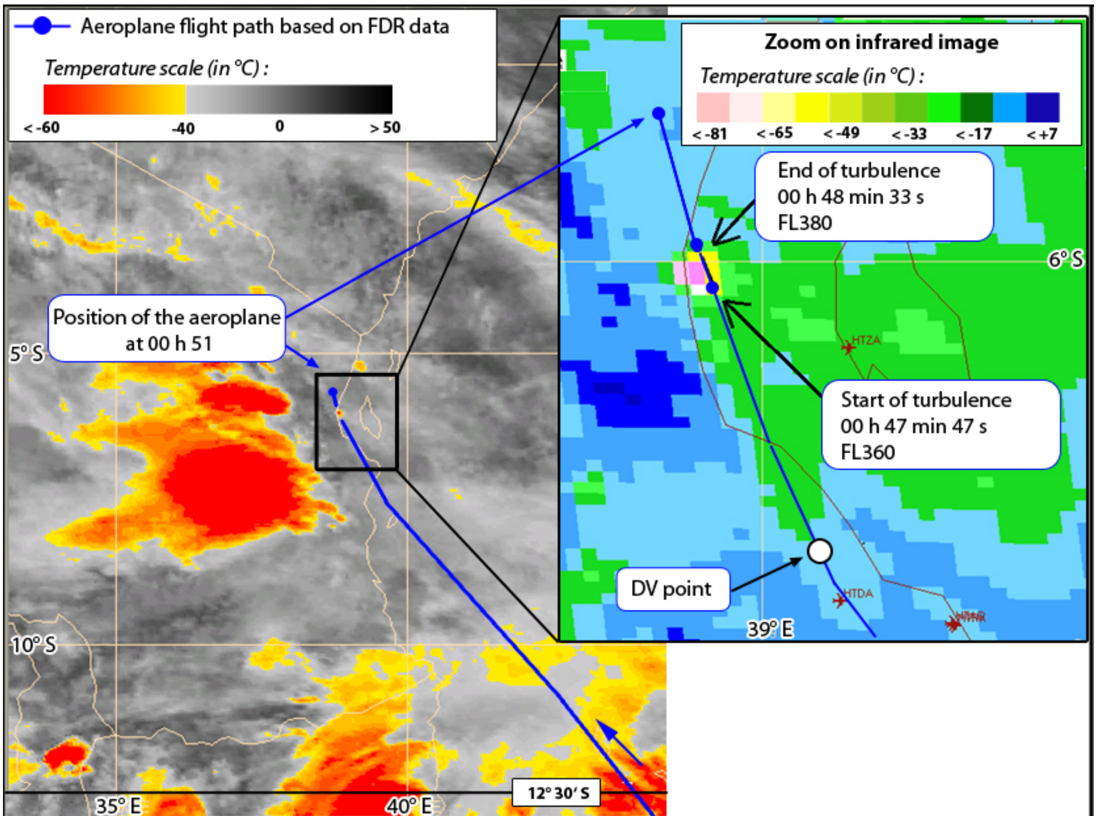
Analysis of the weather situation

The infrared images taken by the Meteosat 9 satellite are available every 15 minutes. They are produced by a satellite scan of the displayed area. This means that the area of the image where the turbulence occurred was scanned by the satellite nine minutes before the time of the infrared image: the turbulent zone flown through by the aeroplane was scanned by the satellite at 00 h 36 (infrared image at 00 h 45) and 00 h 51 (infrared image at 01 h 00).

These images make it possible to assess the temperature of the top of the cloud from which the altitude of the top can be deduced.



Infrared image at 00 h 45, reflecting the meteorological situation at 00 h 36 in the area of the incident



Infrared image at 01 h 00, reflecting the meteorological situation at 00 h 51 in the area of the incident

Figure 2: IR images and position of the aeroplane

On the image corresponding to the situation at 00 h 36, there is cloud cover whose top is located around FL280/300 (dark green). The cell was probably building up, but still undetectable by radar at that time. On the image corresponding to the situation at 00 h 36, cloud tops can be observed between FL360 and FL450 (pink dots). For this reason, the relatively small convective cell is not visible on the image at 00 h 45 but is easily detectable on the image at 01 h 00.

It is therefore a case of particularly rapid development of an isolated thunderstorm cell. The development of this cell into a large convective cluster within a few hours may suggest the presence of strong updraughts and severe turbulence. In addition, this rapid growth could explain the violent phenomena encountered, related to the dynamism and not to the size of the cell.

Weather radar

Weather radar is designed to detect water in liquid form (rain or wet hail). It has difficulty detecting water in solid form, such as ice crystals or dry snow.

The radar image obtained on the ND depends on 3 parameters: the gain, the tilt and the ND range. The tilt adjustment determines the zone scanned by the radar beam. Any cloud located in front of the aeroplane but not swept by the beam remains invisible to the radar. Adjustment of the gain enables it to adapt to the reflectivity of the zones of precipitations encountered.

There are different types of weather radars:

❒ manual radars, whose tilt is adjusted manually by the crew with adjustment common to both NDs;

❒ manual radars whose tilt is adjusted manually by the crew with independent adjustment on each ND;

❒ "*autotilt-type*" radars, whose tilt is adjusted automatically depending on the range, altitude and terrain (using the EGPWS field database);

❒ multiscan-type radars, whose tilt and gain are adjusted automatically according to the geographical position, altitude and season;

❒ fully automatic radars, which permanently store scan data into a three-dimensional volumetric buffer. These radars can be used to display on the ND the weather situation that can be detected at the altitude selected by the crew.

F-GZCG was equipped with Rockwell Collins manual weather radar, whose adjustment is common to both NDs and is thus unique. On this type of radar, the tilt must be adapted to the range of the ND. In cruise, it must be set so that the ground returns only appear within the most distant circles. An Airbus Flight operations briefing note[3] indicates a range of magnitude of values to use in cruise according to the range:

[3]Reference FOBN: FLT_OPS-ADV_WX – SEQ 07 – REV 02 – FEB. 2007.

Range of ND	Tilt (°)
320 NM	-1,0
160 NM	-1,5
80 NM	-3,5
40 NM	-6,0

The operator's instructions recommend using an ND range of 160 NM on standby and 80 NM in an avoidance manoeuvre. In a flight operations briefing note, issued after the event, it was recommended that the PF should use the 80 NM range and the PNF the 160 NM range. The above values are also reproduced.

The operator stated that adjusting the tilt to -3.5° for an ND range of 80 NM is, in practice, only usable during maritime overflight. Overflying land, it is common for such an adjustment to saturate a part of the screen due to the presence of ground returns. The crew stated that, because of the high ground, they received ground returns from -2°.

A common tilt adjustment implies that only one of the two NDs will have an adapted adjustment. Adjustment by default in flight normally corresponds to the 160 NM range. The crew must thus regularly adjust the tilt in order to monitor the ND adjusted to the 80 NM range.

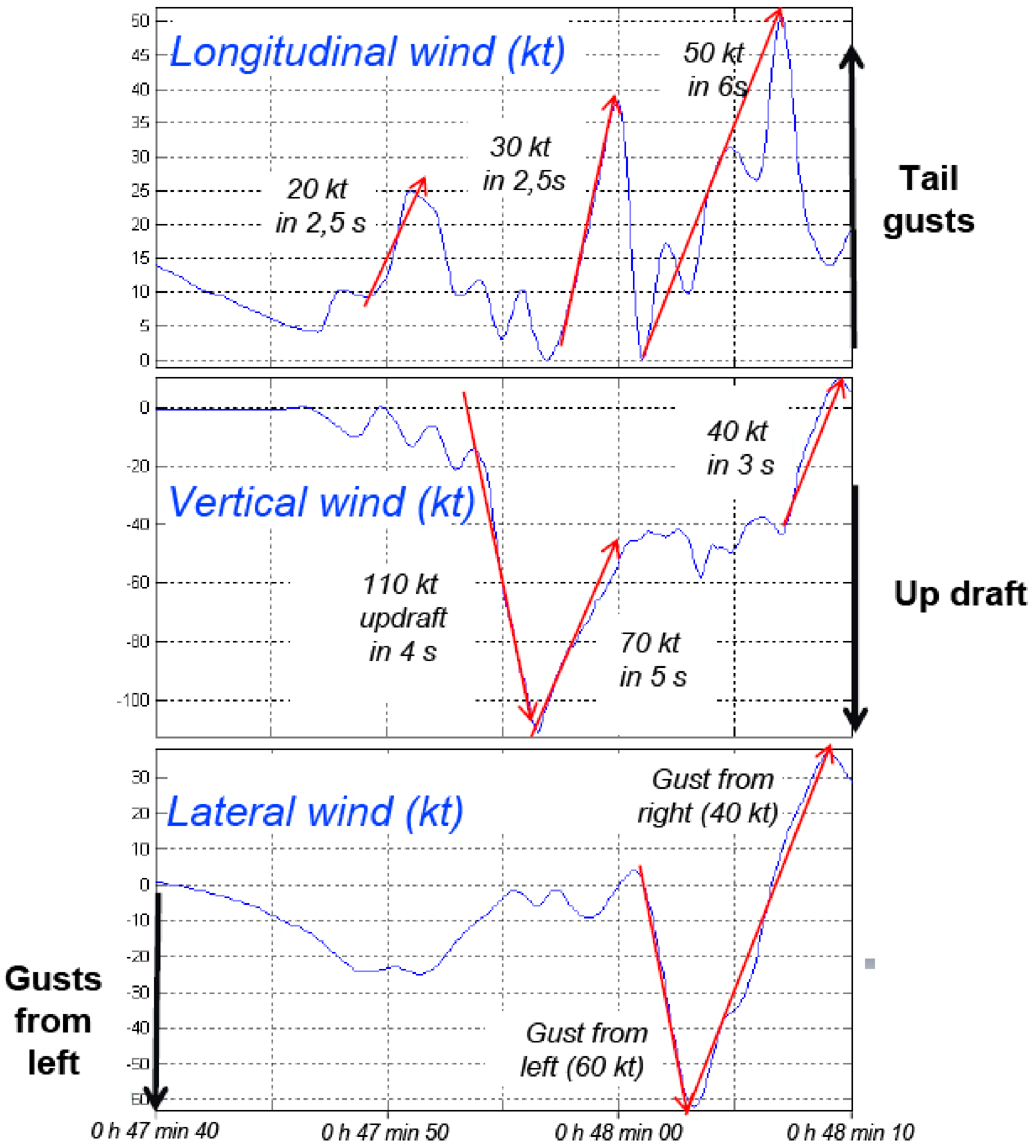
From the position of the centre of the cell, it can be deduced that:

- fifteen minutes before the turbulence, the aeroplane was approximately 120 NM from the centre of the cell. The latter, probably building up, was not detectable by the radar;
- ten minutes before the turbulence, the aeroplane was approximately 80 NM from the centre of the cell. Adjusting the range to 80 NM with a corresponding adjustment of the tilt may have allowed the crew to detect the developing convective cell;
- five minutes before the turbulence, the aeroplane was approximately 40 NM from the centre of the cell. Adjusting the range to 80 NM with a corresponding adjustment of the tilt would probably not have allowed the crew to detect the developing convective cell. Adjusting the range to 40 NM would probably have allowed the crew to detect the cell at that time.

Reconstitution of wind components

The wind components were reconstituted by the manufacturer.

The aeroplane encountered highly dynamic, intense, turbulent phenomena on all three axes.



High angle of attack protection

In manual flying and normal operating conditions, longitudinal control is performed according to the Normal flight control law. Pitch inputs on the sidestick command a load factor. With the sidestick in neutral, wings horizontal, the system maintains a vertical load factor of 1 g in such a way that the flight path is kept constant. Adjustment of the THS is automatic.

In Normal law, when the angle of attack exceeds a threshold called *"Alpha Prot"*, the elevator control changes to a protection mode. The pitch inputs on the sidestick no longer control the load factor but instead the angle of attack, proportionally to the pitch inputs applied. . Whatever the input, the commanded angle of attack cannot exceed a limit called *"Alpha MAX"*.

In clean configuration, the values of *"Alpha Prot"* and *"Alpha MAX"* depend on the Mach and the position of the speedbrakes. Specifically, when the Mach increases as far as MMO (0.86), the value of Alpha Prot decreases. The *"Alpha Prot"* threshold was between 4° and 5° when crossing the turbulent zone.

Functioning of automatic systems

The autopilot, flight director and autothrust functions are ensured by two Flight Management Guidance and Envelope Computers (FMGEC). Each of these two computers can perform the three functions

In normal operation, the AP1 function is ensured by the FMGEC1 and the AP2 function by the FMGEC2. The autothrust function (A/THR) is ensured by priority by the FMGEC associated with the connected autopilot. When the FDs are connected, FD displays the orders from FMGEC 1 on PFD1 (left side) and FD2 displays the orders from FMGEC2 on PFD2 (right side).

To determine the FD cues, the FMGECs use the valid data from at least two ADRs (Air Data Reference) and two IRs (Inertial References). The validity of the data is determined by monitoring any deviations two by two. If monitoring of at least one parameter leads to its invalidity in an ADR, the ADR is considered to be invalid and is no longer used by the FMGECs. The same applies to the IR. If at least two ADRs or two IRs are invalid, the FMGEC can no longer determine the FD cues and the crossbars disappear. However, as long as the FDs are selected on the FCU, the crossbars reappear when the conditions for FD engagement are met again.

If only one of the FMGECs is no longer valid, both PFD FDs display the orders from the other. If the associated autopilot is connected, it will be disconnected automatically. Control of autothrust is automatically transferred to the remaining FMGEC.

If both FMGECs become invalid, the two FDs disappear and the autopilots and autothrust are automatically disconnected, if they had been connected.

Disconnection of automatic systems

- ***First disconnection of the autopilot***

  The autopilot automatically disconnected due to the high angle of attack criteria, and then the high angle of attack protection was activated under manual control. It was activated three times, for a total of eight seconds.

- ***Re-engagement and disconnection of the autopilot***

  The Captain said he tried to re-engage the autopilot, but he thought that he did not manage to do so because of strong shaking due to turbulence. The flight recorder parameters indicated that AP1 was actually re-engaged but only for a very short time (less than two seconds). Analysis of the failures recorded by FMGEC1 showed that AP1 was disconnected because of the rejection of the IRs by the FMGEC1. Control of autothrust was automatically transferred to FMGEC2.

- ***Disconnection of the autothrust***

  Loss of FD2 was recorded almost simultaneously with the disconnection of the A/THR. Analysis of the parameters showed that the disconnection of the autothrust and loss of FD 1 and 2 corresponded to the loss of these functions in FMGEC 1 and 2 following the rejection of IRs by both computers. This means that for two IRs, monitoring of at least one of the IR parameters in the FMGECs detected an invalid element.

It was not possible to determine the reasons for rejection of the IRs by the FMGECs

As from the first disconnection of the autopilot, the repeated losses of both FDs lasted a total of about twenty seconds.

Crew testimony

The Captain said he was surprised by the strong turbulence, which made all flight instruments unreadable, as well as by the intensity of the noise in the cockpit, which resulted in a failure to communicate between the crew. He reported a startle effect followed by a *"state of shock"*.

In addition, he mentioned the sensory illusions which, according to him, made the co-pilot think that the aeroplane was descending while he thought it was climbing.

The co-pilot said he was surprised by the suddenness of the phenomenon. He emphasized the strength of turbulence, which made it impossible to perform routine tasks, and stressed the high level of the aerodynamic noise. He reported focusing on a few parameters (power, attitude and airspeed).

The co-pilot said he was surprised not to have noticed a level bust of more than 2,000 ft because he thought the Captain had managed to maintain the pitch attitude.

LESSONS LEARNED

Weather radar

Use of the radar requires a good knowledge of the structure of cumulonimbus, understanding of the operating principle of radar, active monitoring as well as constant interpretation of the images displayed. Appropriate management of tilt is essential in order to estimate and assess the vertical development of cumulonimbus. Incorrect adjustment can lead to non-detection of such developments.

In the case under consideration the adjustment of the weather radar was not optimised for detecting the convective cell crossed. The two ND ranges were both set to 160 NM though a range set to 80 NM, associated with a proper tilt setting would have been more appropriate.

Nonetheless, the very rapid development of the cell made it difficult to detect: twelve minutes before the incident, it was not visible on the infrared satellite image. It is thus not possible to state with any certainty that optimal adjustment of the radar ND ranges and tilt would have made detection possible.

In addition, in long cruise phases, continuous monitoring by the crew is difficult to imagine. In fact, tilt adjustment common to the two NDs, which was the case on the model installed on F-GZCG, requires regular adjustments by the PF to ensure monitoring of the convective cells on his ND when the ranges used are different.

The BEA issued recommendations on the use of weather radar in its report on the serious incident on 22 July 2011 in cruise at FL350, above the North Atlantic Ocean, involving the Airbus A340-313 registered F-GLZU, operated by Air France:

- *the DGAC ensure that operators provide training and practice to their crews enabling them to improve their use of weather radar. [Recommendation FRAN-2012-023]*

In response to this recommendation, the DGAC said:

- it would study, in conjunction with the FTOs and the TRTOs, the possibility of consolidating initial training on the use of weather radar;
- it would examine, with French airlines involved, the need for further awareness training campaigns on the use of weather radar.

As far as Air France is concerned, reminders about correct use of radar are planned in the three-year review plan of aeroplane systems. In addition, during the 2012-2013 season, this topic is the subject of a specific module including ground training, simulator sessions and line checks.

The BEA also recommended that:

- *the DGAC request that operators check, for example in the context of flight analysis or LOSA, that the use of weather radar is in accordance with procedures or best practices. [Recommendation FRAN-2012-024]*

In response to this recommendation, the DGAC indicated that, in September 2011, they had requested airlines to check that crews had satisfactory knowledge of the functions and could use the onboard radar during line checks. This is the most effective way to increase awareness in this area. The DGAC would evaluate, with the operators involved, additional benefits that could result from flight analysis, or LOSA when implemented

The incident to F-GZCG shows that the type of radar used is also an important criterion for the detection of convective cells, especially when their development is rapid. Installation of a more technologically evolved model would probably have helped the crew to detect this type of cell, though without eliminating the need for active monitoring of the meteorological situation.

Flight monitoring

The CCO provides constant monitoring of weather conditions on the flight paths of aeroplanes. Given the rapid development of the cell and the delay in generating the satellite image, they were not able to alert the crew to the presence of this cell with the tools at their disposal.

The ACARS message sent within one hour after departure confirmed the crew’s conviction that they would not meet a convective cell at this point and did not encourage them to conduct active monitoring of the meteorological phenomena at that time of the cruise.

Crews should therefore be aware that information provided by the OCC is limited and that a constant watch is still needed.

Meteorological information available to crews

The CCO occasionally communicates the general weather situation to crews through short ACARS messages. In other airlines, some aeroplanes are equipped to receive infrared charts via ACARS. This information is then presented on the NDs, superimposed on the aeroplane flight path.

The meteorological analysis showed that such a system would not have been sufficient in this incident, since the thunderstorm cell did not appear on the chart before the aeroplane crossed this area. However, it could be useful in other cases where the storm cell develops earlier or more slowly. This would specifically enhance the situational awareness of crews and therefore increase vigilance and active monitoring of weather phenomena (ND range at 40 NM when necessary).

Furthermore, as indicated in section on *"phenomenology"* lightning is present in cumulonimbus. The crew said they saw flashes on 2 occasions before entering the turbulent zone. In a recent study, the NTSB recommended (ref. A-12-20) displaying lightning strike charts in cockpits.

CONCLUSION

The incident was due to the non-detection of a convective zone during the rapid development of a cumulonimbus cloud in a tropical zone. This zone was all the more difficult to detect because of the extremely rapid development of the cell.

The lack of any onboard means or tools available to the CCO, which would allow more reliable and effective detection of cells that are forming, contributed to the incident. Inappropriate adjustment of the range on the ND meant that the crew did not have optimal detection conditions. Taking into account the extremely rapid development of the storm cell, it is not certain whether such detection may have been possible without active monitoring of the onboard weather radar when approaching the turbulent area.

The crew's appropriate inputs on the flight controls helped maintain control of the aeroplane in flight conditions that had suddenly become very difficult.

RECOMMENDATIONS

Note: In accordance with Article 17.3 of European Regulation (EU) 996/2010 of the European Parliament and Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation, a safety recommendation shall in no case create a presumption of blame or liability for an accident, a serious incident or an incident. The addressee of a safety recommendation shall inform the safety investigation authority which issued the recommendation of the actions taken or under consideration, under the conditions described in Article 18 of the aforementioned Regulation.

Crossing a convective zone with very severe turbulence leads to changes to many parameters (pitch attitude, angle of attack, attitude, speed, vertical speed, load factors, altitude) which, combined with inappropriate actions by a startled crew, can take the aeroplane out of its flight envelope.

This incident showed that the installation of a technologically more advanced type of radar would probably have helped the crew detect the convective cell without, however, neglecting the need for active monitoring of the meteorological situation.

Consequently, the BEA recommends that:

- **DGAC and EASA request that operators study the possibility of deploying existing equipment to their entire fleets; [Recommendation FRAN-2013-055]**

- **EASA and the FAA ensure that aeronautical manufacturers continue their efforts to develop more effective means of detecting convective cells. [Recommendation FRAN-2013-056]**