BEA
Bureau d'Enquêtes et d'Analyses
pour la sécurité de l'aviation civile

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Safety Investigation Following the Accident on 1ST June 2009 to the Airbus A300-203, Flight AF 447

Summary

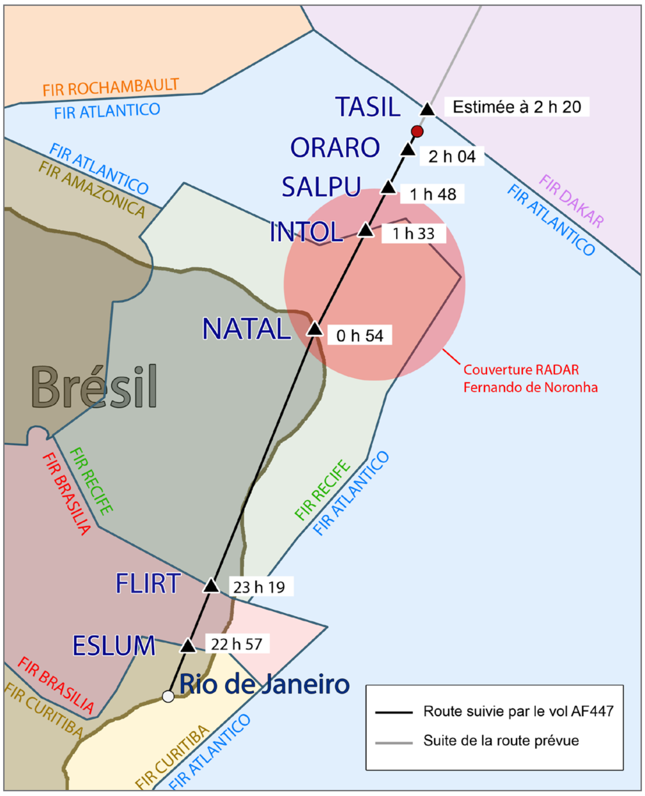
1. The flight as planned

The Airbus A330-203 registered F-GZCP, flight AF447, took off from Rio de Janeiro Galeão airport on 31 May 2009 at 22 h 29[1], bound for Paris Charles de Gaulle, which it should reach after a flight of 10 h 34 min.

The aeroplane was carrying 216 passengers from 32 nationalities, as well as 9 flight attendants and 3 pilots, including a Captain and two co-pilots[2].The fuel on board the aeroplane gave it an estimated autonomy of over 11 hr 30 min.

During the flight, the aeroplane was to fly through the airspace managed by Brazil, Senegal, Cape Verde, Spain (Canary Islands), Morocco, Spain (Madrid) and France. Part of the airspace managed by the Atlantico (Brazil) and Dakar (Senegal) oceanic centres is beyond the range of radar and VHF.

Communication with these two centres is mainly done via HF radio[3], which is the primary means of communication.



The aeroplane was to cross the inter-tropical convergence zone off the coast of Brazil. This area is home to storm phenomena characterised by turbulence and precipitation. The weather situation on the day of the accident was not exceptional for the month of June in this area.

2. Loss of contact with the aeroplane and deployment of SAR services

At 1 h 35, the crew confirmed to the Atlantico controller that they had received a message: this was the last contact between ground and the aeroplane. The aeroplane should then have contacted Dakar ATC before entering its airspace at TASIL point, estimated at 2 h 20[4].

(1) The times in this report are expressed in Universal Time Coordinated. Five hours should be added to obtain Paris time on the day of the flight, and three hours subtracted to obtain Rio de Janeiro time.

(2) The flight crew normally consists of 2 pilots, but it was augmented because of the duration of the flight.

(3) HF communications are frequently disrupted by ionospheric phenomena.

(4) The accident occurred at 2 h 14 min 28.

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At 3 h 45 the next control centre, at Sal (Cape Verde), not seeing the aeroplane on its radar, called the Dakar controller. This was followed by confused exchanges between the various control centres on the aeroplane's route, the associated search and rescue centres and the Air France operations centre. At 5 h 23, the initial search phase, which consisted of collecting information on the flight, was launched by the Atlantico centre, but the Brest centre did not launch the distress phase that triggered the search and rescue operations until 9 h 09, more than six and a half hours after the accident.

The first Brazilian search aircraft took off at 11 h 04. It was followed at 12 h 14 by one Bréguet Atlantique from Dakar, made available to the Senegalese authorities by France.

The bodies of fifty people and the first debris from the aeroplane were found between 6 and 18 June 2009.

3. The investigation up until flight recorder read-out[5]

(5) The history of surface and undersea searches undertaken between the day of the accident and May 2011 is the subject of a separate report.

The only elements available to investigators following the discovery of floating debris and until read-out of the flight recorders in May 2011 came from:

- Information on the aeroplane and crew gathered from the airline;
- The information contained in the 24 maintenance messages (ACARS) automatically transmitted by the aeroplane;
- A message giving the aeroplane position at 2 h 10;
- Examination of the debris.

These initial elements enabled investigators to conclude that:

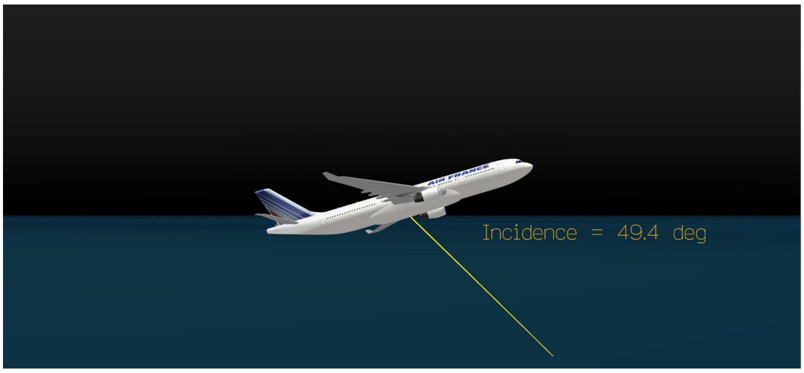
- The aeroplane was intact at the moment of impact;
- It struck the surface of the water with a positive pitch-up attitude, slight bank and a high vertical speed;
- No preparation had been made for ditching;
- No depressurisation had occurred;
- An inconsistency in the measured speeds had occurred shortly after 2 h 10;
- This inconsistency had led to the loss of some automated systems;
- The accident had occurred between 2 h 14 min 26 min and 2 h 15 14.

The obstruction of the Pitot probes by ice crystals was identified as the first in a series of events leading to the accident. However, at this stage, the information available did not make it possible to determine the circumstances of the accident. The localisation of the wreckage and recovery of the recorders were essential to continue the investigation.

It was not until 2 April 2011 that the wreckage was located, near the last known position, at a depth of 3,900 metres, during the fourth phase of underwater searches. The flight recorders were recovered on 1 and 3 May 2011 and were read out on 12 and 13 May 2011 at BEA headquarters. Their read-out made it possible to identify the precise circumstances of the accident. The continuing investigation then focused on the last two hours of flight, broken down into three phases[6]:

(6) See interim report N°3.

- Phase 1: from the beginning of the CVR recording to the autopilot disconnection;
- Phase 2: from the autopilot disconnection to the triggering of the stall warning;
- Phase 3: from the activation of the stall warning to the end of the flight.



Aeroplane attitude in the final seconds of flight

4. Causes of the accident

The blockage of the Pitot probes by ice crystals in cruise was a phenomenon that was known but misunderstood by the aviation community at the time of the accident. From an operational perspective, the resulting loss of all airspeed information was an identified malfunction. After initial reactions involving basic airmanship skills, it was supposed to be diagnosed by pilots, and managed if necessary by precautionary inputs on the pitch attitude and thrust detailed in the associated procedure.

The occurrence of the failure in the context of flight in cruise completely surprised the crew of flight AF 447. The apparent difficulties in handling the aeroplane in turbulence at high altitude resulted in over-handling in roll and a sharp nose-up input by the PF. The destabilisation that resulted from the climbing flight path and changes in pitch attitude and vertical speed therefore added to the incorrect airspeed indications and ECAM messages that did not help any diagnosis. The crew, whose work was becoming disrupted, likely never realised they were facing a «simple» loss of all three airspeed sources.

In the first minute after the autopilot disconnection, the failure of the attempt to understand the situation and the disruption of crew cooperation had a multiplying effect, inducing total loss of cognitive control of the situation. The behavioural assumptions underlying the classification of a loss of airspeed information as «major» were not validated in the context of this accident. Confirmation of this classification therefore requires additional work in terms of operational feedback in order to modify, where necessary, crew training, the ergonomics of the information made available to them, as well as the design of procedures.

The aeroplane went into a sustained stall, signalled by the stall warning and strong buffet. Despite these persistent symptoms, the crew never understood they were in a stall situation and therefore never undertook any recovery manoeuvres. The combination of the warning system ergonomics, the conditions under which pilots are trained and exposed to stalls during their professional and recurrent training, did not result in reasonably reliable expected behaviour patterns.

At present, recognition of the stall warning, even when associated with buffet, assumes that the crew assigns a minimum degree of «legitimacy» to the alarm. This in turn assumes sufficient prior experience with stall conditions, at least some cognitive availability and understanding of the situation, as well as knowledge of the aeroplane (and its protection modes) and its flight physics. A review of pilot training did not provide convincing evidence that the associated skills had been correctly developed and maintained.

More generally, the dual failure of the expected procedural responses shows the limits of the current safety model. When action by the crew is expected, it is always assumed that they will have the capacity to initially control the flight path and to rapidly diagnose and identify the correct entry in the dictionary of procedures. A crew may encounter an unexpected situation causing a momentary but profound loss of understanding. If, in such cases, the assumed capacity to initially control and then to diagnose is lost, the safety model is in «common failure mode». In this occurrence, the inability to initially control the flight path also made it impossible to understand the situation and find the appropriate solution.

Thus, the accident resulted from the following series of events:

- Temporary inconsistency between the measured speeds, likely as a result of the obstruction of the Pitot probes by ice crystals that caused the autopilot disconnection and the reconfiguration to alternate law;
- Inappropriate control inputs that destabilised the flight path;
- The lack of any link, by the crew, between the loss of displayed airspeed information and the appropriate procedure;
- The late identification of the deviation from the flight path by the PNF and insufficient correction applied by the PF;
- The crew not identifying the approach to stall, their lack of immediate response and the exit from the flight envelope;
- The crew's failure to diagnose the stall situation and consequently a lack of inputs that would have made it possible to recover from it.

These events can be explained by a combination of the following factors:

- The lack of effective feedback mechanisms on the part of those involved that made it impossible to:
  - Identify the repeated non-application of the IAS procedure and to remedy this,
  - Ensure that the risk model for crews in cruise included icing of the Pitot probes and its consequences;
- The lack of practical training in high altitude manual aeroplane handling and in the procedure for speed anomalies;
- Task-sharing weakened by:
  - Incomprehension of the situation at the time of autopilot disconnection,
  - Poor management of the startle effect, resulting in a highly charged emotional factor for the two co-pilots;
- The lack of a clear display in the cockpit of the airspeed inconsistencies identified by the computers;
- The crew not taking into account the stall warning, which could have been due to:
  - A failure to identify the aural warning,
  - The appearance at the beginning of the event of brief warnings that could have been considered as spurious,
  - The absence of any visual information to confirm the approach-to-stall after the loss of the characteristic speeds,

- Possible confusion with an overspeed situation in which buffet is also considered a symptom,
- Flight Director indications that may have confirmed the crew's view of its actions, even though they were inappropriate,
- The difficulty in identifying and understanding the implications of the reconfiguration to alternate law with no angle of attack protection.

5. Areas of improvement recommended by the BEA

In addition to the 16 recommendations already issued in Interim Reports N°s 2 and 3, 25 new safety recommendations have now been issued by the BEA.

They include:

- **Crew instruction and training**, in order:
  - To improve crew knowledge of aeroplane systems and changes in their characteristics in degraded or unusual situations,
  - To complete practical crew training and improve the assimilation of theoretical basics, including on performance and flight mechanics,
  - To develop and maintain a crew resource management (CRM) capacity,
  - To improve simulator fidelity for a realistic simulation of abnormal situations;
- **Aeroplane ergonomics**, to provide guidance to crews to help them recognise and manage unusual situations;
- **Feedback mechanisms**, to improve the analysis of the operational risks related to human factors, and change procedures and training content;
- **Surveillance of the operator**, to improve its effectiveness;
- **Deployment of SAR services and localisation of the wreckage**:
  - To accelerate the implementation of reliable means of communication, including in inhospitable areas,
  - To review the organisation of search and rescue operations in case of accidents at sea.

BEA investigations are conducted in accordance with the provisions of Regulation No 996/2010 of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.

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