Interim Report n°3

On the accident on **1st June 2009**
to the **Airbus A330-203**
registered **F-GZCP**
operated by **Air France**
flight AF 447 Rio de Janeiro - Paris

BEA

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

Ministère de l’écologie, du développement durable, des transports et du logement

Foreword

This document presents an update on the progress of the technical investigation as of 29 July 2011. It adds to Interim Reports 1 and 2, published by the BEA on 2 July and 17 December 2009. It contains, in particular, some analysis of the data read out from the flight recorders.

In accordance with Annex 13 to the Convention on International Civil Aviation and with European Regulation n°996/2010, the investigation has not been not conducted so as to apportion blame, nor to assess individual or collective responsibility. The sole objective is to draw lessons from this occurrence which may help to prevent future accidents.

Consequently, the use of this report for any purpose other than for the prevention of future accidents could lead to erroneous interpretations.

SPECIAL FOREWORD TO ENGLISH EDITION

This report has been translated and published by the BEA to make its reading easier for English-speaking people. As accurate as the translation may be, the original text in French is the work or reference.

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Glossary

A/THR	Auto-thrust
ACARS	Aircraft Communications Addressing and Reporting System
ADR	Air Data Reference
AP	Autopilot
EASA	European Aviation Safety Agency
CAS	Calculated Airspeed
CVR	Cockpit Voice Recorder
DGAC	General civil aviation directorate
ECAM	Electronic Centralized Aircraft Monitoring
EFCS	Electronic Flight Control System
ELT	Emergency Locator Transmitter
FAA	US Federal Aviation Administration
FCTM	Flight Crew Training Manual
FD	Flight Director
FDR	Flight Data Recorder
FL	Flight Level
FMGEC	Flight Management Guidance and Envelope Computer
FPV	Flight Path Vector
Ft	Feet
HDG	Magnetic Heading
HF	High frequency
IAS	Indicated Airspeed
ISIS	Integrated Standby Instrument System
kHz	Kilohertz
kt	Knot
N	Newtons
NO	Normal Operation
ICAO	International Civil Aviation Organisation
OCC	Operational coordination centre
PFD	Primary Flight Display
Ps	Static pressure

QRH	Quick Reference Handbook
SSM	Sign Status Matrix
TCAS	Traffic alert and Collision Avoidance System
THS	Trimmable Horizontal Stabilizer
UAS	Unreliable Air Speed
UTC	Universal Time Coordinated
V/S	Vertical Speed

Synopsis

Date of accident

1st June 2009 at 2 h 14 min 28[(1)]

Aircraft

Airbus A330-203
Registered F-GZCP

Site of accident

At reference 3°03'57'' N, 30°33'42'' W, near the TASIL point, in international waters, Atlantic Ocean.

Owner and Operator

Air France

Type of flight

International public transport of passengers
Scheduled flight AF447

Persons on board

Flight crew: 3
Cabin crew: 9
Passengers: 216

Summary

On 31 May 2009, flight AF447 took off from Rio de Janeiro Galeão airport bound for Paris Charles de Gaulle. The airplane was in contact with the Brazilian ATLANTICO ATC on the INTOL – SALPU – ORARO - TASIL route at FL350. At around 2 h 02, the Captain left the cockpit. At around 2 h 08, the crew made a course change of about ten degrees to the left, probably to avoid echoes detected by the weather radar.

At 2 h 10 min 05, likely following the obstruction of the Pitot probes in an ice crystal environment, the speed indications became erroneous and the automatic systems disconnected. The airplane's flight path was not brought under control by the two copilots, who were rejoined shortly after by the Captain. The airplane went into a stall that lasted until the impact with the sea at 2 h 14 min 28.

(1) All times in this report are UTC, except where otherwise specified. Two hours should be added to obtain the legal time applicable in metropolitan France on the day of the event.

INFORMATION ON THE INVESTIGATION

After the publication of the two interim reports, on 2 July and 17 December 2009, the investigation focused essentially on the sea search operations in order to locate the airplane wreckage. Following the first two phases of sea searches undertaken in the weeks following the accident, the BEA launched three new search phases successively:

- Phase 3 took place on site from 2 to 25 April 2010 and from 3 to 24 May 2010. An area of 6,300 km² was covered by means of sonar, without success.

- Phase 4 took place from 23 March to 12 April 2011, using sonar of the same type as some of those used previously. During this campaign, the wreckage of the airplane was located on 3 April, about 6.5 nautical miles north north-east of the last position transmitted.

- Phase 5, to recover the flight recorders, began on 22 April 2011. The Flight Data Recorder (FDR) module was found and brought to the surface on 1 May and the Cockpit Voice Recorder (CVR) on 2 May 2011. The two recorders were taken to Cayenne from 7 to 11 May by a French Navy patrol ship. They were then transported to Paris by airplane and transferred to the BEA's premises on the morning of 12 May. Work on the read-out began in the BEA's premises on 13 May 2011 in the presence of accredited representatives from the CENIPA (Brazil), the NTSB (USA), the AAIB (United Kingdom) and the BFU (Germany). All 1,300 parameters from the FDR were available on 14 May and the read-out of the full 2 hours of CVR recordings was carried out on 15 May 2011.

- As soon as the recorders were recovered, operations continued with the recovery of airplane parts useful to the investigation, then the recovery of the human remains found at the accident site. Phase 5 ended on 16 June with the arrival of the cable vessel transporting the human remains and airplane parts in the port of Bayonne. The human remains were transported to the Villejuif forensic institute for identification. The airplane parts were transferred to the French General Armament Directorate (DGA) hangars in Toulouse for examination.

At the end of the first analysis of the recorders, the BEA published a note which described factually the sequence of events that led to the accident and presented new findings.
Interim report 3 presents all the information available to date. It also contains the first analysis points and new findings.

Ten new Safety Recommendations are included. They relate to:

- Operations,
- Certification,
- Flight recorders,
- Transmission of flight data.

Publication: 29 July 2011

1 - FACTUAL INFORMATION

1.1 History of Flight

On Sunday 31 May 2009, the Airbus A330-200 registered F-GZCP operated by Air France was programmed to perform scheduled flight AF447 between Rio de Janeiro Galeão and Paris Charles de Gaulle. Twelve crew members (3 flight crew, 9 cabin crew) and 216 passengers were on board. The departure was planned for 22 h 00.

Towards 22 h 10, the crew was cleared to start up engines and leave the stand. Takeoff occurred at 22 h 29. The Captain was PNF, one of the copilots was PF.

The takeoff weight was 232.8t (for an MTOW of 233 t), including 70.4 tonnes of fuel.

At 1 h 35 min 15 ❶, the crew informed the ATLANTICO controller that they had passed the INTOL point then announced the following estimated times: SALPU at 1 h 48 then ORARO at 2 h 00. They also transmitted the SELCAL code and a test was undertaken successfully.

At 1 h 35 min 46, the controller asked the crew to maintain FL350 and to give their estimated time at TASIL.

Between 1 h 35 mn 53 and 1 h 36 mn 14, the controller asked again three times for the estimated time at TASIL with no response from the crew. There was no more contact between the crew and ATC.

At 1 h 55, the Captain woke the second copilot and said " *[…] he's going to take my place*".

Between 1 h 59 min 32 and 2 h 01 min 46 ❷, the Captain attended the briefing between the two copilots, during which the PF said, in particular "*the little bit of turbulence that you just saw we should find the same ahead we're in the cloud layer unfortunately we can't climb much for the moment because the temperature is falling more slowly than forecast"* and that "*the logon with Dakar failed*". Then the Captain left the cockpit.

The airplane approached the ORARO point. It was flying at flight level 350 and at Mach 0.82 and the pitch attitude was about 2.5 degrees. The weight and balance of the airplane were around 205 tonnes and 29% respectively. Autopilot 2 and auto-thrust were engaged.

At 2 h 06 min 04, the PF called the cabin crew, telling them that "*in two minutes we should enter an area where it'll move about a bit more than at the moment, you should watch out*" and he added "*I'll call you back as soon as we're out of it*".

At 2 h 08 min 07 ❸, the PNF said "*you can maybe go a little to the left […]*. The airplane began a slight turn to the left, the change in relation to the initial route being about 12 degrees. The level of turbulence increased slightly and the crew decided to reduce the speed to about Mach 0.8.

At 2 h 10 min 05 ❹, the autopilot and auto-thrust disengaged and the PF said "*I have the controls*". The airplane began to roll to the right and the PF made a nose-up and left input. The stall warning sounded twice in a row. The recorded parameters show a sharp fall from about 275 kt to 60 kt in the speed displayed on the left primary flight display (PFD), then a few moments later in the speed displayed on the integrated standby instrument system (ISIS).

Note: Only the speeds displayed on the left side and on the ISIS are recorded on the FDR; the speed displayed on the right side is not recorded.

At 2 h 10 min 16, the PNF said “*we've lost the speeds then” then* ”*alternate law protections*”.

The airplane’s pitch attitude increased progressively beyond 10 degrees and the plane started to climb. The PF made nose-down control inputs and alternately left and right roll inputs. The vertical speed, which had reached 7,000 ft/min, dropped to 700 ft/min and the roll varied between 12 degrees right and 10 degrees left. The speed displayed on the left side increased sharply to 215 kt (Mach 0.68). The airplane was then at an altitude of about 37,500 ft and the recorded angle of attack was around 4 degrees.

From 2 h 10 min 50, the PNF tried several times to call the Captain back.

At 2 h 10 min 51, the stall warning triggered again. The thrust levers were positioned in the TO/GA detent and the PF maintained nose-up inputs. The recorded angle of attack, of around 6 degrees at the triggering of the stall warning, continued to increase. The trimmable horizontal stabilizer (THS) began a movement and passed from 3 to 13 degrees pitch-up in about 1 minute and remained in the latter position until the end of the flight.

Around fifteen seconds later, the speed displayed on the ISIS increased sharply towards 185 kt; it was then consistent with the other recorded speed. The PF continued to make nose-up inputs. The airplane’s altitude reached its maximum of about 38,000 ft, its pitch attitude and angle of attack being 16 degrees.

At around 2 h 11 min 45 ❺, the Captain re-entered the cockpit. During the following seconds, all of the recorded speeds became invalid and the stall warning stopped.

The altitude was then about 35,000 ft, the angle of attack exceeded 40 degrees and the vertical speed was about -10 000 ft/min. The airplane’s pitch attitude did not exceed 15 degrees and the engines’ N1’s were close to 100%. The airplane was subject to roll oscillations that sometimes reached 40 degrees. The PF made an input on the side-stick to the left and nose-up stops, which lasted about 30 seconds.

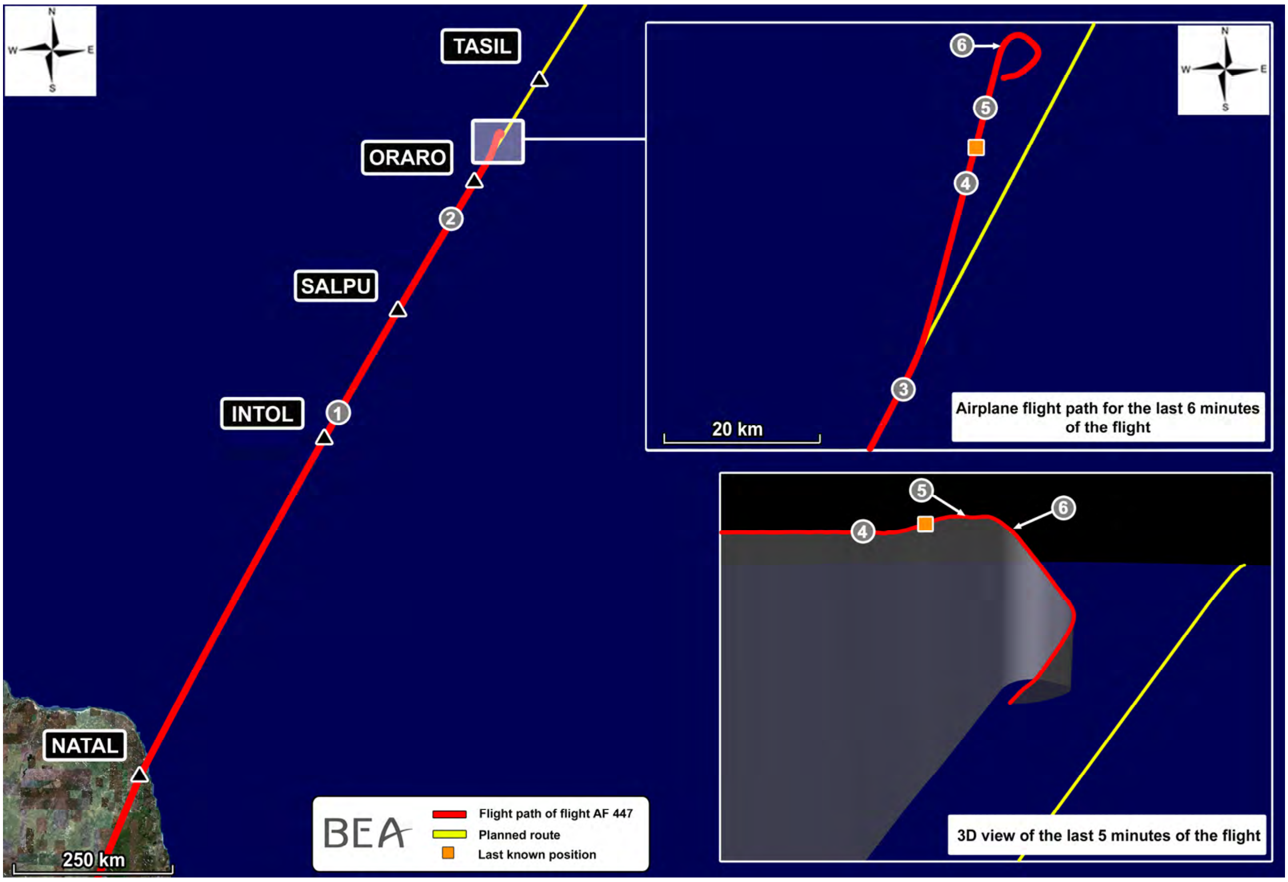
At 2 h 12 min 02, the PF said, “*I have no more displays*, and the PNF “*we have no valid indications*”. At that moment, the thrust levers were in the IDLE detent and the engines’ N1’s were at 55%. Around fifteen seconds later, the PF made pitch-down inputs. In the following moments, the angle of attack decreased, the speeds became valid again and the stall warning triggered again.

At 2 h 13 min 32, the PF said, “[*we're going to arrive] at level one hundred*”. About fifteen seconds later, simultaneous inputs by both pilots on the side-sticks were recorded and the PF said, “*go ahead you have the controls*”.

The angle of attack, when it was valid, always remained above 35 degrees.

The recordings stopped at 2 h 14 min 28 ❻. The last recorded values were a vertical speed of -10,912 ft/min, a ground speed of 107 kt, pitch attitude of 16.2 degrees nose-up, roll angle of 5.3 degrees left and a magnetic heading of 270 degrees.

No emergency message was issued by the crew. The wreckage was found at a depth of 3,980 metres on 3 April 2011 at about 6.5 NM and to the north of the last position transmitted by the aircraft.



Airplane flight path

1.5 Personnel Information

1.5.1 Flight crew

1.5.1.1 Captain

1.5.1.1.1 Aviation career details

- ☐ Private Pilot's License issued in 1974
- ☐ Flight attendant from February 1976 to June 1982 (Air France)
- ☐ Commercial Pilot's License issued in 1977. Practical test taken on a Cessna 177 after training at the training centre of the Technical Control and Training Service of the French civil aviation directorate (Direction Générale de l'Aviation Civile) in Grenoble. Instrument rating (IFR) issued in 1978 (on a PA30).
- ☐ Private flight instructor qualification obtained in 1979
- ☐ 1st class professional pilot theory in 1979
- ☐ Airline transport pilot theory in 1980
- ☐ Mountain rating (altiport category) issued in 1981

- ☐ 1st class professional Pilot's License issued in 1982. Tests taken on a Nord 262 after training at the Technical Control and Training Service centre of the French civil aviation directorate (Direction Générale de l'Aviation Civile) in Saint-Yan
- ☐ Demonstration pilot from January to March 1983 (Inter Avia Service Company)
- ☐ Pilot from June 1983 to August 1984 for various companies
- ☐ Several other type ratings obtained between 1977 and 1987:
  - C177 (1977), C310 (1977), C401 / C402 (1982), C421 (1983)
  - PA23 (1978), PA30 (1979), PA34 (1980), PA31 (1984)
  - BE65 (1981), BE 55/58 (1982), BE60 (1983), BE20 (1987), BE90 and BE10 (1987)
  - BN2A (1981)
  - N262 (1982)
  - MU2 (1983)
- ☐ Independent pilot from October 1984 to February 1988
- ☐ Joins Air Inter airline in February 1988 as copilot
- ☐ Caravelle XII type rating in 1988
- ☐ A300 type rating in 1990 (within Air Inter)
- ☐ Airline pilot training course from 12 August 1991 to 15 January 1992 (within Air Inter)
- ☐ ATPL License without limitations issued 19 February 1992
- ☐ 1st class professional pilot instructor (IPP1) rating issued in 1993
- ☐ A320 type rating issued on 13 March 1997 (within Air Inter). Line training completed and pilot in command for first time on 3 April 1997

Note: the merger between Air France and Air Inter took place on 1 April 1997

- ☐ Boeing 737-200 type rating (within Air France), end of line training and appointed captain on 19 June 1998
- ☐ New A320 type rating issued 29 May 2001 (within Air France)
- ☐ Additional A330 type rating issued 27 October 2006 (within Air France). Unfit after line training test flight 17 January 2007, extended A330 line training (LOFT) and satisfactory test on 17 February 2007
- ☐ Additional A340 type rating issued 9 August 2007 (within Air France). Line training completed and pilot in command for first time on 7 September 2007
- ☐ Last medical certificate (class 1) issued on 10 October 2008, valid until 31 October 2009

2008/2009 and 2009/2010 ECP instruction seasons:

- ☐ A330 (CEL33) line check on 15 February 2007

- ☐ A340 (CEL34) line check on 7 September 2007
- ☐ A330 (E33) training on 12 March 2008
- ☐ A340 (CEL34) line check on 21 July 2008
- ☐ 4S ground training on 7 August 2008
- ☐ A340 (E34) training on 11 October 2008
- ☐ A330 (C33) base check on 12 October 2008
- ☐ S1 ground training on 12 January 2009
- ☐ A330 (E33) training on 22 April 2009
- ☐ A340 (C34) base check on 23 April 2009

1.5.1.1.2 Training courses and specific training

➢ Unreliable IAS

- o FFS session n°1 (Air Inter A320 type rating) on 24 February 1997 "flight with unreliable IAS". This session also includes "Study of high altitude flight (35,000 ft)" exercise.
- o 2008-2009 instruction season training on E33 simulator. "Unreliable IAS" exercise.

Note 1: The exercise took place during take-off from Rio. Air France pilots have indicated that during this exercise, no ECAM alarm was set off as the ADR provided the same erroneous information. The aim of this exercise was to carry out the emergency manœuvre with thrust parameters/corresponding flight attitude to the take-off phase. The brief for the exercise concerned:

- the choice between the "unreliable IAS" emergency manœuvre and the non ECAM "flight with unreliable IAS / ADR Check proc" check-list,
- the conditions for performing the emergency manœuvre,
- the human factors (highly stressful situation, PEQ coordination in particular).

Note 2: The A320 type rating programme at Air France in 2001 did not include an exercise in flight with unreliable IAS.

➢ Stall

- o A300 type rating (Air Inter): FFS session n°3 "level flight (FL 330) - stall / changes"
- o A320 type rating (Air Inter): FFS session n°1 "study of stall and recovery of the trajectory
- o A320 type rating (Air France): FSS session n°7, exercise on "low speed demonstration in direct law and recuperation after a STALL alarm". The stall procedure in force was that of December 1999

➢ Unusual attitudes

- o additional A330 type rating: computer assisted self-learning module "Unusual attitudes – Use of the rudder" issued on 28 September 2006

- Piloting in *alternate law*
  - A320 type rating (Air France): FFS session n°4 “flying in alternate law and direct law”

1.5.1.2 Copilot in left seat

1.5.1.2.1 Aviation career details

- ☐ Basic license issued in 1992
- ☐ Airline pilot theory in 1992
- ☐ Professional Pilot’s License in 1993 (EPT ENAC)
- ☐ Multi-engine instrument rating issued in 1993

Note: In the context of economic crisis in air transport, in autumn 1992 Air France stopped pilot training courses and drew up a waiting list in 1993.

- ☐ Training as Air Traffic Control Engineer at ENAC until 1998. In August 1997, request to delay joining Air France in order to finish this training
- ☐ Fit for starting type rating training at Air France in July 1998
- ☐ Training in Multi Crew Co-ordination (MCC) in August 1998 by the Air France TRTO
- ☐ A320 type rating issued in November 1998 (within Air France). End of LOFT and pilot in command for first time 14 February 1999
- ☐ Commercial airline pilot’s license issued in April 2001
- ☐ Additional A340 type rating in February 2002 (within Air France). End of line training and pilot in command for first time in April 2002
- ☐ Additional A330 type rating and line training in October 2002
- ☐ Assigned to Air Calédonie Internationale airline for two months in 2005 to carry out flights on A330 on the Tokyo – Nouméa route
- ☐ Renewal of SEP rating on TB10 in Nouméa in 2005
- ☐ He was appointed (as) cadre at the Technical Flight Crew Division as representative of the Flight Deck Crew hub at the CCO from 1st May 2008

2008/2009 and 2009/2010 ECP instruction seasons:

- ☐ CEL34 line check 30 October 2007
- ☐ E34 training 22 July 2008
- ☐ C33 base check 23 July 2008
- ☐ CEL33 line check 26 October 2008

- ☐ E33 training 6 December 2008
- ☐ 4S ground training 10 December 2008
- ☐ C34 base flight check 21 December 2008
- ☐ S1 ground training 18 March 2009

1.5.1.2.2 Training

- ➢ Unreliable IAS
  - o 2008-2009 instruction season E33 simulator training. “Unreliable IAS” exercise.

Note: The A320 type rating programme at Air France in 2001 did not include an exercise in flight with unreliable IAS.

- ➢ Stall
  - o A320 type rating: FFS session n°3, “study of alternate law, flight at high angles of attack, stall“

1.5.1.3 Copilot in right seat

1.5.1.3.1 Aviation career details

- ☐ Private Pilot’s License issued in 2000
- ☐ ATPL theory in 2000
- ☐ Professional pilot’s license issued in 2001
- ☐ Multi-engine instrument type rating issued in 2001
- ☐ Glider pilot’s license issued in 2001
- ☐ Following his selection by Air France, pilot training course at the Amaury de la Grange piloting school in Merville from October 2003
- ☐ A320 type rating issued in 2004 (within Air France). End of line training and pilot in command for first time in September 2004
- ☐ ATPL License issued on 3 August 2007
- ☐ Additional A340 type rating issued in February 2008 (with Air France). End of LOFT and pilot in command for first time in June 2008
- ☐ Additional A330 type rating and LOFT in December 2008

2008/2009 ECP instruction season:

- ☐ 4S ground training on 15 January 2009
- ☐ E33 training on 2 February 2009

- ☐ C34 base flight check on 3 February 2009

Note: The validity of the E34, C33, CEL34, CEL33, S1 training courses, checks and ground training is covered by the dates of issue of the Airbus A330 and A340 type rating as well as by the end of line training date.

Training courses and checks were to be scheduled before the following deadlines:

- ☐ E34 training: 31 August 2009
- ☐ C33 base flight check: 31 August 2009
- ☐ CEL34 line check: 31 December 2009
- ☐ CEL33 line check: 31 December 2010
- ☐ S1 ground training: 31 March 2010

1.5.1.3.2 Training courses

- ➢ Unreliable IAS
    - o 2008-2009 instruction season E33 simulator training. "Unreliable IAS" exercise.

Note: The A320 type rating programme at Air France in 2004 did not include an exercise in flight with unreliable IAS.

- ➢ Stall
    - o A320 type rating: FFS session n°4: "piloting in degraded law (effect of buffeting). Changes in alternate law"
    - o A320 type rating: FFS session n°7: "Preventive recognition and countermeasures to approach to stall. DEMONSTRATION STALL WARNING". The STALL procedure in force was that of December 1999

General note: The additional A330 and A340 type ratings deal only with the differences in relation to the type ratings already issued on other types (A320, A330, A340).

1.6 Aircraft Information

1.6.3 Weight and balance

The airplane left the stand with a calculated weight of 233,257 kg. The estimated takeoff weight was 232,757 kg (11) for a maximum authorised takeoff weight of 233 t. This takeoff weight was broken down as follows:

- an empty operating weight of 126,010 kg
- passenger weight of 17,615 kg (126 men, 82 women, 7 children and 1 baby (12))
- hold weight (cargo and baggage) of 18,732 kg
- fuel weight of 70,400 kg

The fuel weight on board corresponded to a planned fuel-burn of 63,900 kg, an en-route reserve of 1,460 kg, a final reserve of 2,200 kg, a diversion reserve of 1,900 kg and 940 kg of additional fuel. A LMC (last minute change) corrected the final weight to take into account one passenger and baggage less than planned.

The balance corresponding to the airplane's takeoff weight and shown on the final load sheet (after LMC) was 23.3% of the MAC (mean aerodynamic chord), which was within the limits.

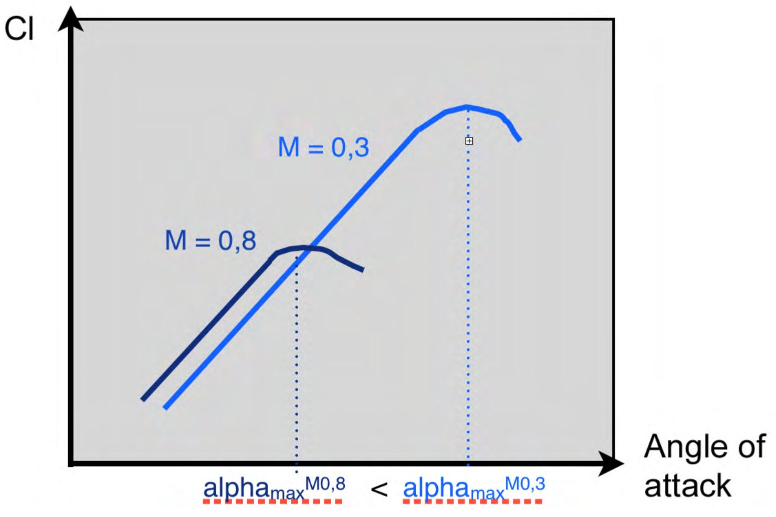
The recorded data indicates that at the time of the event, the airplane's weight was 205.5 tonnes and the balance was 28.7%, which was within the limits.

1.6.12 Information on the Stall

1.6.12.1 Background Information on Stalls

The lift of an airfoil depends on its lift coefficient (Cl) and the square of the speed of the airflow. The lift coefficient increases with the angle of attack (noted as alpha) up to a maximum value, after which it decreases when the angle of attack continues to increase. This tipping point, where the lift coefficient is at maximum is the marker, from an aerodynamic point of view, for the stall. The angle of attack at which the Cz is at a maximum is thus the stall angle of attack ($alpha_{max}$).

The aerodynamic characteristics of an aerofoil, thus the evolution of the Cl = f (alpha) curve, are different between the lower layers (low Mach, subsonic airflow, incompressible air) and the high altitudes (higher Mach, trans-sonic airflow, influence of the compressibility of the air).



Lift graph with high and low Mach

At a high Mach, the compressibility of the air is manifested by the appearance of *buffet* at a high angle of attack, whose amplitude can then increase until it becomes dissuasive (*deterrent buffet*). Test flights are then stopped before reaching Cl_{max}. It is then considered that the Cl_{max} is the maximum Cl reached during the manoeuvre.

Note 1: The appearance of *buffet* (*buffet onset*) is defined by an oscillatory vertical acceleration whose amplitude reaches 0.2 g from peak to peak at the pilot's seat. The notion of *deterrent buffet* is subjective.

Note 2: This type of test flight is always undertaken during the day, in VMC conditions and in a calm atmosphere.

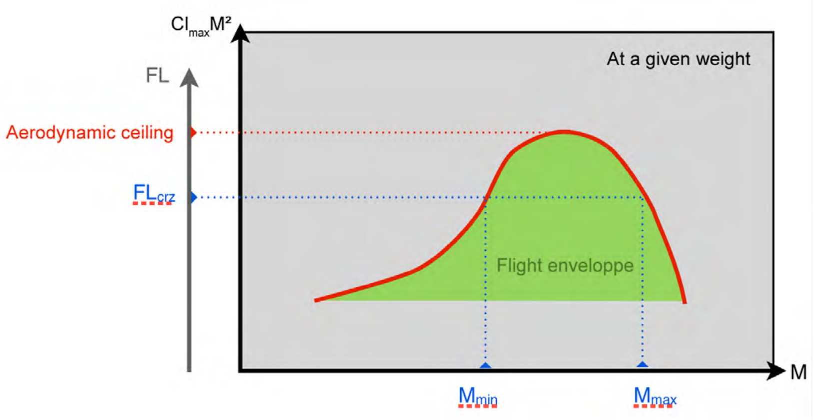
1.6.12.2 Flight envelope and margin for manoeuvre at high altitude

The lift equation in straight, level flight at a given flight level can be noted as:

$$m.g = K.Ps.Cl.M^2$$

where Ps is the static pressure, M is the Mach number, K is an airplane-dependant constant

At the lift ceiling, Cl is equal to $Cl_{max,}$ so that $m.g = K.Ps.Cl_{max}.M^2$. There is therefore a direct relation between $Cl_{max}.M^2$ and the flight level. The flight envelope can then be represented by tracking $Cl_{max}.M^2$ as a function of M:



Flight envelope at high altitude

Thus, at a fixed mass and flight level FL_{crz}, the flight envelope is framed by two Mach values:

- the lower limit M_{min} marks the stall, associated with the appearance of the first of the following phenomena:
  - o a loss of lift and the impossibility of maintaining level flight
  - o the presence of *buffet*, linked to the instability of the separation point of the boundary layer
- the upper limit M_{max}, on the other hand, is linked to the effects of the compressibility of the air. It is also defined by the presence of *buffet*, which is then due to the presence of a shock wave on the upper wing surface destabilising the airflow

Note: This upper limit Mmax was never encountered on the A330, even during test flights. The upper limit on this airplane is MMO which does not depend on altitude and includes structural and aero-elastic limitations.

The higher the cruise level, the more the available Mach range is reduced. In an extreme case, the maximum altitude at which the airplane can fly (lift ceiling) cannot only be reached and maintained at a very special Mach. This maximum altitude can in addition be limited by the propulsive capacities of the airplane: this is known as the propulsion ceiling.

Note: The lift ceiling is a theoretical notion. Operationally, the mark range available at a given level is between VLS and MMO.

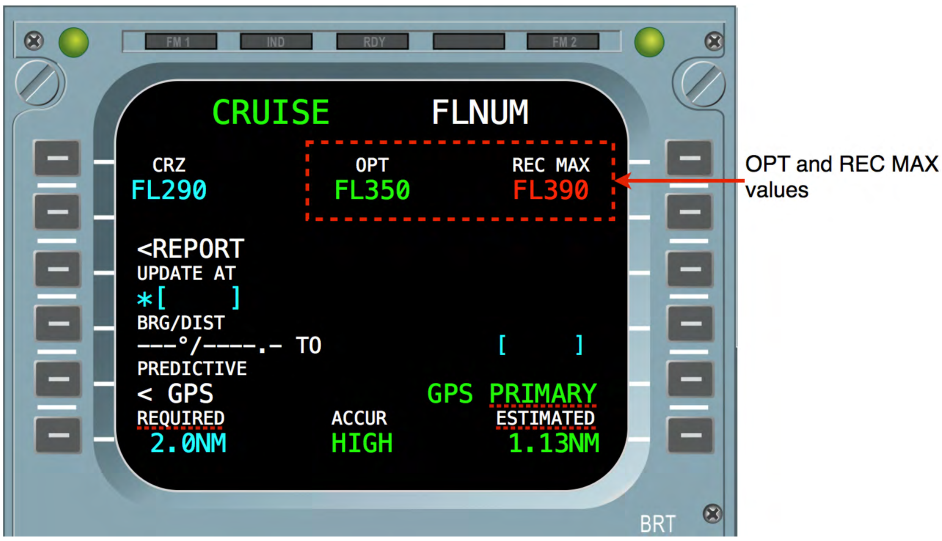
By including performance driven margins, the manufacturer defines a recommended maximum flight level, called “REC MAX”, which is lower than the maximum certified flight level. It is calculated by the FMS by taking into account the following margins:

- it can be reached with a climb speed at least equal to 300 ft/min at MAX CLB thrust setting
- it can be maintained at a speed not less than “GREEN DOT” and with a thrust setting not above the maximum cruise thrust (MAX CRZ)
- there is a guaranteed margin of at least 0.3 g in relation to the appearance of *buffet* (that’s to say that *buffet* does not appear as long as vertical acceleration remains below 1.3 g.)

Note: The FMS does not take into account in this calculation the use of the anti-icing equipment (nacelles or wings) or the level of bleed air (hold cooling or high level rate of the a/c packs).

The manufacturer also defines an optimal flight level, called “OPT” or “OPTI”, calculated by taking into account additionally the wind data and a performance parameter, entered by the crew, called the “COST INDEX”. A low COST INDEX minimizes fuel consumption; a high COST INDEX favours higher speed.

The value of these two levels is shown on the FMS PROG page:



“PROG” page from FMS

1.6.13 Angle of attack protection and stall warning

Note: On an ARINC 429 data bus, the parameters are transmitted with validity information called SSM. A parameter is described as “valid” when its SSM status is “Normal Operation” (NO), “invalid” when it is “Not Computed Data” (NCD) or “Failure/Warning” (FW).

The normal law of the fly-by-wire flight control system on the A330 offers high angle of attack protection that limits it to a value that is below the stall angle of attack. When this protection works, the airplane can thus not stall even if the crew maintains a full nose-up control input to the stop.

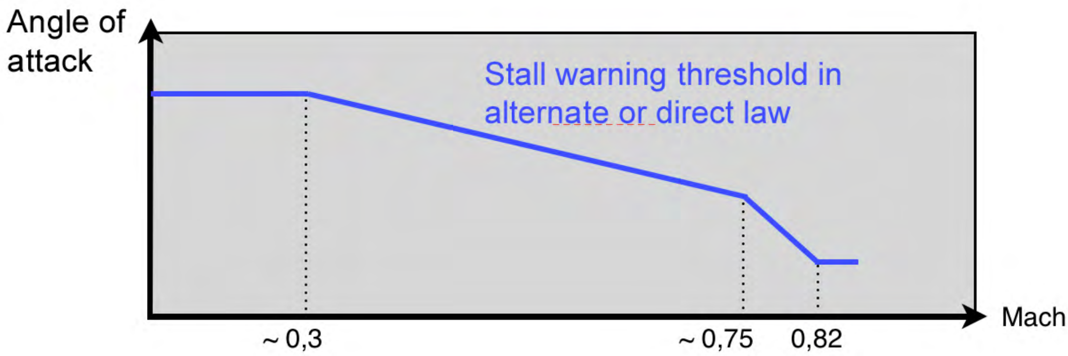
Note: At the maximum angle of attack authorized by the normal law, if a nose-up input is maintained and the thrust is not sufficient to maintain level flight, the airplane descends.

In alternate or direct law, the normal law high angle of attack protection is lost but the stall warning is available. It consists of a “STALL, STALL” aural warning, followed by a characteristic cricket sound. It is triggered by the FWC when the highest of the valid angle of attack values exceeds the threshold fixed for the flight conditions at that time. If the CAS measurements for the three ADR are lower than 60 kt, the angle of attack values of the three ADR are invalid (NCD status) and the stall warning is then inoperative. This results from a logic stating that the airflow must be sufficient to ensure a valid measurement by the angle of attack sensors, especially to prevent spurious warnings on the ground.

On older types of airplanes, because of the presence of *buffet* in the approach to stall, the warning threshold is often independent of Mach and determined for lower altitudes. On the A330 as on other airplanes of the same generation, the threshold of the stall warning varies with the Mach, in such a way that it is triggered - in alternate or direct law – before the appearance of *buffet*.

Note: The highest of the valid Mach values is used to determine the stall warning threshold. If no Mach is valid, the low Mach threshold is used.

In a schematic manner, the threshold is stable below a Mach of the order of 0.3, then reduces in a quasi-linear manner to a Mach of the order 0.75, after which it falls more rapidly when the Mach increases up to Mach 0.82:



Evolution of stall warning threshold in relation to Mach

An increase in angle of attack results in a decrease in the speed, if the load factor is constant. In this case, the decrease in speed corresponding to an increase in a given angle of attack depends on the flight conditions:

Flight condition	Cruise	Takeoff / Approach
Level of decrease in dedicated speed for an increase of 1° in the angle of attach	25 kt	5 kt

In cruise at Mach 0.8, the margin between the flight angle of attack and the angle of attack of the stall warning is of the order of 1.5 degrees, but the stall warning speed displayed on the air speed tape (in *alternate* or direct law) will be around 40 kt below the actual speed.

The value of the angle of attack is not directly displayed to the pilots. The angle of attack is the parameter that allows the stall warning to be triggered, but the activation threshold of this warning is indicated by a marker on the airspeed tape. When the ADR are rejected by the flight control computers, this marker disappears

1.6.14 Onboard weather radar

The Air France Airbus A330's are fitted with Collins WXR 700X-623 type weather radar with a flat antenna (P/N : 622-5132-623). The opening angle of the radar beam is 3.6° in elevation and 3.7° in azimuth.

Adjustments to the tilt and the gain are made manually.

Each airplane is equipped with two systems, only one antenna and only one control box. Only one system is active at a time.

The radar image is presented on the ND overlaid with navigation and TCAS information. It is presented when the radar is operating, when the ND is not in PLAN2 mode and when the TERR3 mode is not selected. Range adjustment is done manually.

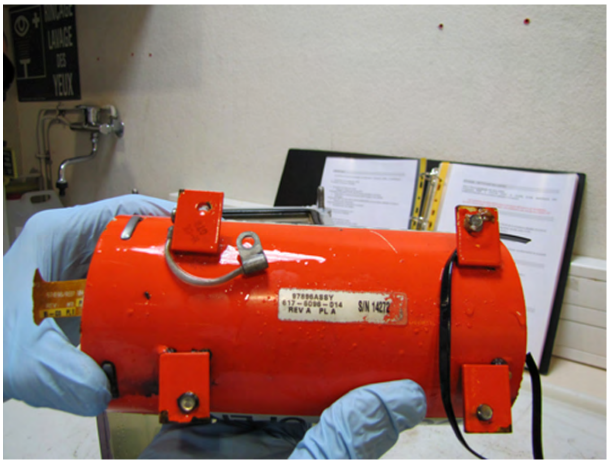
Note: Adjusting the luminosity of the terrain and weather information is done independently of that of other information on each ND.

No malfunctions of the weather radar were reported on the other ATL of F-GZCP in the last 6 months prior to the accident.

1.11 Flight Recorders

1.11.1 Flight recorder opening operations and read-out

The two flight recorders arrived at BEA headquarters in Le Bourget on 12 May 2011. They were stored under judicial seal in two water-filled containers.



FDR

CVR

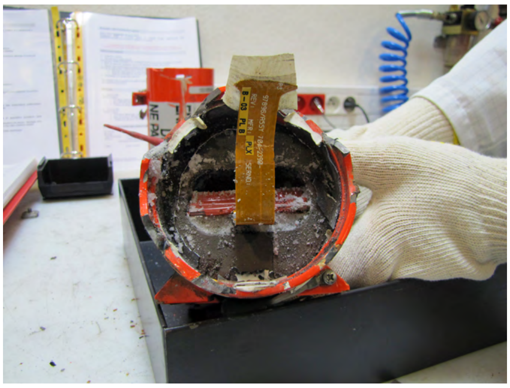
[2] Display mode that presents, as a fixed image, the route of the flight plan on A map oriented towards true north centred on a preference point chosen by the pilot.
3 When the TERR ON ND pushbutton is in the ON position, the ND displays the terrain contained in the EGPWS Data Base.

For the FDR, only the protected unit (CSMU or memory module) was present. The CVR was complete.

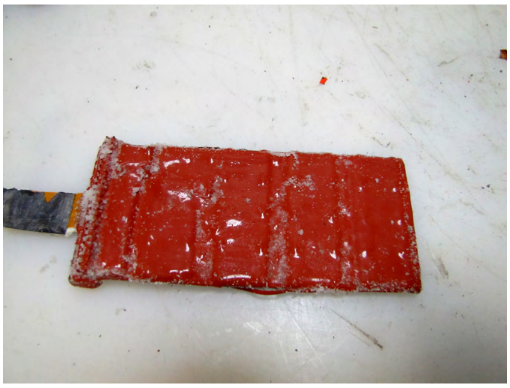
- **Flight Data Recorder - FDR**

  - Manufacturer: Honeywell
  - Model: 4700
  - Part number (P/N): 980-4700-042
  - Serial number (S/N): 11469

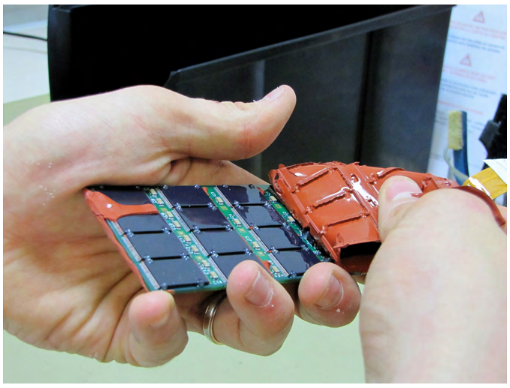
The CSMU was opened and the various internal protective layers removed. The memory board was extracted, and its protective coating removed.



FDR CSMU after removal of cover



FDR memory board



Removal of protective coating

The memory board was cleaned. Visual inspection did not reveal any damage to the board. The board was placed in an oven for 36 hours in order to remove the moisture in the components and the printed circuit board. The impedance measurements that were then made on the input connector were in accordance with the measurements made on reference units.

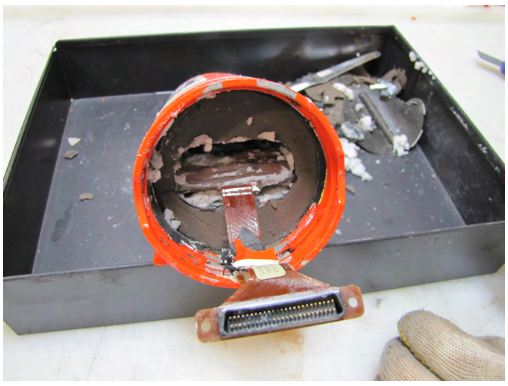
The memory board was then connected to the BEA's memory reader. Each memory component was addressed individually and reading in its entirety. Analysis of the binary contents confirmed that the reader communicated correctly with the memory components and that the data extracted from each memory component was consistent. The memory board was then connected to the BEA's chassis and the data was extracted using the manufacturer's official hardware. The data was synchronised and the event flight was identified.

➢ **Cockpit Voice Recorder - CVR**

- Manufacturer: Honeywell
- Model: 6022
- Part number (P/N): 980-6022-001
- Serial number (S/N): 12768

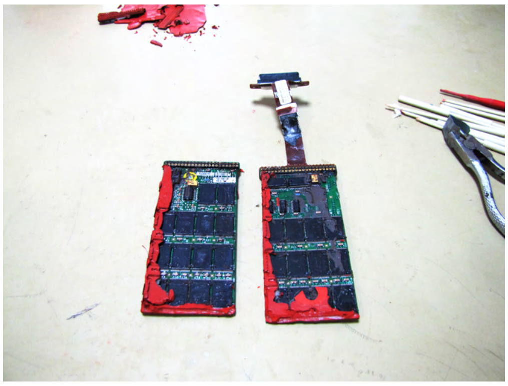
The CSMU was released from its chassis and opened. As with the FDR, the various layers of thermal protection were removed, the double memory board[4] was extracted, and then the protective covering was peeled off.

Opening of CVR CSMU



CVR memory board after removal of thermal protections

[4] The CVR's data storage medium consists of two interlinked memory boards.



CVR memory boards after cleaning

Visual inspection of the boards revealed damage: a capacitor and a resistor were cracked on one of the boards; two decoder-type components were damaged on the other board.

The boards were placed in an oven for 42 hours. The damaged components were unsoldered and replaced. The impedance value measured at the input connector complied with the measurements made on reference boards.

The memory boards were then connected separately to the BEA's memory reader. A few memory components selected previously were addressed and read entirely. The consistency of the binary contents of each memory could then be checked using the manufacturer's hardware and software. The boards were then connected to the BEA's chassis and the data was extracted and decompressed using the manufacturer's official hardware.

The following tracks were recorded:

- track 1: radio communications and the signal from the microphones for the pilot seated on the left
- track 2: radio communications and the signal from the microphones for the pilot seated on the right
- track 3: radio communications, the signal from the second copilot's microphone (rear seat), and the FSK signal
- a track made up from the first 3 tracks mixed together
- CAM track: the signal from the cabin area microphone

Analysis of the 5 audio files downloaded revealed that the event did not occur at the end of the sequence of data recorded on the 5 tracks, and that the tracks lasted for less than a few dozen seconds at the expected values.

Synchronisation of the various channels showed that some of the data was missing. Moreover, analysis of the binary contents of the EEPROM memory confirmed the inconsistency of the pointers[5] used by the manufacturer's reader to start and end the downloading of the data.

[5] Information indicating the position of an item of data in a binary file

The method subsequently adopted to recover all the saved data involved reading the binary contents of each memory component using the BEA's memory reader. By analysing the binary contents of the memory components, the value of the various pointers could be determined. These pointers were then used to reconstruct the file in is correct chronological order. The files compressed in the manufacturer's format were reconstructed using software developed by the BEA based on information provided by the manufacturer. The files were then decompressed using the manufacturer's official hardware and software.

The 5 audio tracks obtained in this way were synchronised and their duration was found to comply with the expected values: more than 30 minutes for tracks 1 to 3 and more than 2 hours for tracks 4 and 5.

1.11.2 Analysis of the flight recorder data

- ***Synchronisation of the recorders***

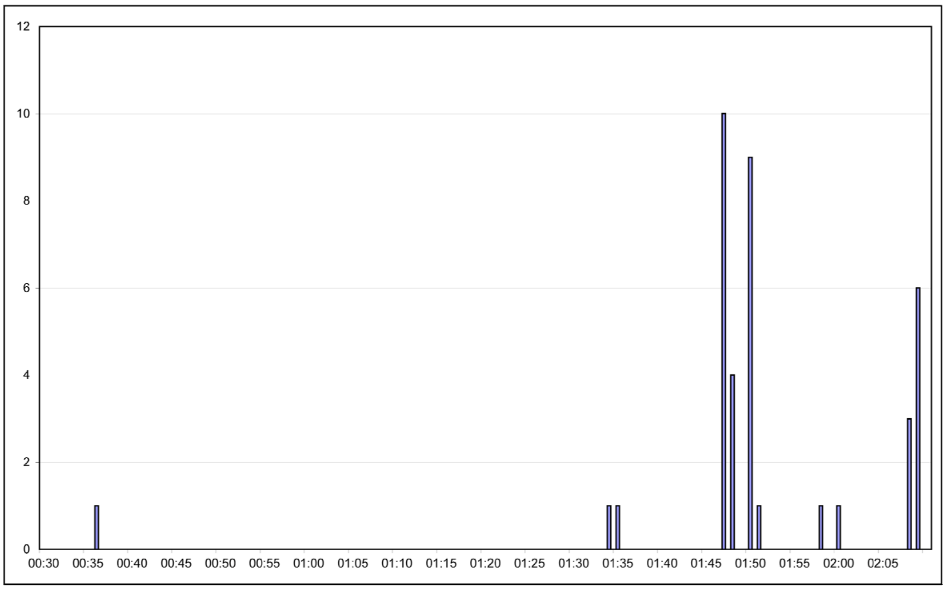
The recorders were synchronised using the various alarms triggered during the flight, particularly the stall warning. The number of alarms made it possible to synchronise the recorders with an accuracy of approximately 100 ms.

The CVR recording started at about 0 h 09 UTC on 1 June.

- ***CVR analysis***

The CVR audio recording starts at 00 h 09 min 15. The cockpit door was opened once at 0 h 26 min 19. It was later closed and opened again several times. It stayed opened for some time on several occasions. The door security system (electrical opening command by the pilots) was not heard on the overall recording.

At 0 h 36 min 26, an electrical phenomenon (audio discharge) linked to atmospheric conditions appeared on the CAM track and could be heard until the end of the recording. The following figure shows the distribution of those audio discharges as a function of time:



Distribution of audio discharges as a function of time

The signal corresponding to the "fasten seat belts" information was not heard on the recording. Several modifications in the background noise were noted during cruise between 0 h 49 min 17 and 2 h 09 min 40.

A call signal was heard in the "flight rest" compartment at 1 h 56 min 06. The relief copilot entered the cockpit at 1 h 59 min 26. The Captain left the cockpit at 2 h 01 min 58 and the door was closed.

The aural autopilot disconnection warning (cavalry charge) was heard at 2 h 10 min 04.6. A first call signal to flight attendants or the flight rest compartment was heard at 2 h 10 min 53.5. Vibration noises were heard from 2 10 min 54 to 2 h 12 min 57. Five call signals were transmitted in the flight rest compartment between 2 h 11 min 09.8 and 2 h 11 min 27. The Captain returned to the cockpit at 2 h 11 min 42.5. The recording stopped at 2 h 14 min 28.4.

- ***Flight control and navigation***

The aircraft took off from Rio de Janeiro at 22 h 29 on 31 May. One of the copilots was the PF and performed take-off. Auto-pilot 2 was engaged at about 22 h 33. The aircraft climbed gradually to flight level 350, reached at about 23 h 00.

The flight followed the route envisaged in modes ALT CRZ / NAV. The table below shows the times at which certain waypoints in the flight plan were reached:

Name of point	Time of passage
RUMBA	**0 h 44 min 37**
NATAL	**0 h 54 min 18**
FEMUR	**1 h 13 min 22**
INTOL	**1 h 32 min 46**
SALPU	**1 h 48 min 32**
ORARO	**2 h 04 min 11**

Passage time at some points in the flight plan

- ***Turbulence***

Analysis of the recorded normal load factor revealed zones of slight turbulence. The table below provides a summary of this analysis.

Note: According to the ICAO, “light” turbulence is defined as being changes in the normal load factor at the centre of gravity of less than 0.5 g peak to peak.

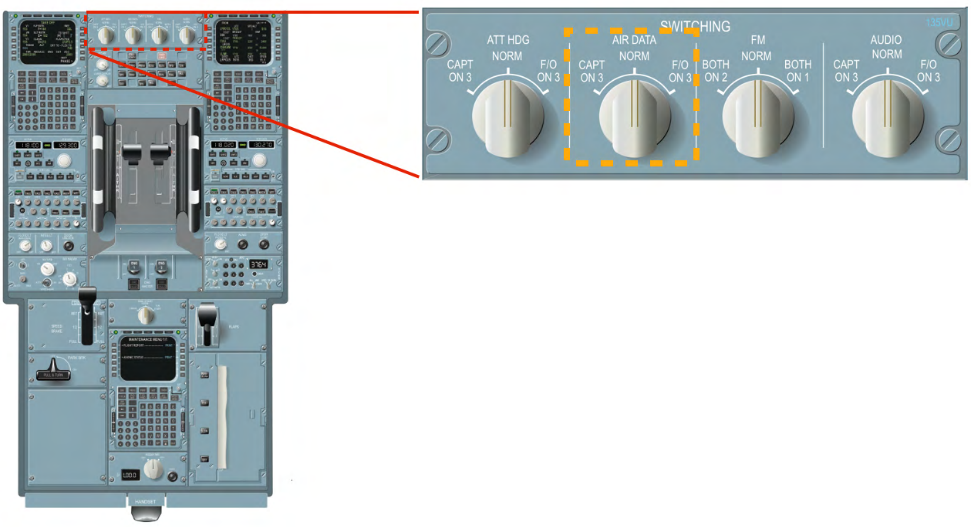
Start	End	Duration	Amplitude
22:30	23:45	1h15	<=0,2
23:45	1:02	1h17	calm
1:02	1:32	30 min	<=0,15
1:32	1:36	4 min	0,2
1:36	1:45	9 min	<=0,1
1:45	1:48	3 min	0,2
1:48	1:52	4 min	0,3 – 0,4
1:52	2:02	10 min	<=0,15
2:02	2:07	5 min	increase from 0,1 to 0,25
2:07	2:10	3 min	maximum 0,5

Level of turbulence observed during flight

➢ ***Speed parameters***

The calibrated airspeed recorded in the FDR is that displayed on the left-hand PFD, unless it is invalid (if the speed is less than 30 kt, in which case the SPD flag replaces the speed scale). In this case, the airspeed recorded on the FDR is then that displayed on the right-hand PFD. This change to the source of the recorded parameter is not explicit. If both airspeeds are invalid, the SPD flag appears on both sides and the airspeed saved is then also invalid, and has an accompanying NCD status. Its variation then follows a specific profile.

Note: The airspeed displayed on the left-hand PFD is generally derived from ADR1, but may also be derived from ADR 3, if the “AIR DATA” rotary switch located on the central console is actuated.



Position and detail of “AIR DATA” selector

The airspeed displayed on the ISIS is also recorded by the FDR. This is comparable with the calibrated airspeed derived from ADR 3, since ADR 3 and the ISIS use the same external sensors (refer to interim report No. 1, section 1.6.6.1). It is always valid, even at airspeeds of less than 30 kt, as long as the dynamic pressure (total minus static) does not fall below a certain threshold. If this threshold is reached, the airspeed is invalid with a FW status (failure warning) and a message is sent to the CMC.

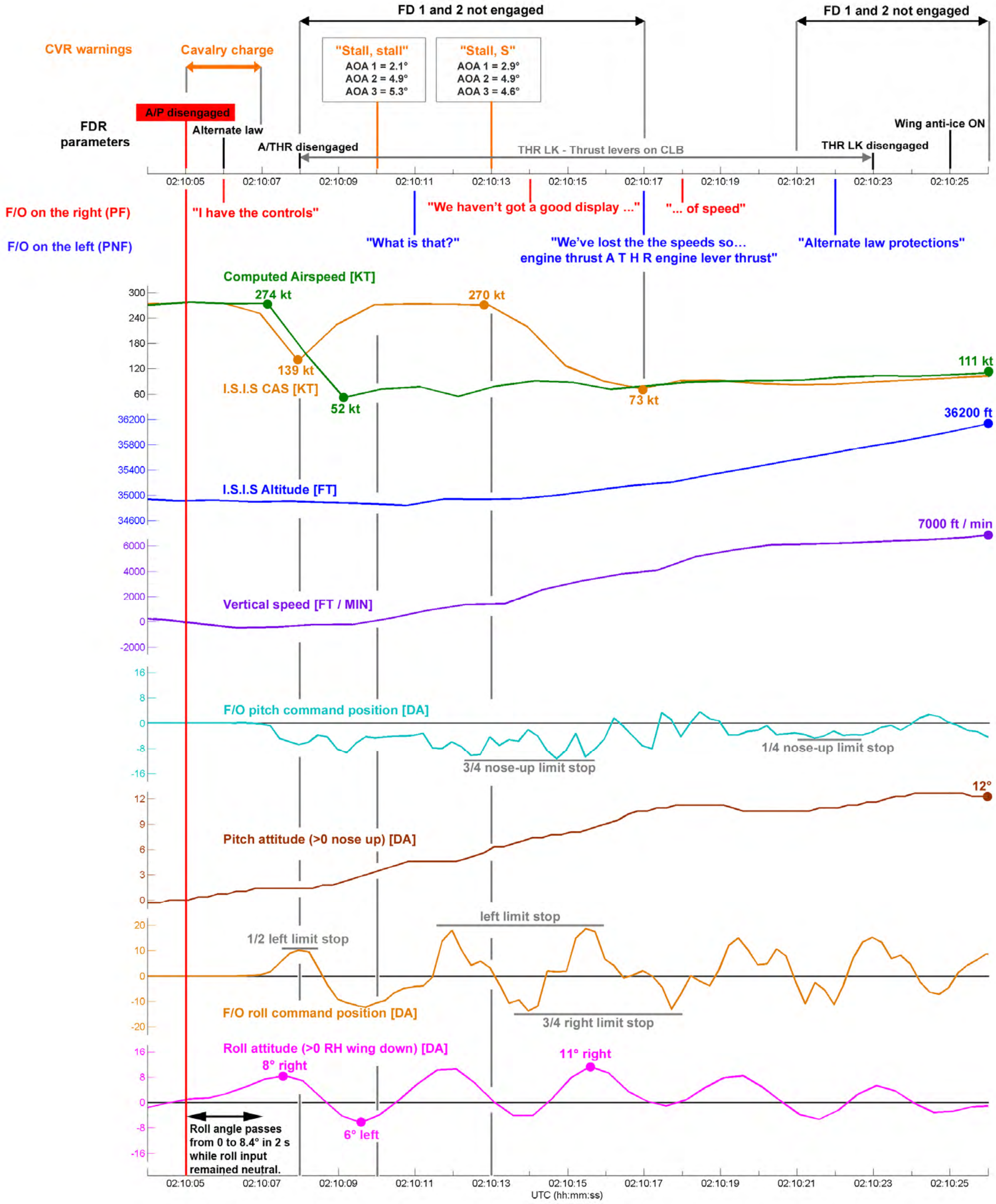
The Mach from the ADR which provides information to the left-side PFD is also recorded. It is only displayed on the PFD when it is greater than 0.5.

➢ ***ISIS parameters***

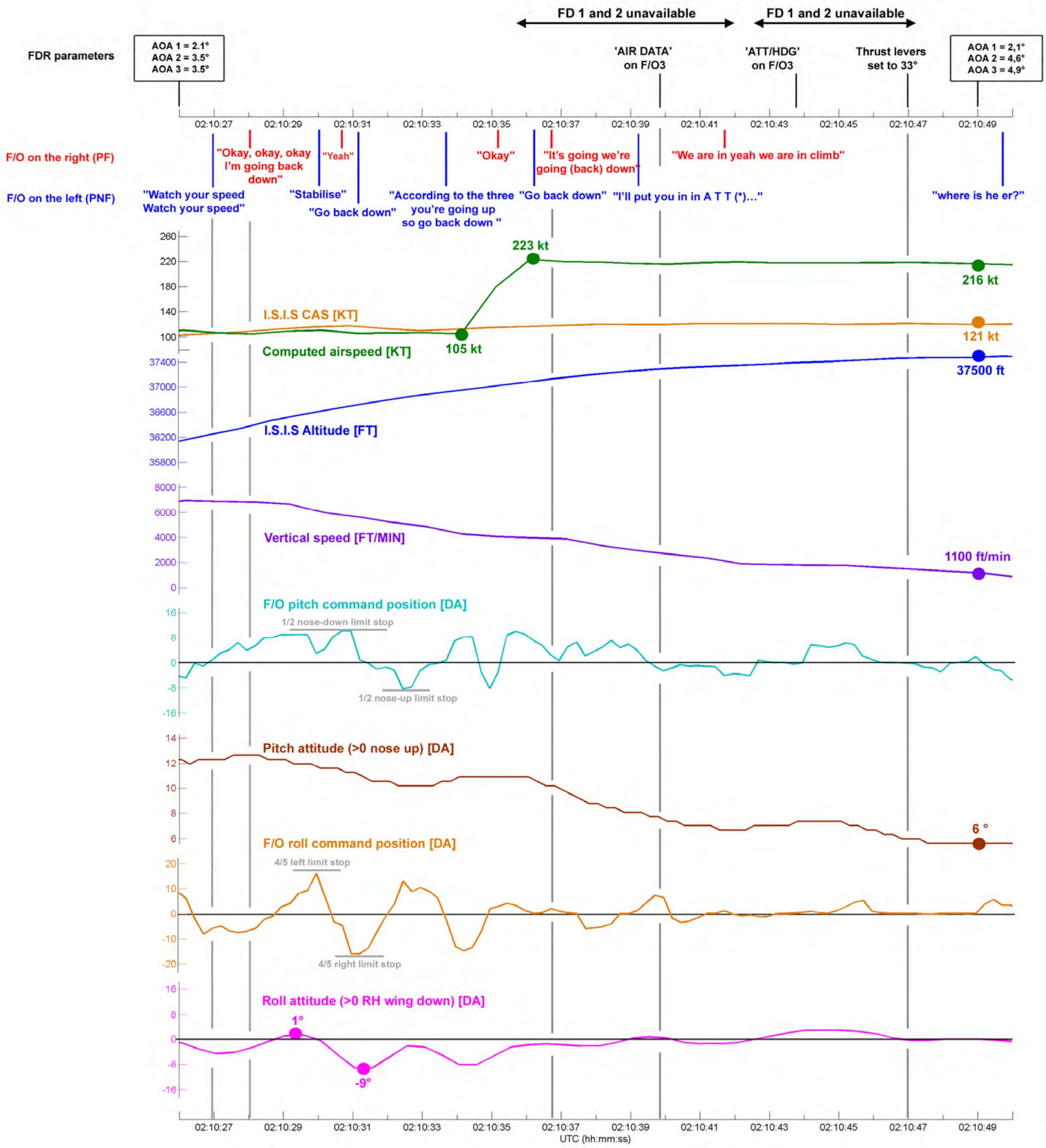
In addition to the airspeed, the inertial parameters and the altitude displayed by the ISIS are also recorded. Note that the ISIS has its own inertial measurement unit; whereas it is fed by the external aerodynamic sensors which also provide pressure data for ADR 3.

➢ ***Parameters linked to the flight directors***

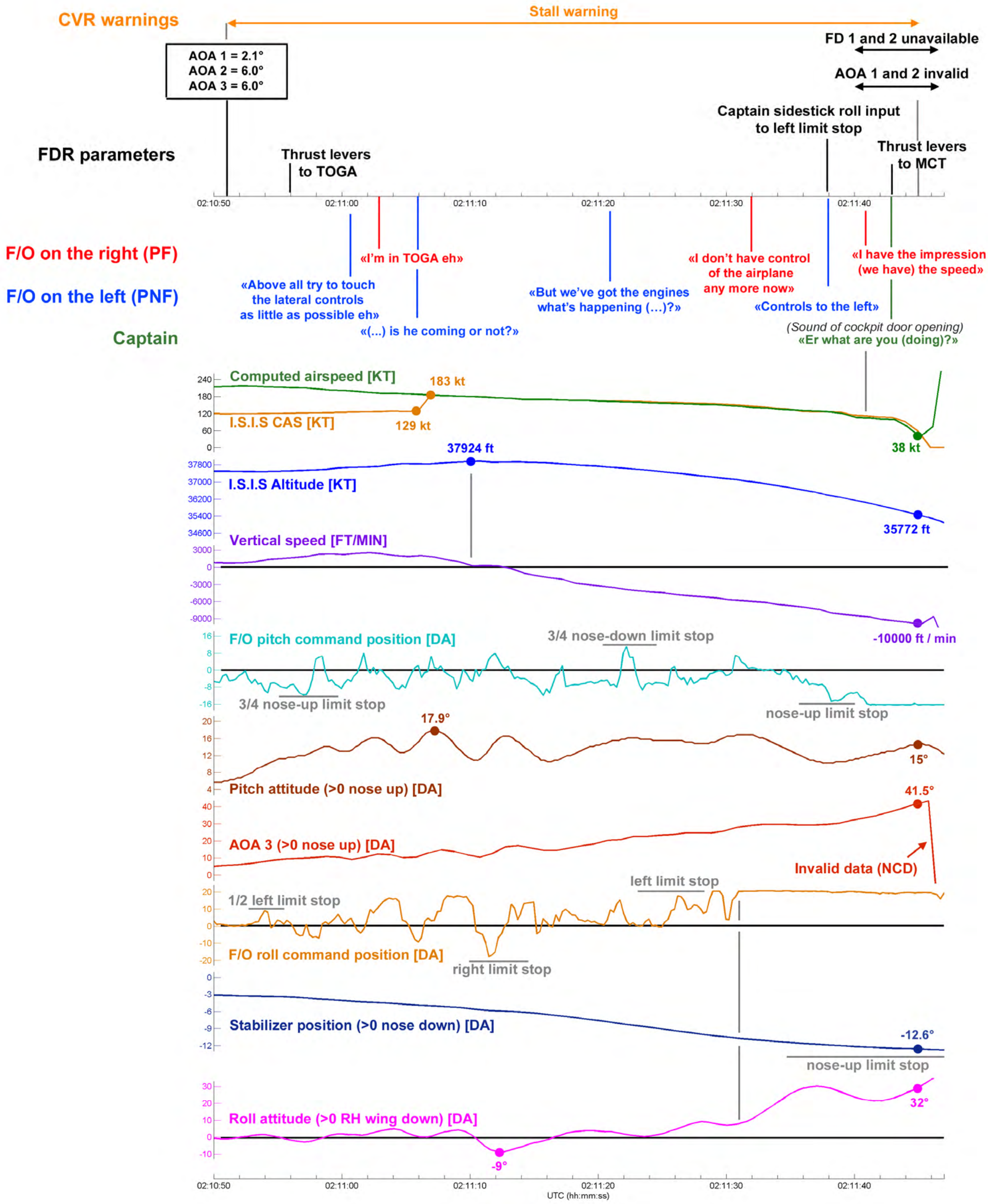
The recorded parameters do not reflect the state of the FD 1 and 2 selection pushbuttons located on the Flight Control Unit (FCU), but the state of the respective FD crossbars display on the PFD. The evolution of these parameters shows changes that are so simultaneous that they indicate that the FD's were never disengaged by the use of the pushbuttons. Thus they show that the FD crossbars disappeared and reappeared several times during the flight.



Parameters from 2 h 10 min 04 to 2 h 10 min 26



Parameters from 2 h 10 min 26 to 2 h 10 min 50



Parameters from 2 h 10 min 50 to 2 h 11min 46

1.11.3 Analysis of the computers

Without prejudging any future analysis work on other computers, the priority analysis work was selected to be on the two FMGEC, the two FCDC and the ISIS. It is possible that data recorded in non-volatile memory devices can still be analysed, which could make it possible to determine the airspeed rejection sequence (occurring at 2 h 10) or to confirm certain events (e.g. crew intervention to shut-down PRIM 1 and SEC 1).

At this stage in the investigation, it still has not been possible to perform the examinations. The on-going operations to recover the information primarily involve:

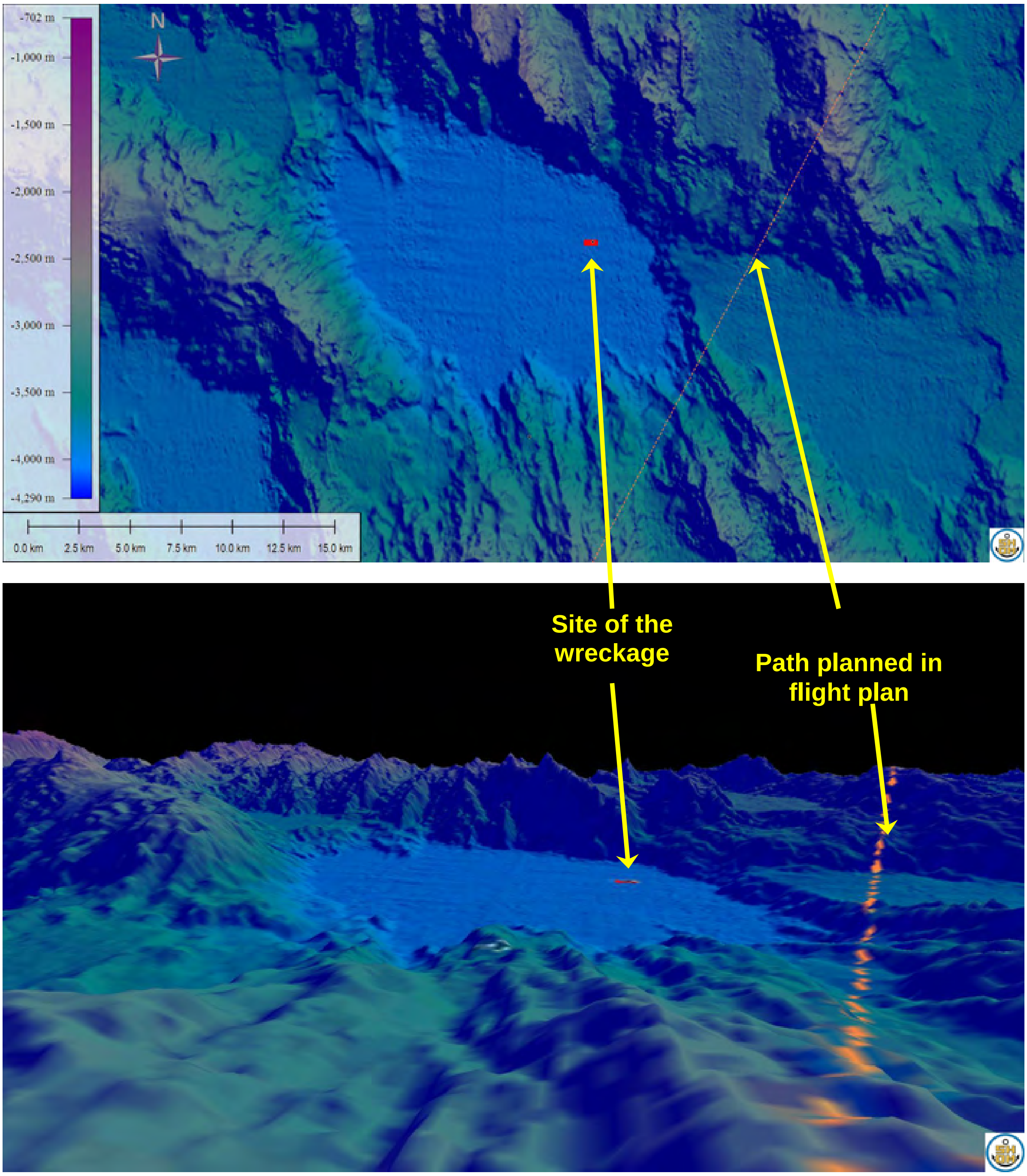
- identifying the type of information saved;
- locating the data storage media (non-volatile memory component);
- setting up a data recovery protocol in conjunction with the equipment manufacturer;
- preparing the reading and decoding of the data.

1.12 Site and Wreckage Information

1.12.1 The site

The site of the accident was east of the Mid-Atlantic ridge, in a region with rugged terrain and whose ocean bed presents great variations in depth over short distances of between 700 metres and 4,300 metres.

The wreckage rested on an abyssal plain at a depth of 3,980 metres. This plain, surrounded by terrain, made of a clay type sediment, was around 15 km wide and was located west of the scheduled airplane flight path.



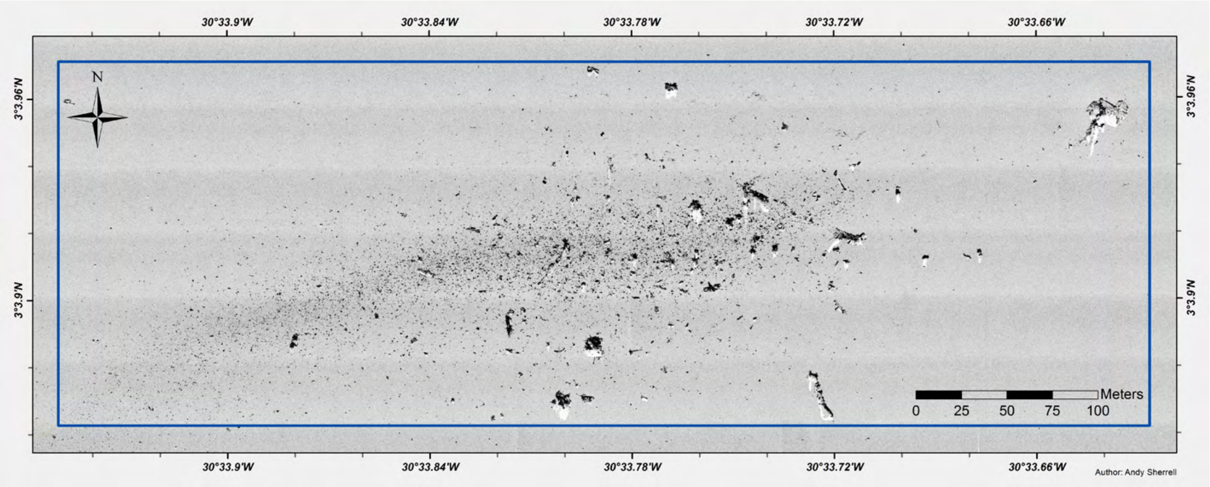
Site of the accident

1.12.2 The wreckage

The aircraft debris was dispersed over an area around 600 metres long and 200 metres wide and the debris field was roughly oriented 080° / 260°.

The whole wreckage was highly fragmented with some large pieces of debris.

The densest debris (central section, engines, APU, landing gear) was found to the east of the site and the lighter debris to the west.
Outside the main area of 600 metres by 200 metres, a rear left fuselage panel containing eleven windows and around seven metres long was found approximately two kilometres south-west of the area. Part of the lower surface of the trimmable horizontal stabiliser was also found slightly to the south-west of this area.



Sonar images of debris field

1.12.3 Debris identification

Identification of the main pieces of debris was carried out during phase 5 of the search from images transmitted on board the *Ile de Sein* by Phoenix International's underwater robot REMORA (see details on the resources used in paragraph 1.19). The following diagram shows the map of the main elements identified.

1.12.4 Examination of airplane elements

1.12.4.1 Examination from video images transmitted by the ROV Remora

The lower elements of the fuselage were badly broken up and deformed. In these areas, crushing of the sheet-metal between the ribbing was noted, which indicates a vertical component at the time of impact.

Parts of the fuselage

The upper elements of the fuselage are generally larger. They often had significant lengthwise folding.

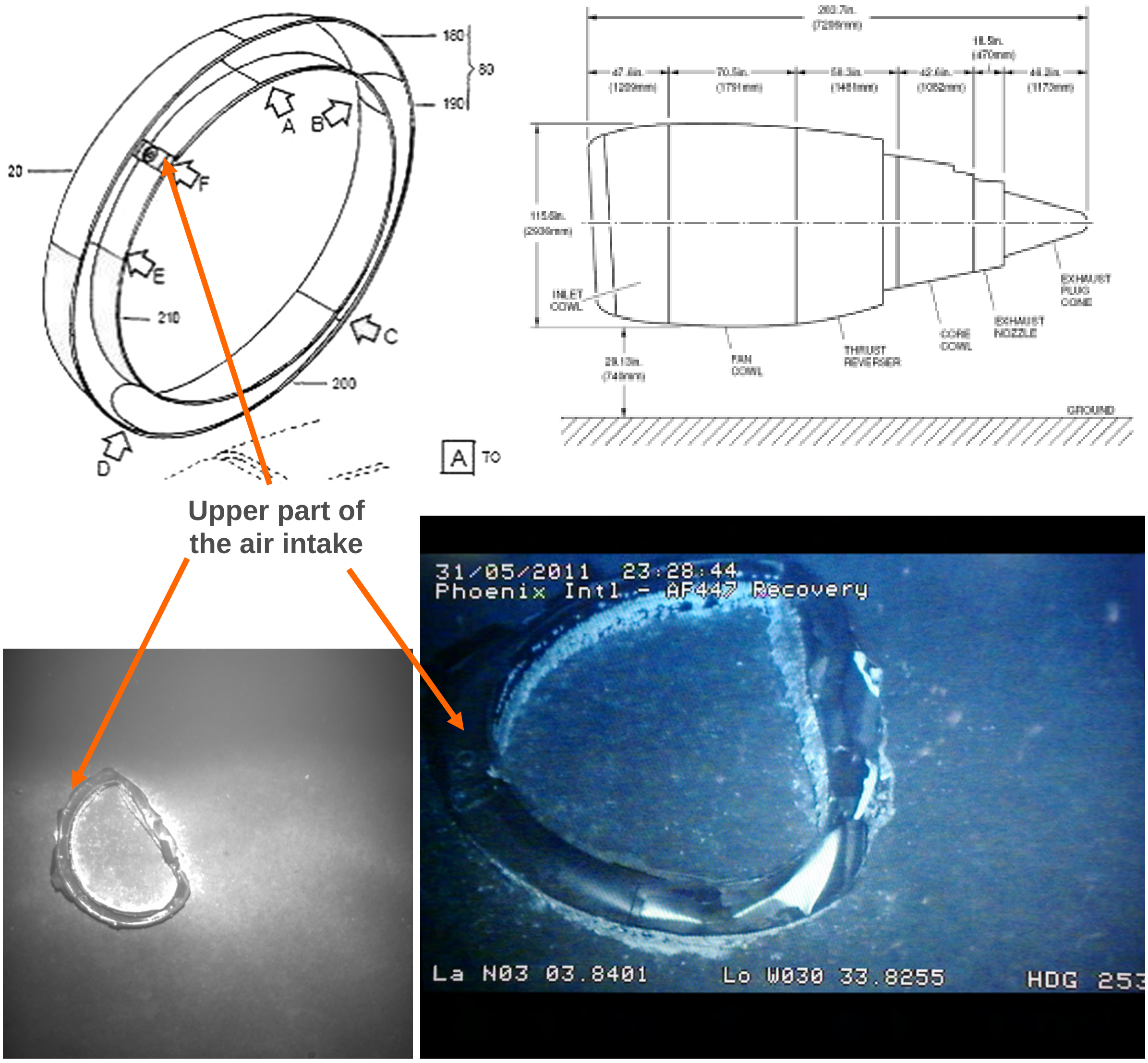
Both wing boxes had multiple ripped openings. The left wing suffered more damage than the right wing. The central wing box, despite its rigidity, was broken up.

The right half of the lower surface of the trimmable horizontal stabiliser, made of composite carbon fibre, had broken off on impact.

The level of debris fragmentation and deformation indicated very high energy on contact with the surface of the water.

1.12.4.1.1 Left engine air intake

From the images supplied by the AUV REMUS and by the ROV, the leading edge of the left engine air intake showed a significant rectilinear deformation on its lower part.



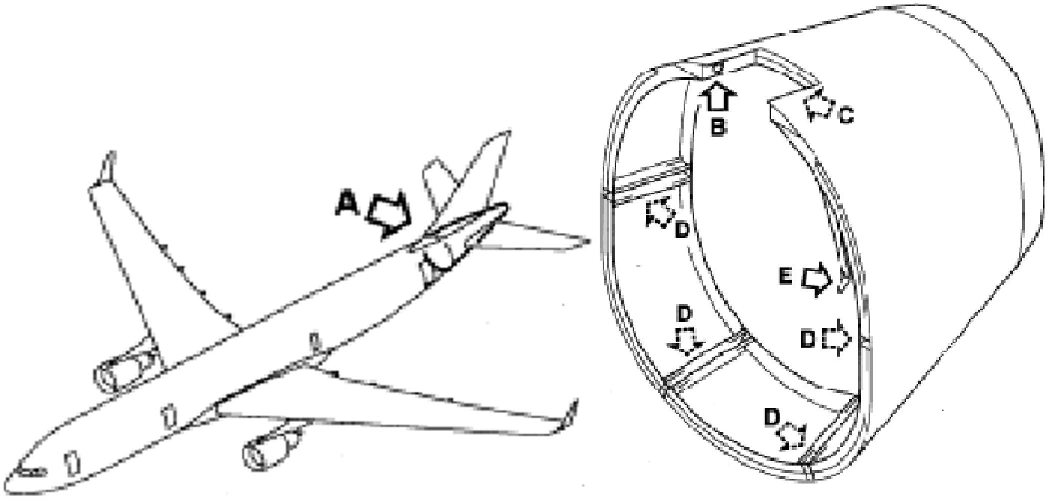
Left engine air intake

1.12.4.1.2 Engine pylons

The engine pylons were found separated from the wings. They had deformations compatible with stress on the engines from below to above.

1.12.4.1.3 APU exhaust

The APU exhaust broke off from the fuselage rear cone on impact. It had deformations on the whole of the lower section.

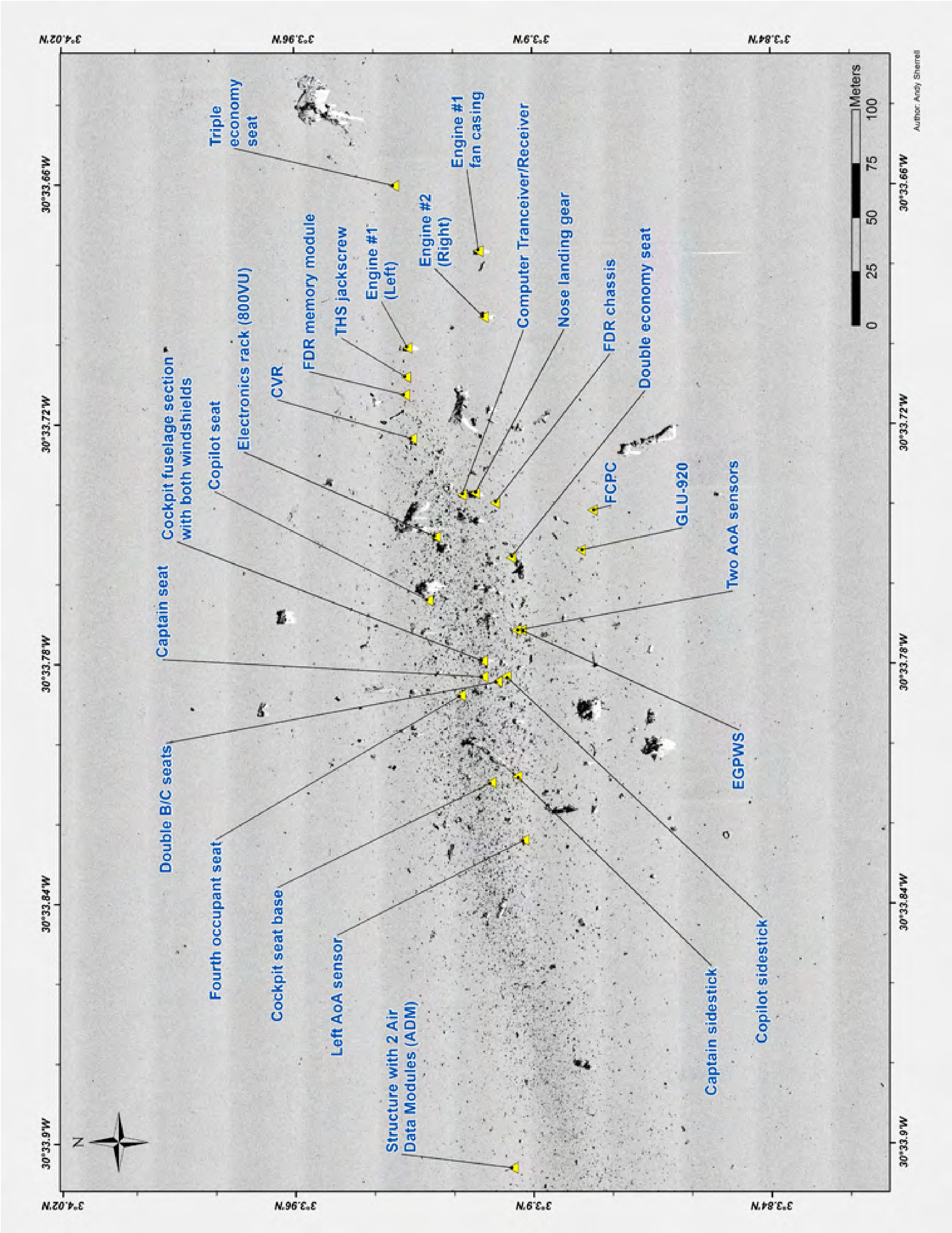


APU exhaust

1.12.4.2 Examination of elements brought to the surface

As well as the flight recorders that were found and brought to the surface respectively on 1st and 2nd May 2011, specific parts were raised for observation and examination on board the ship.

They are indicated on the map below and will ultimately be subject to more detailed examination whose results will be known after the publication of this report.



Map of parts brought to the surface

1.12.4.2.1 Initial observations on board

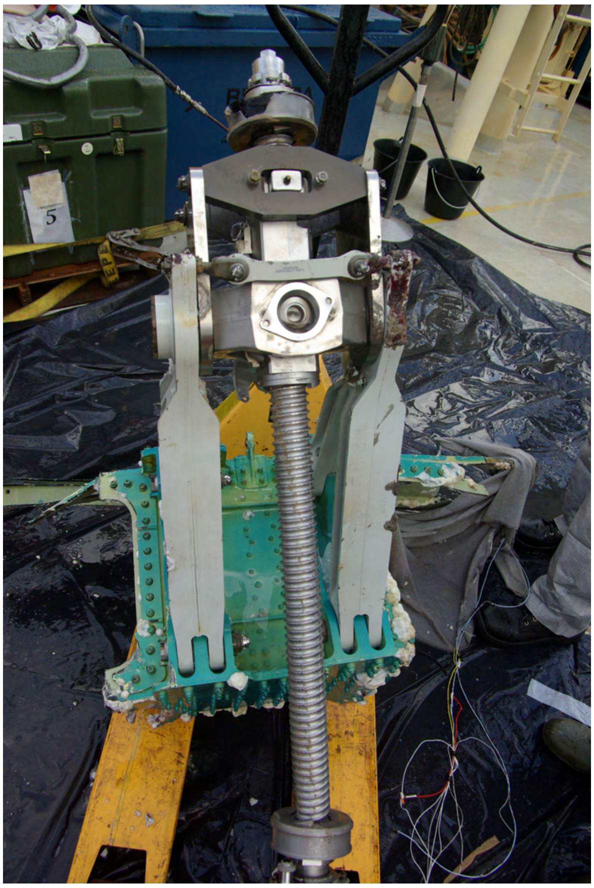
1.12.4.2.1.1 The engines

Both engines were visually examined. This examination showed that they were producing power at the time of impact.

1.12.4.2.1 2 The trimmable horizontal stabiliser screwjack

The trimmable horizontal stabiliser screwjack was recovered on 5 May 2011 by the REMORA ROV.

According to the manufacturer's technical documentation, the relative position of the actuator and the THS screwjack corresponded to a THS position of between 13° and 13.5° nose-up.



Trimmable horizontal stabiliser screwjack after being raised on board

1.12.4.2.1 3 The cockpit seats

On the left side seat the lap belts were attached, the crotch belts and the shoulder harnesses were not.

On the right side seat no belt was attached.

1.13 Medical and Pathological Information

Examination of the bodies recovered during phase 5 confirmed the observations reported in Interim Report n°2.

1.16 Tests and Research

1.16.4 Preliminary analysis of the operation of the systems

1.16.4.1 Analysis of the initial sequence

Based on the parameters saved in the FDR and on the analysis of the ACARS messages conducted since the accident, and presented in the first two interim reports, it may be stated that the monitoring of the airspeeds by the FMGEC and the EFCS was triggered by the same variations in airspeed parameters, and thus at the same time, between 2 h 10 min 04 and 2 h 10 min 05 UTC. The two airspeeds recorded were still valid at this time; however, a false value point is present in the recording of the Mach. The low sampling frequency makes it impossible to determine the duration of the disturbance in the measured values; however, it is likely that it corresponds to when monitoring was triggered.

This ADR rejection sequence will be specified in as much detail as possible, but in any case the triggering of the monitoring caused:

- the immediate disengagement of the auto-pilot (PA 2) and the transient disappearance of the associated flight director;

- the loss of the normal law between 2 h 10 min 05 and 2 h 10 min 06. The position of the rudder limiter, set by the rudder travel limitation unit (RTLU) was stuck at 2 h 10 min 04.5 and the non-availability of the RTLU function was recorded between 2 h 10 min 17.5 and 2 h 10 min 18.5.

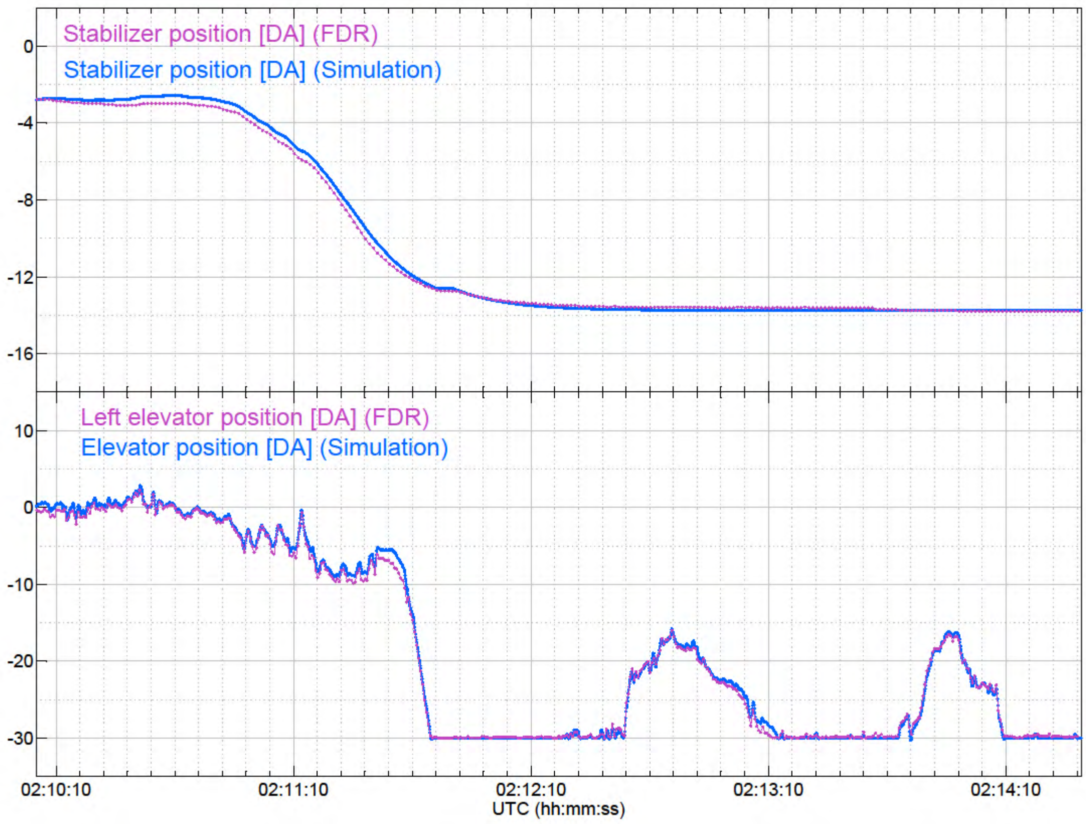
At 2 h 10 min 08, the two flight directors disappeared and auto-thrust was lost. This time interval was probably due to the fact that the three ADR were not rejected at the same time in the two FMGEC. The FMGEC which controls the active auto-pilot remembers any rejection of an ADR, and consequently does not behave in the same way as the other FMGEC which does not remember ADR rejection. Moreover, the auto-thrust function may be provided by either FMGEC, even if the one which controls the auto-pilot is normally the master.

The FMGEC were then behaving in the same way, which is logical since no auto-pilot was engaged.

1.16.4.2 Analysis of the flight control law

The flight control law switched from normal to *alternate* at about 2 h 10 min 05. The alternate law adopted was *alternate 2B* and it did not change again subsequently. Due to the rejection of the three ADR by the flight control computers (PRIM), the abnormal attitudes law could only have been triggered for criteria relating to inertial parameters, but these conditions were never met.

At the request of the BEA, Airbus conducted a simulation of the operation of the flight control computers, which involved recalculating the movements of the elevators and of the trimmable horizontal stabiliser (PHR) based on pilots' inputs and compare the results against FDR parameters. This simulation could be continued up until the end of the flight. The recalculated deflection angles for the elevators and the PHR are consistent with the parameters recorded.



Comparison between recorded elevator positions and the THS in the simulation

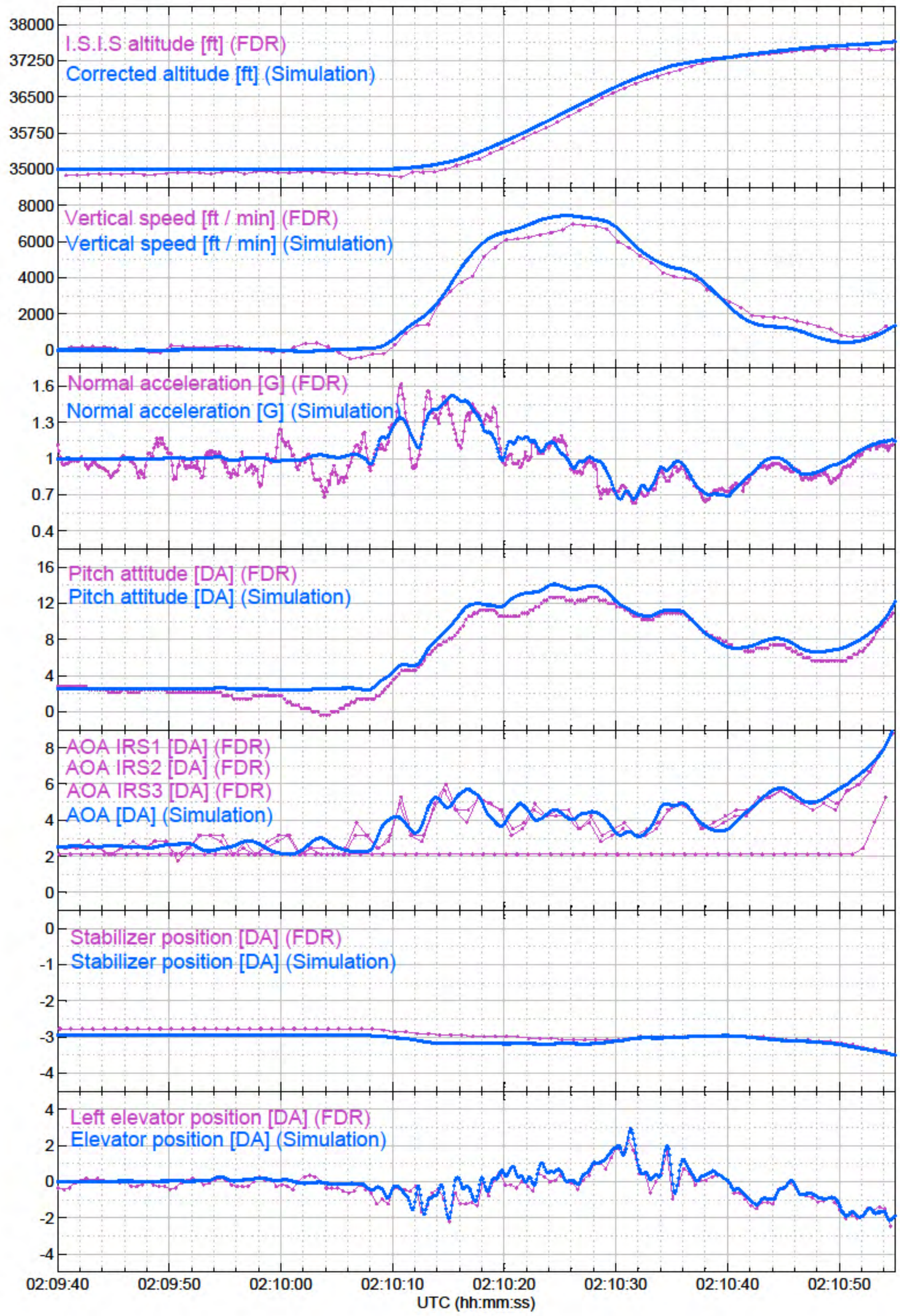
1.16.5 Analysis of aircraft performance

1.16.5.1 Aircraft behaviour

At the request of the BEA, Airbus conducted a simulation of the aircraft behaviour based on the theoretical model and on the actions of the PF (sidestick and thrust). The validity of the model is limited to the known flight envelope based on wind tunnel and flight tests data. Consequently, it was possible to conduct the simulation to mirror the period from 2 h 10 min 00 to 2 h 10 min 54. However, in view of the complexity of such a simulation, it was agreed that, initially, the simulation would be confined to the longitudinal axis, without introducing turbulence. The lateral parameters used are those recorded in the FDR.

A constant headwind component of 15 kt had to be added to make the simulation's ground speed match the parameter recorded. This value is consistent with the wind parameters recorded. The results obtained reveal that before approximately 2 h 10 min 40, i.e. the time when the aircraft was climbing at about 37,000 ft, the parameters recorded (angle of attack, normal load factor, and attitude) fluctuated around the simulated parameters, indicating the presence of turbulence. After this time, this turbulence appears to disappear and the parameters simulated and recorded are highly consistent.

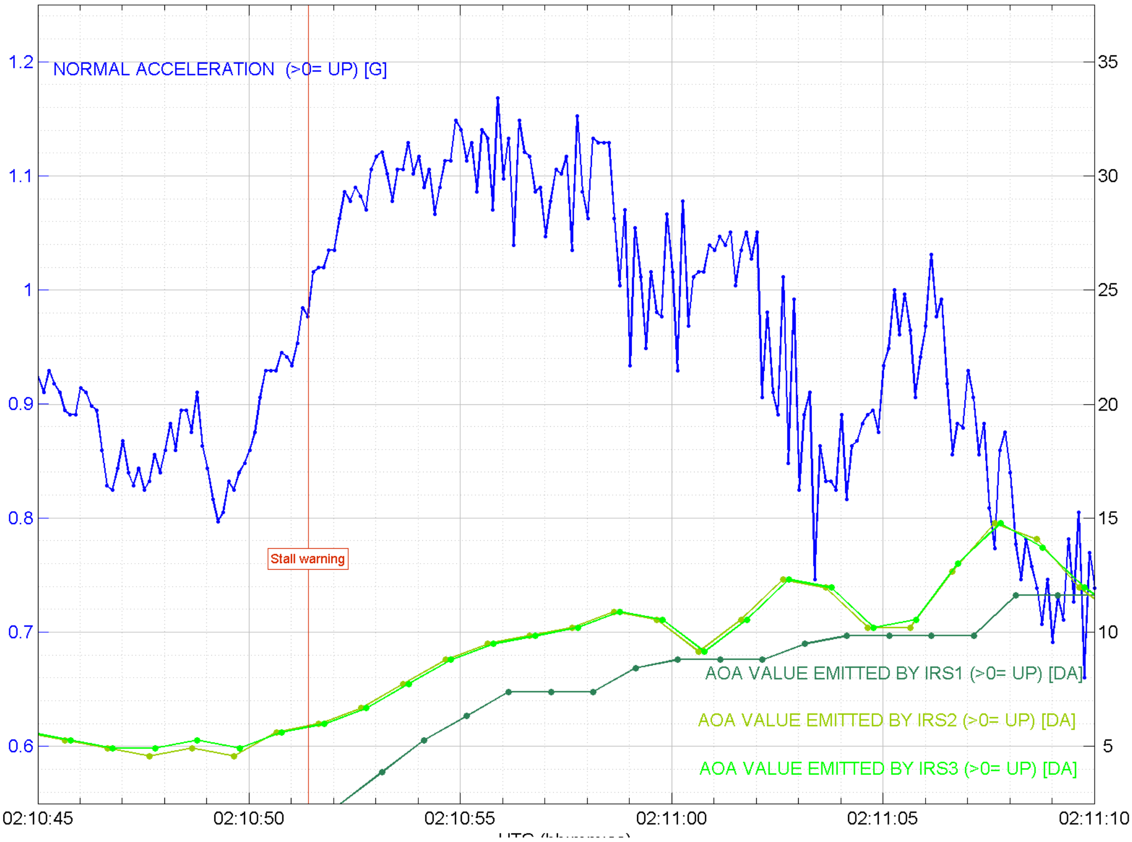
Consequently, it would appear at this stage in the work that the bulk of the aircraft movements in the longitudinal axis (attitude, vertical speed, altitude) result from the actions of the PF, with the exception of small variations that are probably due to the meteorological disturbances.



Comparison between the airplane attitudes and the simulation (longitudinal axis)

1.16.5.2 Analysis of the stall

At 2 h 10 min 51, when the aircraft was at about 37,500 ft and still climbing, the stall warning was activated (refer to 1.6.3). A change in the recorded normal acceleration behaviour was revealed from 2 h 10 min 53, at an angle of attack about 1 to 2 degrees greater than the warning activation threshold.



Evolution in the normal acceleration
recorded at the time of the triggering of the stall warning

This modification of the behaviour in the load factor at the centre of gravity results in the appearance of a high frequency component of an amplitude increasing to until about 0.1 g peak-to-peak, and with a signature that is very different from a turbulence signature of meteorological origin. Moreover, there is a noise on track 1 of the CVR, at about 2 h 10 min 55, which might be the impact of the microphone striking a wall, heard at a stable frequency.

Note: According to the simulation of the aircraft movements, at this time the turbulence observed in the first seconds of climbing had stopped.

Additional analyses were conducted with Airbus to determine if this phenomenon could correspond to buffeting. The difficulty with identifying this phenomenon lies in the fact that, on the one hand, the concept of buffeting is defined as accelerations at the pilots' seats and not at the centre of gravity and that, on the other hand, no flight test has been conducted under conditions that correspond exactly to those of the event (particularly in terms of Mach).

Note: Examination of flight test data revealed, based on the frequency and amplitude, that this signature could in fact be that of buffeting. By drawing analogies with the flight tests, the amplitude of 0.1 g at the centre of gravity suggests that the amplitude of the buffeting at the pilot seat is high (approximately 0.6 g peak to peak).

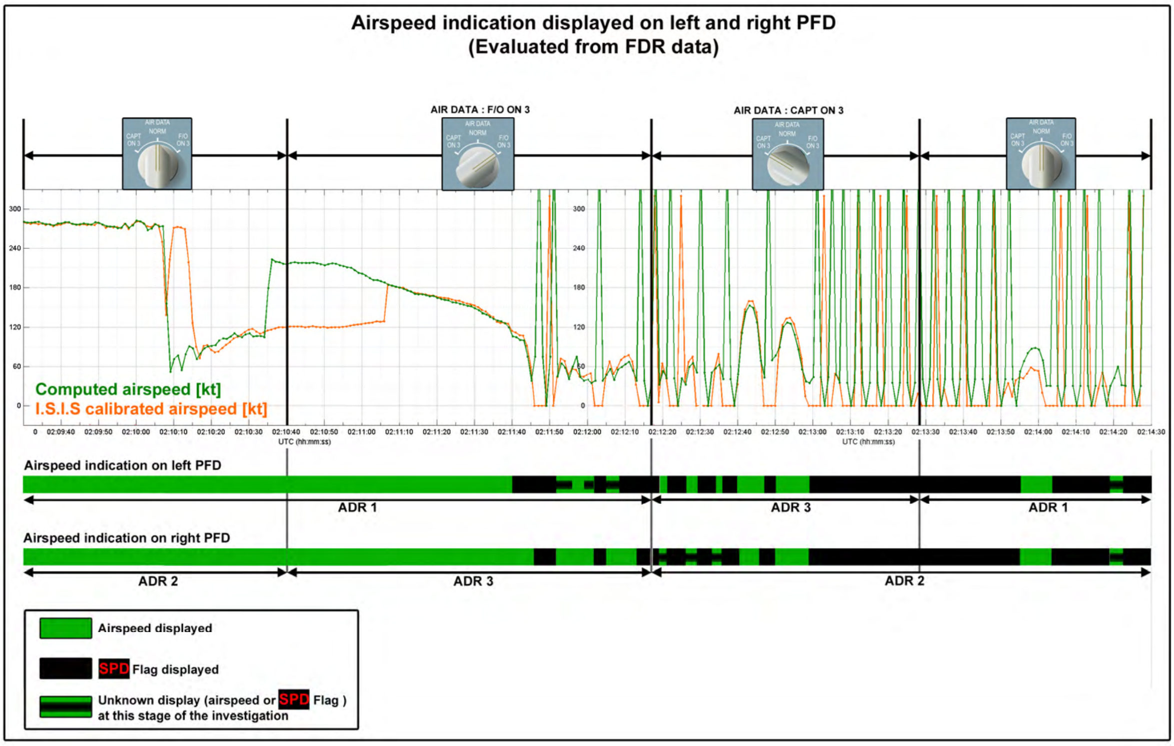
Thus, the stall warning was triggered at 2 h 10 min 51 at an angle of attack corresponding to the theoretical threshold for the measured Mach value. Two seconds later, vibrations that might correspond to buffeting appeared. The aircraft left the known flight envelope at about 2 h 10 min 54, and the angle of attack continued to increase.

1.16.6 Reconstruction of the information available to the crew

1.16.6.1 Preliminary analysis of the change in airspeed displayed on the PFD and ISIS

Analysis of the FDR data (refer to section 1.11.2) has provided an almost complete picture of the airspeed displayed on the left-hand PFD. The airspeed displayed on the right-hand side may be partially deduced from the recording logic and from the fact that the associated angle of attack value from the ADR becomes invalid if the airspeed is less than 60 kt (the systems consider that the airspeed is insufficient for the angle of attack sensor to provide reliable information).

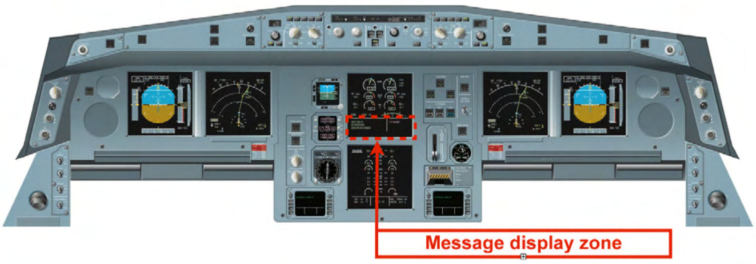
At this stage in the investigation, the changes in displayed airspeeds may be summarised as follows:



Evolution of the speeds displayed by the right and left PFDs

1.16.6.2 Analysis of the sequence of appearance of ECAM messages

The drop in the measured airspeed triggered monitoring within the various computers (refer to the analysis of the ACARS messages in interim reports 1 and 2), which in turn led to the loss of automatic systems and the appearance of ECAM messages.



Position of the area where ECAM messages are displayed

The table below lists the messages generated during the event, in order of priority and in a form similar to that in which it was displayed to the crew.

Note: The NAV ADR DISAGREE message is the only message in the sequence that is accompanied by an ECAM procedure.

Title	Theoretical symptoms	Time	Display Time
AUTO FLT AP OFF	cavalry charge + MW	02:10:05	02:10:05
NAV ADR DISAGREE -AIR SPD.........X CHECK •IF NO SPD DISAGREE -AOA DISCREPANCY •IF SPD DISAGREE -ADR CHECK PROC..APPLY	SC + MC	02:12:xx	02:12:xx
ENG THRUST LOCKED -THR LEVERS.........MOVE	SC + MC	02:10:08	02:10:15
AUTO FLT A/THR OFF -THR LEVERS.........MOVE	SC + MC	02:10:08	02:10:10
F/CTL ALTN LAW (PROT LOST) -MAX SPEED.......330/.82	SC + MC	02:10:06	02:10:08
F/CTL RUD TRV LIM FAULT RUD WITH CARE ABV 160 KT	SC + MC	02:10:18	02:10:19
F/CTL SEC 1 FAULT	SC + MC	02:13:39	02:13:41
F/CTL PRIM 1 FAULT	SC + MC	02:13:37	02:13:39
AUTO FLT REAC W/S DET FAULT	SC + MC	02:10:06	02:10:07
NAV TCAS FAULT	SC + MC	02:10:xx	02:10:xx

Seven lines are available on ECAM for the display of messages. If the number of lines required to display all the messages exceeds this number, a green arrow pointing downwards appears to indicate that other messages of lower priority have not been displayed. To make them appear, the crew must process the first messages, then clear them. It is not possible to know if any of the crew members cleared one or more ECAM messages during the event; however, no announcement to this effect was made.

If the assumption is made that no message was cleared, and without taking into consideration the NAV TCAS FAULT message, the statuses of the ECAM at different times would have been as follows:

ECAM displays at different moments (if no message has been erased)

1.16.6.3 Contribution from the analysis of the ACARS messages

Most of the maintenance messages analysed in the interim reports can be correlated with data extracted from the flight recorders.

This correlation confirmed the preliminary analyses written in the interim reports. Study of the transmission times between the computers that identified the triggering of the monitoring and the CMC also made it possible to explain and check the order in which the messages were sent by ACARS. This order may differ from the order of appearance of the ECAM messages.

The presence of the "FLAG FPV ON PFD CAPT (F/O)" message indicates that TRK-FPA (Flight Mode Annunciator) mode was selected by the crew during minute 2 h 11, but that the FPV was unavailable (see interim report 2 for details on the conditions of availability). Based on a study of the other relevant parameters it may be concluded that the FPV was selected between 2 h 11 min 48 and 2 h 11 min 54.

The end of the flight occurred shortly after the sending of the last maintenance message "Maintenance status ADR 2", which confirms the reason for the absence of an associated fault message: the correlation window open for a period of one minute did not close and the fault message was not sent.

The table in appendix 1 summarises the correlation made between the FDR data and the maintenance messages received.

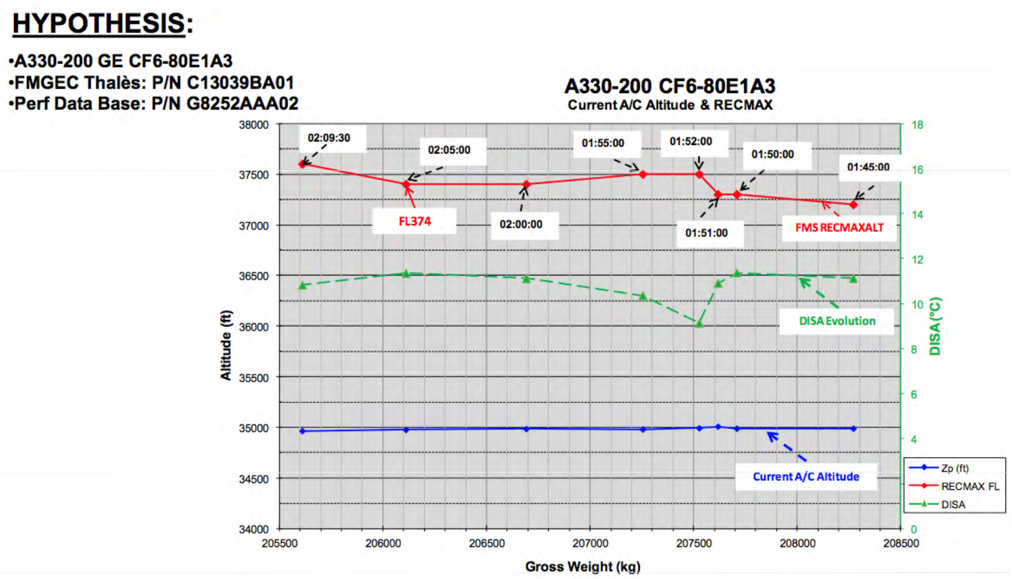
1.16.6.4 Calculation of the REC MAX

At the request of the BEA, Airbus conducted a simulation of the calculation of the REC MAX flight level by the FMS between about 1 h 45 and 2 h 09 min 30. In order to ensure that the calculation is representative of what might have been presented to the flight crew during the flight, the altitude of the tropopause that the crew entered in the INIT A page of the FMS had to be known. In view of the operational procedures in force at the time of the event, the default altitude proposed by the FMS (36,090 ft) was retained.

Based on the FDR parameters saved (notably the temperature and weight), the simulation shows that REC MAX varied only slightly over the period considered, between FL 372 and FL 376. The temperature difference compared with the standard atmosphere was fairly stable at about +11 °C, except between 1 h 51 and 1 h 59 during which the difference was smaller and the minimum of +9 °C was reached.

The REC MAX calculated at 1 h 45 was FL 372 and the overall trend of increasing altitude was approximately 100 ft per tonne of weight lost (i.e. about 9 minutes of flight). The drop in temperature at about 1 h 50 was expressed as reaching a local maximum of REC MAX at FL 375. It then reduced to about FL 374 at 2 h.

Note: At 1 h 52, the PF said to the captain "look, the REC MAX has changed to three seven five" which appears to correlate with the extreme recalculated REC MAX.



Evolution of the REC MAX (simulation) Source Airbus

1.16.7 Other on-going analyses

At this stage in the investigation, other analyses are still in progress. Notable amongst these are the attempts to recalculate the airspeed from ADR 2 in order to determine what was displayed on the PF's PFD and to be able to work out what instructions were displayed by the flight directors' crossbars. The airplane's movements in three axes will also be simulated to supplement the longitudinal analysis already performed and to quantify the turbulence experienced by the aircraft.

1.17 Information on Organisations and Management

1.17.2.3.3 Relief Captain and crew composition

Authority of the Captain

The Air France operations manual gives the Captain the function of command which includes taking all decisions required for carrying out the mission. The Captain is responsible for the entire execution of the flight and must intervene each time he or she deems it necessary.

In-flight relief Captain

Regulations[6] state that the Captain may delegate flight planning to a Captain or, for operations performed above FL200, to another pilot. The latter must satisfy the following requirements:

- A valid commercial pilot's license,
- An adaptation course and operator's check (including the aircraft type rating),
- All the specified recurrent training and periodic checks,
- The specified route qualification.

[6] European Commission Regulation No 859/2008 of 20 August 2008 called EU-OPS appendix 1 to OPS 1.940

In the Air France operations manual applicable on the day of the accident, the Captain's replacement was a copilot designated as *relief pilot*. As such, he made the necessary operational decisions for flight planning according to the Captain's instructions. He stayed in the right seat and from this seat carried out the PF function. He performed tasks marked "C" in the check-lists and emergency procedures.

It falls to the Captain, from flight preparation, to distribute the tasks of each of the crew members and to define the possible field of intervention of the relief pilot(s) during the flight when the basic crew is at the controls.

Before any prolonged absence, the Captain:

- Designates his or her replacement in compliance with part A of the operations manual,
- Confirms the new task-sharing,
- Specifies to the pilots the conditions requiring his or her return to the cockpit.

Note: The investigation has not made it possible to determine any task-sharing by the Captain at the time of flight preparation.

Specific briefings for flights with additional flight crew

According to the Air France operations manual, before the Captain takes a rest period, a briefing must be given and the following points mentioned:

- Route: follow-up and resources used. ATC clearances and contact frequencies,
- Aircraft: Technical condition. Review of fuel consumption, remaining fuel and configuration of the fuel system,
- Meteorology: relevant information on the journey.

In the present case, after the relief pilot took his position in the left seat, the copilot in the right seat started a briefing in the presence of the Captain. He mentioned:

- The presence of past and future turbulence,
- The fact that they were passing through a cloud layer,
- That they could not climb owing to a higher temperature than forecast and so the REC MAX was "a little too low",
- HF contact with the Atlantico centre and the failed logon with the Dakar centre,
- The contact made with *dispatch*.

During this briefing, the Captain noted the Dakar Oceanic HF frequencies at the request of the copilot in the left seat.

The Captain then left the cockpit without specifying the conditions that would require his early return.

1.17.3 Onboard weather radar

1.17.3.1 Background

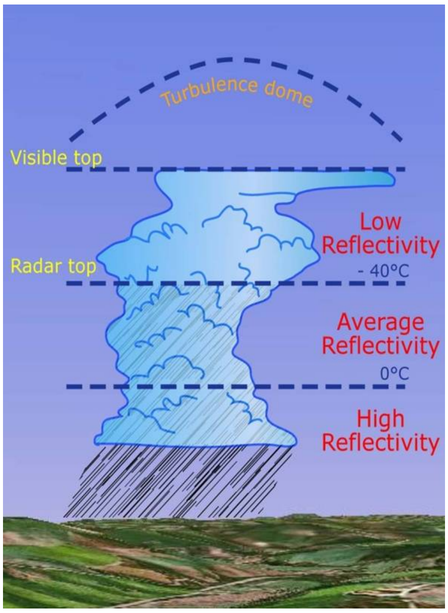
Weather radar is designed to detect precipitation: it helps to identify that associated with the most active convective cells in order to avoid the dangers associated with them (turbulence, hail and lightning).

Weather radar can detect water in liquid form, such as rain and wet hail. However, it hardly detects water in solid form such as dry snow and ice crystals. It can partly detect dry hail depending on the size of the hailstones.

In a convective cell, in the part situated below freezing point (0 °C)[7], liquid precipitation constitutes the most reflective areas. Below -40 °C[8] water no longer exists in general in a liquid state. In the part of the cumulonimbus between freezing point and the altitude where the temperature reaches -40 °C, liquid water and ice crystals produce areas where reflectivity decreases depending on the variation of the presence of liquid water. In the part above the altitude where the temperature reaches -40 °C, where there are only ice crystals, reflectivity is very low.

Areas returning most of the radar signal may be harmless for flight, like melted snow showers for example, whereas hail showers which constitute a genuine threat to navigation may only return a weak radar echo.

When cumulonimbus clouds swell swiftly, they may be overtaken by a zone of severe turbulence which could stretch several thousand feet above the visible peak. This turbulence zone is invisible to weather radar and the naked eye[9].



Anatomy of a cumulonimbus

The representation of the same cumulonimbus cloud will therefore be totally different depending on the part of the cloud that is scanned by the radar beam.

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[7] At FL 75 in standard atmosphere.
[8] At FL 275 in standard atmosphere.
[9] The TURB function, which uses the principle of the Doppler effect, only helps detection of turbulence in wet zones.

Cloud mass reflectivity depends on the type of air mass and on the season. Cumulonimbus reflectivity is not the same in temperate regions and below the equator. An oceanic cumulonimbus reflects radar waves less than a continental cumulonimbus cloud of the same size and height.[10]

Gain, *tilt* and the ND scale enable pilots to adjust the weather radar. Gain defines the level ratio between the signal received and the signal emitted according to the distance of the echoes. The CAL position of the gain control sets radar sensitivity at the standard calibrated level of reflectivity. The equivalence in precipitation is thus associated with a colour of the echoes presented on the ND:

COULEUR DES ECHOS	NIVEAU	EQUIVALENCE EN PRECIPITATIONS
NOIR (pas d'écho)	1	< 1 mm/H
VERT	2	1 à 4 mm/H
JAUNE	3	4 à 12 mm/H
ROUGE	4	>12 mm/H
MAGENTA (si installé)	TURB	Effet Doppler

Extract from Air France A330/340 operations manual

The gain control allows the manual adjustment of radar sensitivity for a more precise evaluation of atmospheric conditions.

Tilt is the angle between the horizontal and the centre of the radar beam. The *tilt* control enables the range explored in the vertical plane to be varied manually. Depending on the altitude of the aircraft, at a specific *tilt,* the radar beam is reflected by the ground. Ground echoes are then present on the radar image.

Collins control unit

Adjusting the ND scale enables monitoring at varying distances of the aircraft.

Heavy precipitation that returns most of the radar signal may also hide another disturbed area situated behind.

Representation of the weather situation by crews is thus mainly linked to the use of the 3 setting parameters and their knowledge of radar, particularly of its limitations.

[10] The Ice Particle Threat to Engines in Flight (Mason Strapp Chow).

Onboard radar does not directly detect dangers to be avoided and has specific limitations which require active monitoring from the pilots and constant analysis of the images presented to limit the risk of underestimating the danger of the situation. It should be noted that, at the time of the accident, the presence of ice crystals at high altitude was not considered to be an objective danger and that crews were not made aware of this.

1.17.3.2 Air France instructions for use

1.17.3.2.1 Operator's documentation

The following documents include information on the operation and use of weather radar:

- the General Operations manual, called GENOPS describes the general use policy for weather radars for the prevention of hazards associated with storms,
- the TU 330 and TU 340 aircraft operating manuals describe the weather radars that these aircraft are equipped with as well as their operating procedure based on Airbus documents,
- training material associated with type ratings describe the weather radar system and its use,
- the MAC.

1.17.3.2.2 Instructions for use of weather radar

In cruise mode above 20,000 feet, a slight downwards adjustment of *tilt*, depending on the scale selected, is recommended so that the ground echoes only appear on the ND at the edge of the furthest distance circles. This method enables the simple and practical application of the height/*tilt* rule of equivalence providing the optimum *tilt* adjustment.
When pilots monitor the weather situation, gain can remain in CAL position. In the confirmed presence of storms and during their avoidance, a manual adjustment can be used for comparison with the CAL image.

A scale of 160 NM enables the change in the weather situation to be assessed and anticipate route changes. A scale of 80 NM is used for avoidance. Short scales must be periodically discontinued in order to observe distant weather conditions and to avoid an impasse amid the disturbances.

The shape of the echoes may alert the crew to the possible presence of hail. Zones of turbulence may be presented above a detected zone of precipitation.

Red or magenta zones as well as fringe-shape echoes must in this way be by-passed from windward by regularly adjusting the *tilt* and the *range*. The avoidance decision must be taken before the echoes are at 40 NM.

The operator recommends avoiding flying less than 5,000 ft above or below a storm cell. It provides a formula for pilots to estimate the separation height between the top of a detected cell and the airplane. This formula uses the distance and the *tilt* points from which the zone echo disappears. Above 23,000 ft, it is recommended to fly more than 20 NM from these zones[11].

1.17.3.1.3 Additional documentation for the crew

The MAC is not part of the operations manual. It contains information enabling pilots to update and keep up their theoretical and practical knowledge. It contains a detailed chapter on weather radar, its use and illustrations of typical echoes for dangerous phenomena. This chapter was drafted based on information and recommendations transmitted by Collins, the radar manufacturer.

In addition Air France regularly transmits information on the hazards associated with convective environments and on the use of radars to anticipate them. Previous to June 2009, the following communications can be quoted: a flight safety news flash, articles published in the flight safety bulletin (*Sûrvol*), a publicity campaign, a special issue bulletin on radar, conferences given in the context of recurrent training, type ratings or route training.

Information received from Airbus is analysed by Air France, which decides on the necessity of passing it on to its crews.

1.17.3.3 Airbus documentation

On 1 June 2009 the operation and use of radar were contained in the following Airbus documents:

- Flight Crew Operating Manual (FCOM):
  SUPPLEMENTARY TECHNIQUES / NAVIGATION / WEATHER RADAR

- Flight Crew Training Manual (FCTM) :
  SUPPLEMENTARY INFORMATION / USE OF RADAR
  SUPPLEMENTARY INFORMATION / TURBULENCE / IN-FLIGHT/ USE OF THE RADAR

These 2 documents from the FCTM are to be used in the context of pilot training, whether type rating or during recurrent training.

Two additional documents are also available:

- Flight Operations Briefing Notes – "*Adverse Weather Operations, Optimum Use of the Weather Radar*"

- Getting to grips "*Surveillance*"

This information was also provided during conferences dedicated to operators and via publications (*Safety First*).

[11] Compensated by 50%, that is 30 NM for U- or finger-shape echoes or with scalloped edges (storms, presence of hail).

The manufacturer indicated that the assessment and detection of cells was done by gradually reducing the gain from the calibrated value: the last echoes that turn yellow express the most active zones.

The manufacturer recommended using a 160 NM scale for the PNF and 80 NM for the PF.

For cruise the manufacturer specified the *tilt* value to use according to the scale:

FLIGHT PHASE	DETECTION AND MONITORING PROCEDURES	COMMENTS
CRUISE	Use TILT slightly NEGATIVE to maintain ground returns on top of ND: Range 320 TILT≅ 1 DN Range 160 TILT≅ 1,5 DN Range 80 TILT≅ 3,5 DN Range 40 TILT≅ 6 DN In higher altitudes, closing weather: - Decrease ND - TILT down Use TURB to ISOLATE Turbulence - GAIN to AUTO.	No ground returns beyond line of view. Dnm = 1,23 $\sqrt{ALT}$ ft FL 370 D 240nm Poor ground returns over calm sea / even ground.

Extract from FCTM A330/A340

The manufacturer advised against flying below a storm cell. It notes that there may be strong turbulence 5,000 feet above the detected echo and that storms with peaks above 35,000 feet are dangerous.

1.17.4 Air France crew operational instructions

1.17.4.1 Instructions by the operator

- Method for processing a failure: Any flight deck crew noticing an anomaly, whether effective or setting in, must inform the rest of the crew without delay.

Before any other action, the Captain must secure the aircraft flight path and define the task-sharing.

The failure must then be processed using the following sequence:

- Confirmation of the type of failure
- Application of check-lists or abnormal procedures and possible system resetting,
- Technical, operational and commercial assessment
- Decision on the rest of the flight
- Information to: ATC, cabin crew, airline (OCC, Maintenance, etc), passengers.

- Emergency manoeuvre: The content and task-sharing for an emergency manoeuvre must be known from memory by all flight deck crew.

- Action-check: When he or she acts on a system or control in the cockpit, the pilot must do it in two distinct phases:

  - Action: the pilot acts on the control,
  - Check: the pilot ensures that the result of his action complies with his initial intention.

- Cross check: Pilots must complement each other and cross check each other mutually to ensure flight safety and this mutual check applies to all tasks: trajectory handling, systems implementation, ATC communications, etc. Any discrepancy noted in relation to the planned flight profile or to standard procedures must be clearly called out.

- Technical callouts: The use of technical callouts formalises exchanges and facilitates communication within the cockpit, particularly in phases with heavy workloads. Technical callouts are used to transmit a command, initiate an action or inform the other flight deck crew, particularly in the event of a failure, anomaly or deviation.

The operator's standard callouts are given in appendix 2.

1.17.4.2 Definitions provided by the operator

- Emergency manoeuvre: An immediate action performed from memory when the safety of the flight is directly compromised. It is noted ion the QRH for individual skills maintenance.

- Emergency procedure: Action performed from a *do-list* when the safety of the flight is directly compromised:

  - Dangerous configuration or at the edge of the flight envelope,
  - Failure of a system degrading the safety of the flight.

- Backup procedure: action performed from a *do-list* when the safety of the flight is not directly compromised:

  - Failure of a system that has no immediate consequence on the safety of the flight ,
  - Failure causing the loss of redundancy or degradation of a system.

- Additional abnormal procedure: Abnormal procedure linked to a degradation of an airplane system that does not require the application of an emergency or backup procedure.

Note: The standard handling of an abnormal additional procedure is as follows: complete readout by the PNF of the procedure then performance of the procedure from a *do-list* with manual control.

1.17.4.3 Manufacturer's terminology

- Memory item: The following procedures are to be applied without referring to paper: immediate actions of UNRELIABLE SPEED INDICATION/ADR CHECK PROC

- Abnormal or emergency procedures: Maintain adequate safety and help to ensure the conduct of the flight. The flight crew uses the "READ and DO" oral reading principle when performing these procedures

- Supplementary Techniques: Some normal procedures, that are non routines will be found in the SUPPLEMENTARY TECHNIQUES CHAPTER (3.04)

1.18 Additional Information

1.18.5 Evolution of the unreliable speed indication procedure

Air France translated the title of this procedure by "Flight with unreliable IAS".

The first member of the crew to obtain his A320 type rating within Air France was the copilot in the left seat, in November 1998. At this date, the flight procedure with unreliable IAS in force at Air France was dated 23 April 1998:

A319/320/321
AIR FRANCE
DT-NT

Procédures anormales
URGENCE / SECOURS
ATA 34 - NAVIGATION

TU **03.02.34.89**
23 AVR 98
A320

VOL AVEC IAS DOUTEUSE (A320)

Une indication de vitesse non fiable peut être la conséquence de l'endommagement du radôme ou d'un défaut de sonde pitot ou de prise statique (panne réchauffage, obstruction, déformation etc...).

ATTITUDE / POUSSEE..AJUSTEES
Ajuster l'assiette et le N1 en fonction du tableau ci-après.

ATTENTION

Si la défaillance est due à l'endommagement du radôme, la traînée sera plus importante. En conséquence, le N1 devra être augmenté de 5 % (FF augmentera d'environ 27 %).

Bouton d'or

A319/320/321
AIR FRANCE
DT-NT

Procédures anormales
URGENCE / SECOURS
ATA 34 - NAVIGATION

TU **03.02.34.90**
23 AVR 98
A320

PHASE DE VOL	MASSE	NIVEAU DE VOL	ASSIETTE	N1
DECOLLAGE (V2 + 10)			13°	TO ou FLX
ACCELERATION F			+ 14°	CL
ACCELERATION S			+ 10°	CL
MONTEE (280 kt/M 0.76)		0 à 100	+ 7°	CL
		100 à 200	+ 5°	
		> 200	+ 3°	
CROISIERE (280 kt/M 0.76)	≥ 55 t	50	+ 2°	67 %
		150	+ 2°	75 %
		250	+ 2°	82 %
	< 55 t	50	+ 2°	65 %
		150	+ 2°	72 %
		250	+ 2°	79 %
DESCENTE (M 0.76/280 kt) Ne pas utiliser les SPEED BRAKES (effets trop importants sur l'assiette)			- 2°	IDLE
APPROCHE Sélection VOLETS 1 - 2 - 3	40 à 50 t		+ 5°	53 %
	50 à 60 t		+ 7°	58 %
	60 à 70 t		+ 7°	63 %
Sélection VOLETS FULL	40 à 50 t		+ 7°	58 %
	50 à 60 t		+ 7°	63 %
	60 à 70 t		+ 7°	68 %
APPROCHE FINALE (PENTE -3°, VREF + 10)	40 à 50 t		+ 1.5°	48 %
	50 à 60 t		+ 1.5°	52 %
	60 à 70 t		+ 1.5°	57 %

Bouton d'or

Extract from the Operations Manual

The following table summarises the evolutions in this procedure:

	FCOM / TU	QRH
November 1997	Airbus A320 FCOM Rev 24	Airbus A320 Rev 24
April 1998	Air France (03.02.34.89) ATA 34 Navigation	Air France: no procedure in the QRH
July 1998	Airbus A320 Rev 26	Airbus A320 Rev 26
November 1998	A320 type rating: copilot in left seat	
December 1999	Air France: ATA 34 Navigation Appearance of immediate actions Distinction between immediate actions et actions when flight stabilised	
May 2001	A320 CDB type rating	
October 2001	Airbus: Self-learning module including PowerPoint briefing of erroneous speeds (standard type rating)	
June 2002	Airbus A320 Rev 35 : Procedure shift from various (03.02.80) to Navigation (03.02.34) Additional note on application conditions of the *Unreliable Speed* Vs ADR Check Description of symptoms and consequences of *Unreliable Speed Indication*. Description of the application conditions according to the impact or not on the conduct of the flight	Airbus A320 Rev 35
31 October 2002	Air France: 3.02.34.85 Explanatory note on the context of use of ADR Check and unreliable IAS procedures. Application rule for unreliable IAS Vs ADR Check procedures	
June 2004	Airbus: Vol 3. inclusion of the 810/1 bulletin: notes and details on systems and *Unreliable Speed* procedure (including a list of possible symptoms linked to erroneous speed or altitude information, among which the possible existence of *undue stall warning*)	

	FCOM / TU	QRH
September 2004	A320 type rating copilot in right seat	
September 2005	Airbus A320 Rev 39: immediate actions highlighted by a box	Airbus A320 Rev 39
October 2005	Air France: appearance of the emergency manoeuvre	Air France: appearance of the emergency manoeuvre
July 2006	Airbus A320 Rev 40 : Fusion ADR Check et *Unreliable Speed* “Immediate actions” become “memory items”. Note : FCTM additional explanation on the “Unreliable speed indication situation and associated procedures”	Airbus A320 Rev 40
October 2006	Air France 03.01.01.03 ”Abnormal Procedures – Emergency manoeuvres”: development of the explanatory note, detailing the need to respect the STALL warning not affected by erroneous speeds	
February 2007	Air France : specifies that FD switch-off is performed by each pilot	
2008	Airbus: new FWC T2 standard	Change of denomination of the ECAM **F/CTL** ADR DISAGREE en **NAV** ADR DISAGREE warning
March 2009	Air France: TU 03.02.34.145 Update of Flight attitude / thrust values according to flap config Addition of a line requesting level flight at safe or holding altitude.	

A330/340
AIR FRANCE
OA.NT

Procédures anormales
MANOEUVRES D'URGENCE

TU **03.01.01. 03**
15 FEB 07

IAS DOUTEUSE

SI CONDUITE DU VOL AFFECTEE DANGEREUSEMENT,
le CDB annonce "IAS DOUTEUSE", effectuer les actions immédiates suivantes :

PF	**AP**	**OFF**
C/P	**FD 1 et 2**	**OFF**
PF	**A/THR**	**OFF**
PF	**POUSSEE / ASSIETTE**	**SELECTEES**

➤ Avant la réduction de poussée :

- **POUSSEE / ASSIETTE *(A330)*** . . . . . **TOGA / 15°**
- **POUSSEE / ASSIETTE *(A340)*** . . . . . **TOGA / 12°5**

➤ Après la réduction de poussée :

- Au dessous du FL 100
  - **POUSSEE / ASSIETTE** . . . . . **CLB / 10°**
- Au dessus du FL 100
  - **POUSSEE / ASSIETTE** . . . . . **CLB / 5°**

PNF	**VOLETS**	**CONFIG MAINTENUE**
PNF	**SPEED BRAKES**	**VERIFIES RENTRES**
PNF	**TRAIN**	**RENTRE**

Respecter les alarmes décrochage.
LORSQUE LA TRAJECTOIRE EST STABILISEE,
se référer à la procédure URGENCE / SECOURS non ECAM "VOL AVEC IAS DOUTEUSE / ADR CHECK PROC" (QRH 1.34.xx ou TU 03.02.34.1XX).

"Unreliable IAS" in force at the time of the accident

1.18.6 Evolutions in the "STALL" procedure

The first member of the crew to obtain his QT A320 type rating was the left seat copilot, in November 1998.

At that time, there was no STALL procedure in the Air France Operations Manual.

Since November 1997, Airbus has had the following procedure in force in the FCOM volume 3.

A319/320/321 FLIGHT CREW OPERATING MANUAL	SUPPLEMENTARY TECHNIQUES	3.04.27	P 6
	FLIGHT CONTROLS	SEQ 001	REV 24

ABNORMAL CONTROL LAWS - IN DETAIL

ALTERNATE LAW

Pitch

Alternate law in pitch is almost the same for the pilot as the normal control laws. However, alternate law does not maintain any of the protections except maneuver protection. As a result, the pilot must fly the aircraft more attentively so as to avoid exceeding the normal limits inadvertently.

Alternate law reduces VMO in order to restore a normal aircraft speed margin to VDF in case of upset (320 knots). This is not necessary in the Mach range because the margin there is in any case conventional.

R An aural stall warning "STALL, STALL, STALL" sounds at low speeds. Upon hearing it, the pilot must return to the normal operating speed by taking conventional actions with the controls :

R THRUST LEVERS . . . . TOGA

R At the same time :

R PITCH ATTITUDE . . . . REDUCE

R BANK ANGLE . . . . ROLL WINGS LEVEL

R SPEEDBRAKES . . . . CHECK RETRACTED

R · If a danger of ground contact exists reduce pitch attitude no more than necessary to allow airspeed to increase. After initial recovery maintain speed close to VSW until it is safe to accelerate.

R · If below 20000 feet and if in clean, select FLAP 1.

R · Out of stall, when no threat of ground contact :

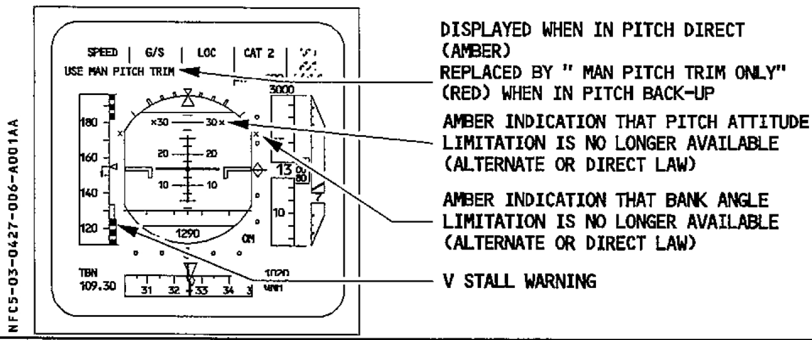
R LANDING GEAR . . . . UP

R – Recover to normal speeds and select flaps are required.

R – In case of one engine inoperative use power and rudder with care.

The aural stall warning may also sound at high altitude, where it warns that the aircraft is approaching the angle of attack for the onset of buffet. To recover, the pilot must relax the back pressure on the sidestick and reduce bank angle, if necessary. When the stall warning stops, the pilot can increase back pressure again, if necessary, to get back on the planned trajectory.

R



Extract from the FCOM

The following table summarises the evolutions in this procedure:

	FCOM / TU	QRH
November 1998	A320 type rating copilot in left seat	
December 1999	Air France: Additional Abnormal Procedure 03.03.27.01	
May 2001	A320 type rating Captain	
September 2004	A320 type rating copilot in right seat	
July 2006	Airbus A320 Rev 40: Addition of note on possibility of STALL warning on take-off if AOA sensor damaged. Introduction of distinction between take-off and other flight phases	
September 2006		Air France: Procedure in the PAC list (04.30.01)
February 2007 (330/340) October 2007 (320)	Air France Addition of note on possibility of STALL warning on take-off if AOA sensor damaged leading to the appearance of the distinction on take-off and the other flight phases. Procedure in force at time of the accident.	

A330/340 — AIR FRANCE — OA.NT

Procédures anormales complémentaires
ATA 27 - COMMANDES DE VOL

TU 03.03.27. 01
15 FEB 07

ALARME "STALL"

Cette alarme peut apparaître en loi ALTERNATE ou DIRECTE à l'approche du décrochage : une voix synthétique "STALL, STALL, STALL" retentit accompagnée d'une alarme sonore (cricket). Cependant une fausse alarme "STALL" peut retentir en loi normale juste après le décollage si une sonde AOA est endommagée. Dans ce cas, le pilote doit immédiatement reprendre une vitesse opérationnelle normale en agissant sur les commandes :

➤ Au décollage :

PF **MANETTES DE POUSSEE.................................... TO.GA**

En même temps :

PF **ASSIETTE LONGITUDINALE.................................... 12.5°**

PF **INCLINAISON.................................... AILES HORIZONTALES**

PF **SPEED BRAKES.................................... VERIFIES RENTRES**

Note : *Une fois que la trajectoire et la vitesse sont rétablies, si l'alarme est toujours active, la considérer comme une fausse alarme.*

➤ Dans toutes les autres phases :

PF **MANETTES DE POUSSEE.................................... TO.GA**

En même temps :

PF **ASSIETTE LONGITUDINALE.................................... REDUITE**

PF **INCLINAISON.................................... AILES HORIZONTALES**

PF **SPEED BRAKES.................................... VERIFIES RENTRES**

ATTENTION

S'il existe un risque de contact avec le sol, ne pas réduire l'assiette plus que nécessaire pour permettre une augmentation de vitesse.

- Après arrêt de l'alarme initiale :
  Maintenir la vitesse proche de VSW jusqu'à ce qu'il soit possible d'accélérer.

A330/340 — AIR FRANCE — OA.NT

Procédures anormales complémentaires
ATA 27 - COMMANDES DE VOL

TU 03.03.27. 02
15 FEB 07

- Si avion en-dessous de 20000 ft en configuration lisse :

PNF **VOLETS.................................... 1**

Après arrêt de l'alarme, quand il n'y a plus de risque de contact avec le sol :

PNF **TRAIN.................................... RENTRE**

- Retrouver une vitesse normale et positionner les volets comme nécessaire.
- En cas de perte d'un réacteur, utiliser la puissance des autres réacteurs et la direction avec précaution.

L'alarme sonore "STALL" peut également retentir à haute altitude, où elle avertit que l'avion approche l'incidence où débutent les vibrations. Pour l'arrêter, le pilote doit relâcher la pression à cabrer exercée sur le manche et diminuer l'inclinaison si nécessaire.
Quand l'alarme de décrochage s'arrête, le pilote peut retirer sur le manche, si nécessaire, pour retourner sur la bonne trajectoire.

Note: Stall and stall recovery exercises are undertaken during initial pilot training (in particular basic training, private pilot, professional pilot).

➢ Subsequent evolutions

Following several loss of control accidents at low altitude, an FAA / Industry working group including Airbus, Boeing, Bombardier and Embraer defined a generic stall procedure. It deals with both approach to stall and stall recovery and is detailed by airplane type.

- **Airbus**

The procedures were modified by Airbus in May 2010: replacement of the “Stall warning” additional abnormal procedure by the “Stall recovery” and “Stall warning at lift-off” procedures.

- **Air France**

Modification of the stall procedures following the modification of the “STALL” procedures by the manufacturer and training of crews for these new procedures through the establishment of a new Emergency Manoeuvres session:

- Airbus fleet: Summer 2010
- Boeing fleet: Spring 2011
- Brochure and briefing: technical reminders, HF aspects and TEM
- New Emergency Manoeuvre(s) (triggering of the STALL warning)
- *Upset Recovery*
- Visual illusions

Note: these elements have been integrated into the type rating.

1.18.7 Operator information on anomalous speed situations

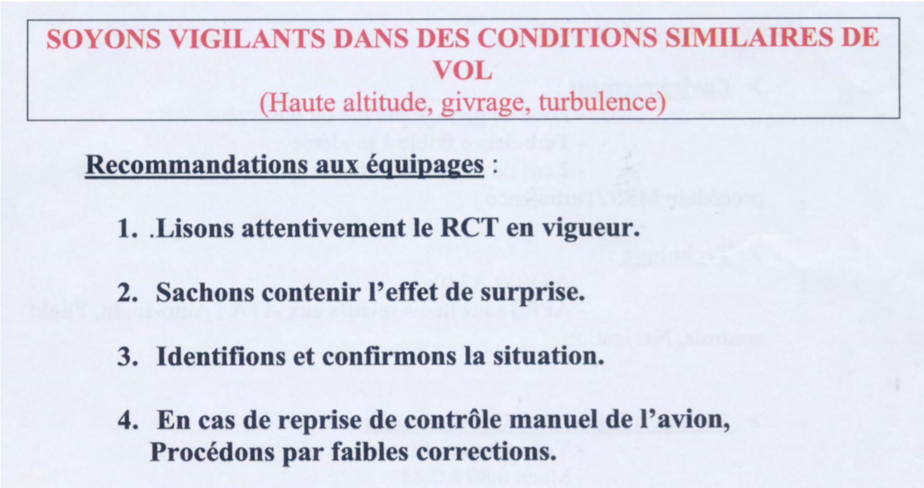
On 6 November 2008, information on speed anomalies that occurred in cruise on the A330/A340 fleet was issued at Air France to pilots in that sector. The “OSV info” document stated that six events of this type were reported in crew accounts. It stated that the incidents were characterised by the loss of speed indications, by numerous ECAM messages and sometimes configuration warnings. The events took place at high altitude in forecast or observed icing zones with turbulence, at a Mach varying between 0.80 and 0.82 with auto-pilot and auto-thrust engaged.

The chronology of the anomalies described is the following:

1. Indications IAS sur 1 ou 2 PFD erronées (400kt – VLS-50)
2. Ecarts significatifs entre 2 PFD et/ou stand by instruments.
3. Message ECAM : - NAV IAS Discrepancy/ NAV ADR Disagree
   - F/CTL PRIM Fault
   - NAV…xx V/S Det fault
4. Passage en ALTN LAW
5. Dégagement de l’A/P et /ou des ATHR
6. Annonce furtive ou persistante « STALL »

It is specified that “during this phase, lasting around several minutes, the crews did not report any sensation of overspeed (vibration, acceleration) or approach to stall (pitch attitude, angle of attack, reference to the horizon) despite the appearance of the STALL warning”.

While specifying that investigations on this type of event were ongoing, the document recommended that crew:



SOYONS VIGILANTS DANS DES CONDITIONS SIMILAIRES DE VOL
(Haute altitude, givrage, turbulence)

Recommandations aux équipages :

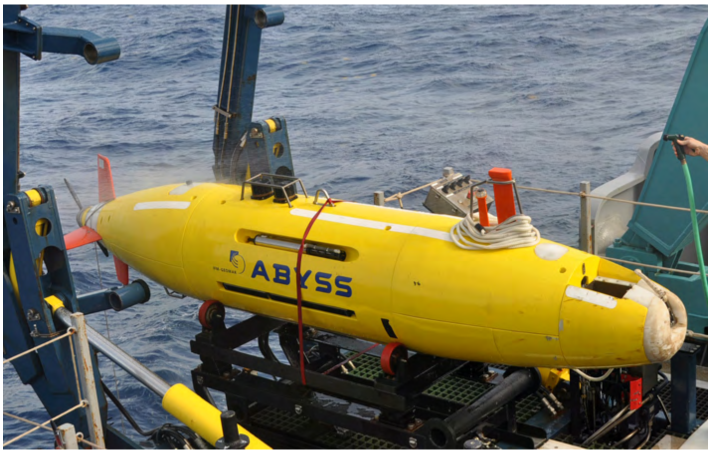
1. .Lisons attentivement le RCT en vigueur.
2. Sachons contenir l'effet de surprise.
3. Identifions et confirmons la situation.
4. En cas de reprise de contrôle manuel de l'avion, Procédons par faibles corrections.

1.19 Useful or Effective Investigation Techniques

1.19.1 Resources used for phase 4

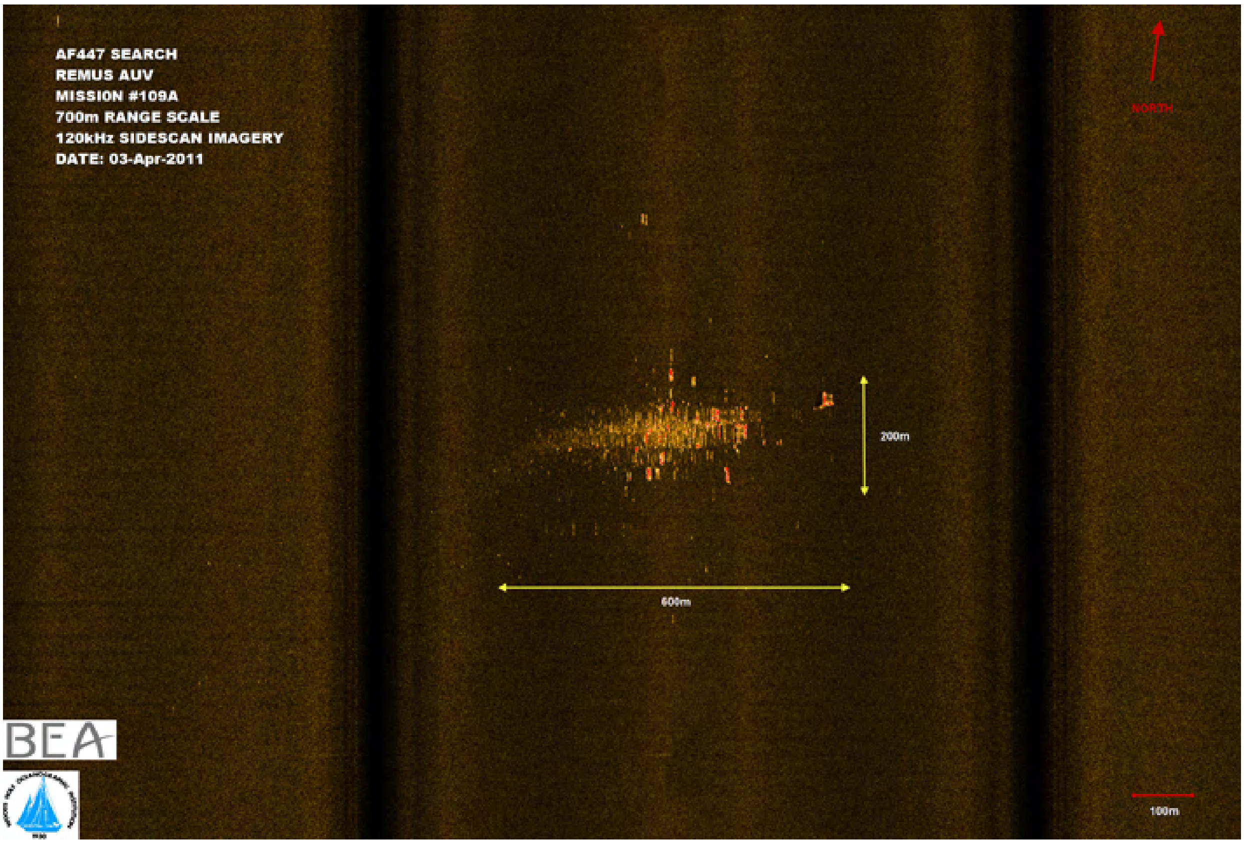
Phase 4 proceeded on site from 25 March to 9 April 2011 with the same underwater means which had already been used in the previous campaign (phase 3). The resources involved were two REMUS 6000 autonomous underwater vehicles (AUV) belonging to the Waitt foundation and the German oceanographic institute Geomar (Research Center for Marine Geosciences). These vehicles were used by the Woods Hole Oceanographic Institute (WHOI) from the exploration vessel M/V *Alucia*.

M/V Alucia



REMUS 6000 AUV

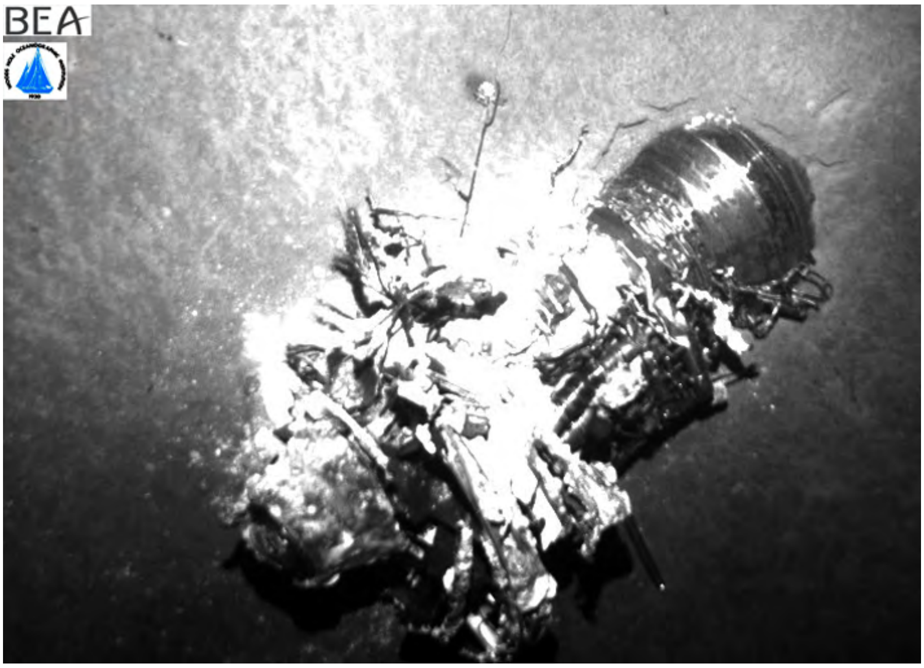
The wreckage was discovered on 3 April 2011 with the aid of the REMUS AUV's side scan sonar adjusted to a frequency of 120 kHz and a 700-metre range.



General view using sonar imaging: 120 kHz, range of 700 m

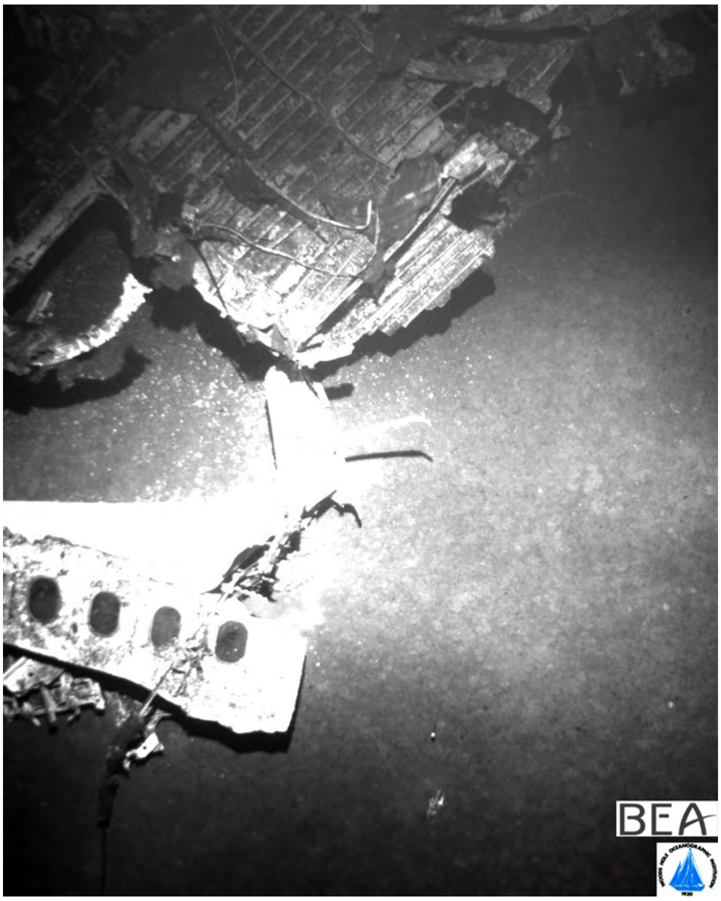
The first passage highlighted a bottom feature of backscattered data on an area of around 600 metres by 200 metres.

During the course of the following mission, the REMUS was programmed to take photos in bursts at a height of around ten metres to formally identify the wreckage of flight AF447. Some of these pictures (see the following figure) were put on line by the BEA as of 4 April 2011.

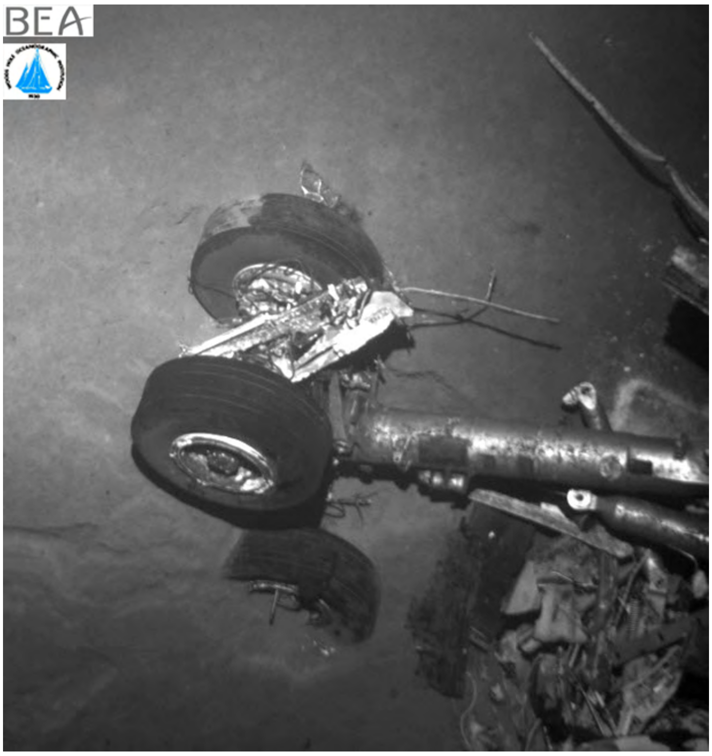


Engine

Wing

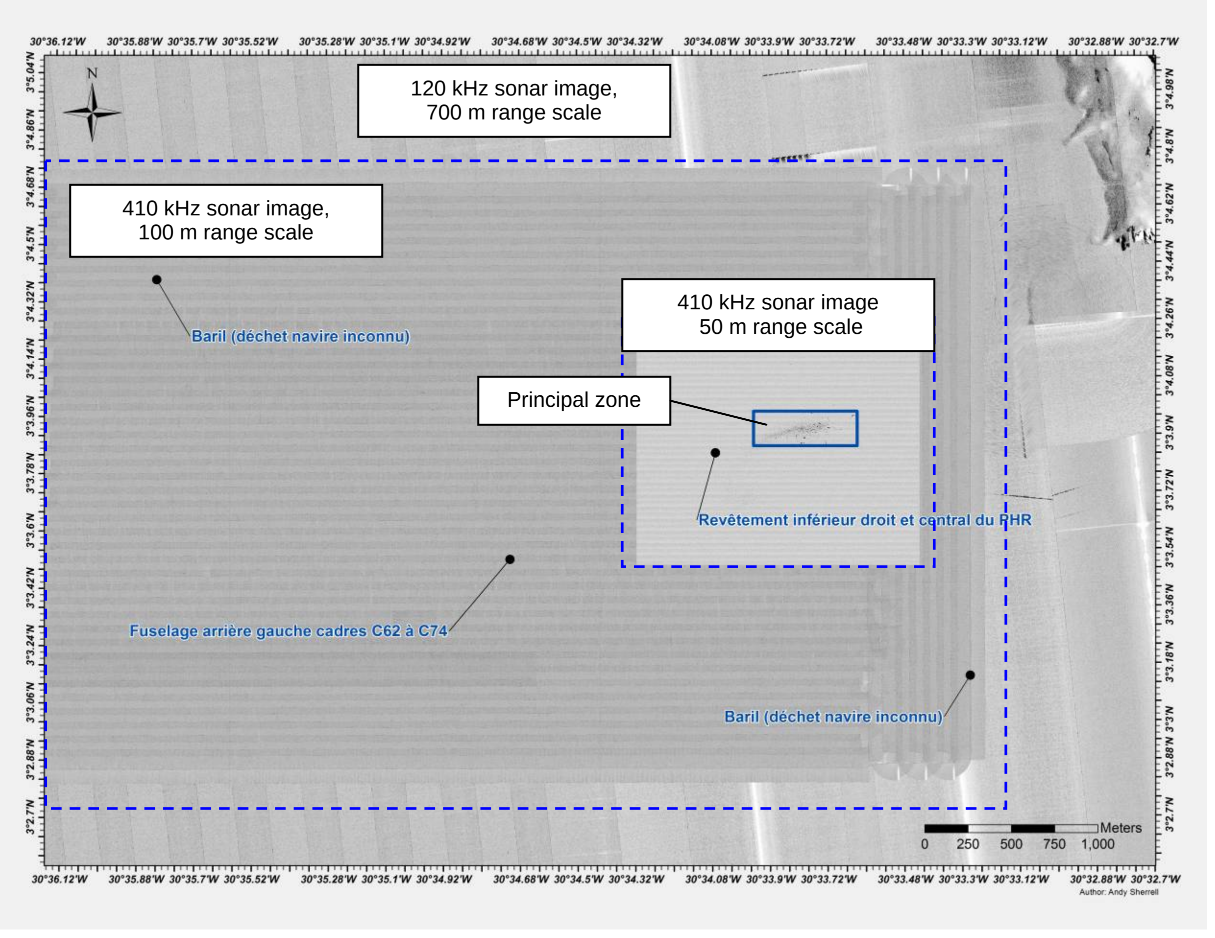


Section of fuselage



Landing gear

During phase 4, the area was scoured several times by the REMUS AUVs with different sonar settings to make sure that no possible debris, located beyond the main zone, was forgotten. This exploration enabled in particular the localisation of a fuselage element about two kilometres from this zone as well as objects such as oil drums that did not come from the aircraft (see the following figure). The initial imagery was subsequently enhanced by high resolution 410 kHz sonar images at various range scales.

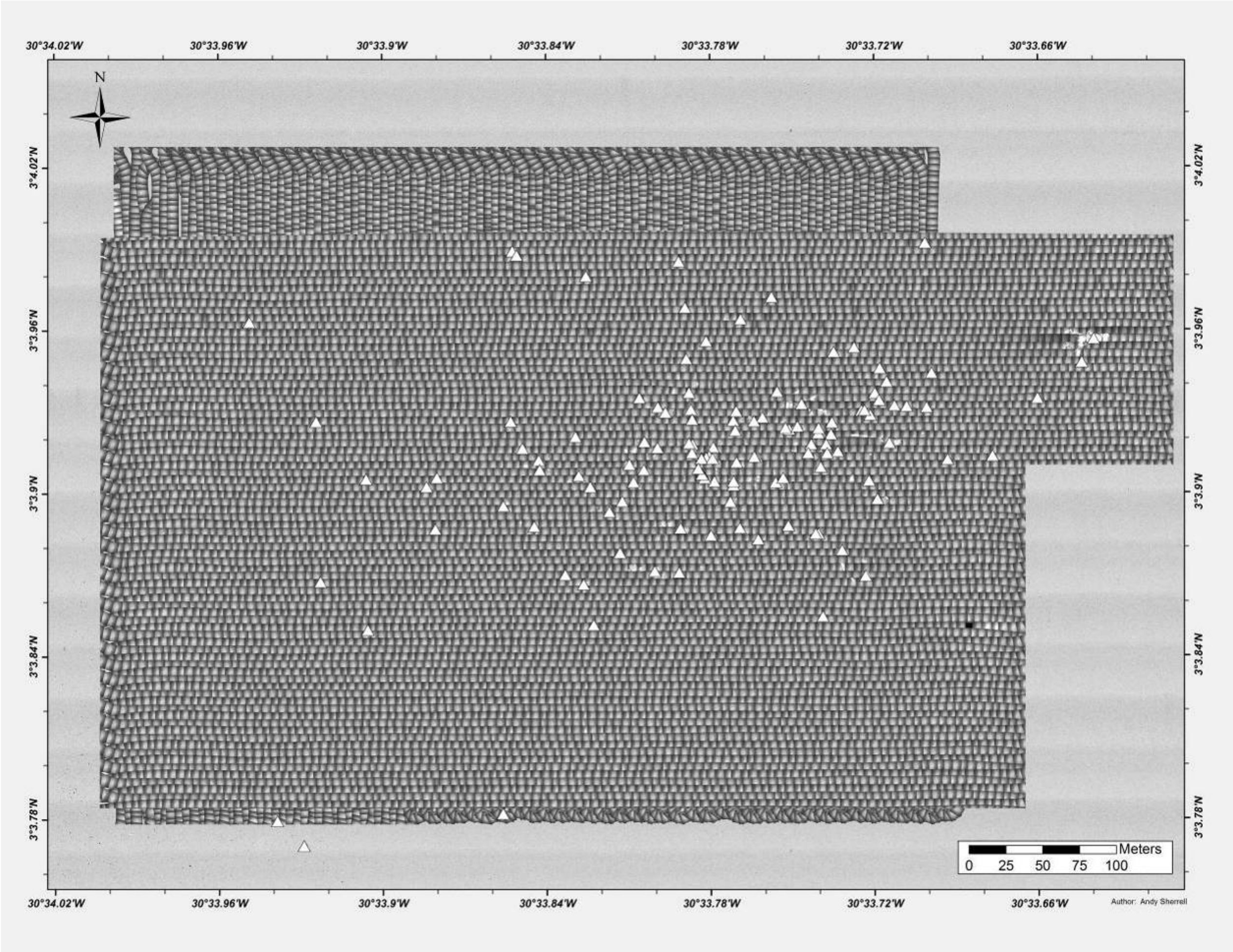


Overlay of sonar images taken with various settings:
120 kHz, 700 m range scale - 410 kHz, 100 m range scale - 410 kHz, 50 m range scale

These representations of the wreckage site were also enhanced and completed by photographs, taken by the REMUS AUVs at a height of about ten metres above the seabed.

These photos were taken from crossed axes in order to skim over each piece of debris several times, along different directions. A total of around 85,000 photographs were taken in this way.

These photographs enabled the first chart of the wreckage site to be produced in mosaic form (see diagram below).



Visualisation of the photo mosaic obtained with REMUS AUV images and the airplane debris identified by using the REMORA ROV

The data produced during phase 4, especially the photo mosaic of the accident site, helped the BEA to save a considerable amount of time in the following phase. This was the first time that investigators had a complete two-dimensional representation of the crash site based on high resolution side-scan sonar images and photos before working on site with an ROV.

These aerial photos proved very useful for both preparing phase 5 and then conducting the survey of the site. They would have provided even more information if they had been in colour.

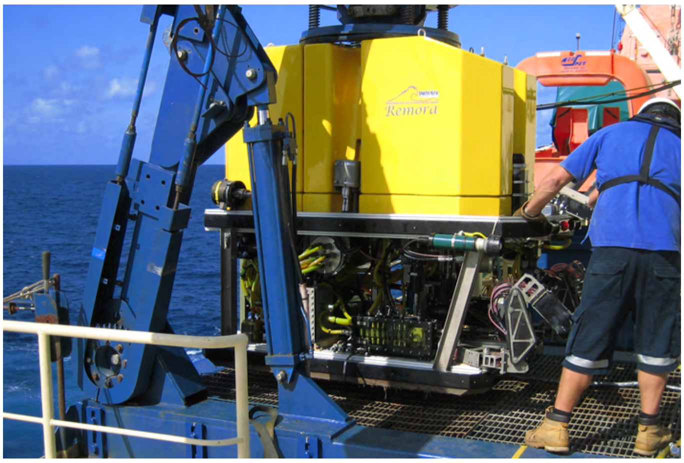
1.19.2 Resources used for phase 5

Phase 5 was carried out in two parts:

- The first part dealt with the search and recovery of the recorders as well as other airplane parts. This part was undertaken on site from 26 April to 13 May 2011
- The second part involved mapping the site and its surroundings and the recovery of the bodies. These operations lasted on site from 21 May to 3 June 2011

To accomplish these tasks effectively, the BEA chose Alcatel Lucent and Louis Dreyfus Armateurs cable vessel the *Ile de Sein* which was equipped with the Phoenix International Remora III ROV (Remotely Operated Vehicle) capable of working at a depth up to 6,000 metres.

Cable vessel “Ile de Sein”



REMORA III ROV

REMORA’s manipulating capabilities were jointly used with the *Ile de Sein*’s cranes to move and recover airplane debris to the surface. The zoom capacity of the ROV “Pan & Tilt” camera enabled investigators to read most part number references to precisely identify and map the debris scattered over the ocean bed.

1.19.3 Optimisation of underwater positioning through resource synergy

Underwater positioning has always presented a challenge for underwater operations as it is carried out using systems which depend on acoustic wave propagation in a liquid environment. This propagation is linked to parameters which vary in particular according to the depth, temperature and salinity of the water.

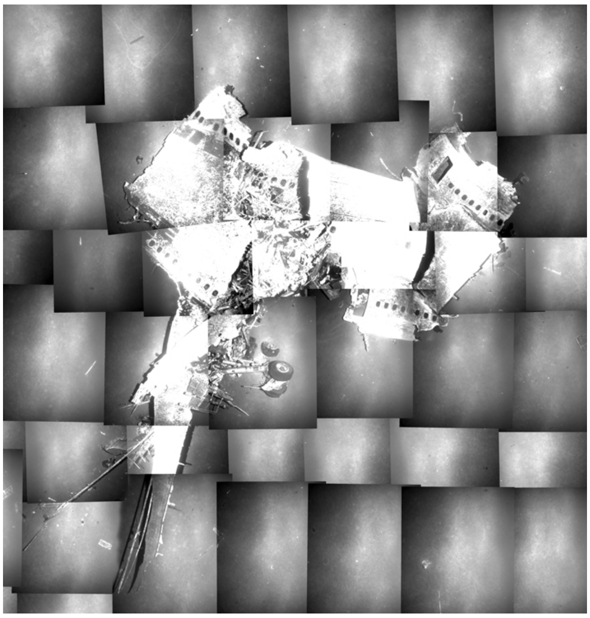
For phase 5, a new system of acoustic positioning was installed on board the *Ile de Sein*. It obtained very good results for ROV navigation and the positioning of the recovery baskets. The use of the phase 4 data with this system greatly contributed to improving the performance and consistency of the device. The sonar maps and the photo mosaic were geo-referenced to the ROV, whose navigation software had been interfaced with the "Ile de Sein" positioning system.

The processing software used by WHOI and the Waitt institute enabled the construction of this mosaic which proved very efficient for precise navigating on the ocean bed. The frog-leaping technique used consisted of navigating by bearing and distance from one part to another, these being recognisable most of the time from the aerial photos of the mosaic.

These photos were available to the Phoenix ROV operators who had these images of the site in real time in two dimensions and the third dimension sent back by the ROV cameras. The large pieces of debris from the side-scan sonar images were systematically searched for and identified.

1.19.4 Fusion of REMUS images

During phase 4, the REMUS AUVs took photos which were presented in mosaic form. Software tools developed by WHOI and the Waitt institute enabled to stitch and merge the photos from the mosaic. The image below illustrates this fusion process on one of the largest onsite debris. This type of image is particularly useful for preparing on site operations with an ROV.



Example of the fusion process results

2 - HISTORY OF FLIGHT: POINTS FROM THE ANALYSIS

The flight has been broken down into three phases:

Phase 1: from the beginning of the flight to the autopilot disconnection.

Phase 2: from the autopilot disconnection until the triggering of the stall warning.

Phase 3: from the triggering of the stall warning until the end of the flight.

➢ Phase 1

At the beginning of the CVR recording, just after midnight, the airplane was in cruise at flight level 350. Autopilot 2 and autothrust were engaged. The automatic fuel transfer to the "trim tank" was carried out during climb, and the airplane's balance 27.5%, for a weight of 218 tonnes. The flight was calm. The crew, made up of the Captain and a copilot, was in VHF contact with the Recife control centre.

The crew mentioned the high temperature (standard plus eleven) and made an estimation of the reserve fuel on arrival, which was evolving. The crew saw the city of Natal and noted that the meteorological conditions posed no problem. They were concerned about the closing of one of the ETOPS alternate airfields, Sal-Amilcar in Heading Verde. They asked the OCC for a change who answered that the airfield was open in case of emergency.

The Captain proposed that the copilot take a rest due to the length of his shift. The latter answered that he didn't feel like sleeping.

At around 1 h 35, the airplane arrived at the INTOL point and the crew left the Recife frequency to pass over to HF communication with the Atlantico oceanic control centre. A SELCAL test was carried out successfully, but the attempts to make the ADS connection with Dakar Oceanic failed.

Just afterwards, the copilot modified the scale of his ND from 320 NM to160 NM and noted that "*there's something straight ahead*", which was doubtless a reference to some direct radar echoes detected by the weather radar. The Captain confirmed and the crew again discussed the fact that the high temperature meant that they weren't able to climb to FL370.

A 1 h 45, the airplane entered a slightly turbulent area, just before the SALPU point.

Note: at around 0 h 30 the crew had received some information from the OCC on the presence of a convective zone linked to the ITCZ between SALPU and TASIL.

The crew dimmed the cockpit lighting and turned on the lights "to see outside". The copilot noted that they were going to "*go into the layer*" and that it would have been good to be able to climb. A few minutes later, the turbulence became a little stronger and the copilot proposed requesting a climb to level 360 non standard because he thought he was "*really at the edge*" of the cloud layer. The Captain answered that they would wait a little. He reduced the scale on his ND to 40 NM; the weather radar then changed to weather + turbulence mode. A little later he mentioned the appearance of Saint-Elmo's fire and said that "*it's going to be turbulent*" when he went to take a rest.

A little after 1 h 52, the turbulence stopped. The copilot drew the Captain's attention to the value of REC MAX, which then reached FL 375. The Captain made no comment and, a few moments later, he woke the second copilot, said he was taking his place, and asked the copilot in the right seat if he had a commercial pilot license. He thus ensured that he was qualified to act as relief and implicitly designated him as relief pilot. This question to the copilot probably meant that the issue of the relief pilot for the Captain had not been raised during the briefing before the flight.

On his return to the cockpit, the second copilot said that he had dozed. He sat in the left seat and the copilot in the right seat gave him a briefing, telling him that "t*he little bit of turbulence that you just saw […] we should find the same ahead […] we're in the cloud layer unfortunately we can't climb much for the moment because the temperature is falling more slowly than forecast*". Before leaving the cockpit, the Captain reminded them of the HF frequencies to contact Atlantico and Dakar Oceanic. In fact, after the Captain's departure, the copilot in the right seat remained PF and the copilot in the left seat was PNF.

The two copilots discussed the temperature and the REC MAX again. The turbulence increased slightly and they decided to warn the cabin crew they were entering a more turbulent zone. The copilot in the right seat said that they were "*apparently on the edge of the layer*", before adding that he would have preferred to climb to FL 360. Climbing to a higher level was a constant preoccupation for the crew. The pilots clearly wanted to fly outside of the cloud layer, probably to limit turbulence.

At around 2 h 08, the copilot in the left seat, doubtless having seen some echoes detected by the weather radar, proposed to *"move to the left a little"*. The HDG mode was activated and the heading selected decreased by 12° compared to the route. The copilot in the left seat moved the weather radar gain control to maximum, after noticing that he was in calibrated mode. The discussion was interrupted by a sensation of an increase in temperature and appearance of a smell that the pilots discussed for over a minute. The copilot in the left seat identified this smell as that of ozone.

The conversations in the cockpit did not reveal any malfunction of the weather radar and indicate that the latter displayed a usable image.

The background noise changed rapidly around 2 h 09 min 46. This change in the background noise was identified as possibly being characteristic of the presence of ice crystals but did not give rise to any specific comments from the crew, the phenomenon being little known to pilots at the time. The PNF then took the initiative to reduce the Mach towards 0.8 and the engine anti-ice devices were triggered.

The Captain's departure was made without him leaving any clear operational instructions, in particular on the role of each of the two copilots. The absence of any formalised working framework for a crew made up of two copilots may have led to the non-optimal task-sharing observed between them.

➢ Phase 2

At 2 h 10 min 05, the sudden drop in the measured airspeeds, likely due to the obstruction of the Pitot probes by ice crystals, caused autopilot and autothrust disconnection (the thrust was then locked) and the change in the flight control law from normal to *alternate*. The presence of turbulence, shown by the inputs by the AP to control the roll in the previous seconds, led on disconnection to the airplane beginning a roll to the right of up to about 8°.

The PF copilot said "*I have the controls*" and made rapid and high amplitude lateral, almost stop to stop, inputs. He also made a nose-up input that increased the airplane's pitch attitude up to 11° in ten seconds. The Flight Directors were not disengaged by the crew, but the crossbars disappeared.

At 2 h 10 min 10, the PF's nose-up inputs increased the angle of attack and the stall warning triggered twice transitorily. Probably in reaction to this warning, the PNF exclaimed "*what is that?*". The PF then said "*We haven't got good … We haven't got a good display … of speed*" and the PNF *"We've lost the speeds".* The angle of attack recorded was around 5°, for a theoretical stall warning threshold trigger value of slightly over 4°.

The crew identified the loss of the speed displays but neither of the two copilots called out the associated procedure. The "Unreliable IAS" emergency manoeuvre requires as a first step to disconnect the automatic flight controls and disengage the Flight Directors. The two copilots had only been trained for the emergency manoeuvre at lower levels, in the course of which the pitch attitude to adopt is 10° or 15°.

However, an OSV note described the problems of the loss of speed indications up to then on the A330/A340 fleet in cruise and recalled the procedures to apply. This note had been distributed to all the flight crew in the A330/A340 division.

Between 2 h 10 min 18 and 2 h 10 min 25, the PNF read the ECAM messages in a disordered way but mentioned the loss of autothrust and the change to *alternate* law. The *thrust lock* function was de-activated. The PNF called out and triggered the wing anti-icing.

The PNF then drew the PF's attention to the speed. At that moment, the two recorded speeds (the one displayed on the left on the PFD and that on the ISIS) were below 100 kt and the vertical speed reached a maximum of 7,000 ft/min. The airplane's longitudinal movements resulted from the inputs by the PF, who in addition continued to make high amplitude lateral inputs to control the roll, below 10° to the right and to the left.

Reading the three instruments (the two PFD's and the ISIS), the PNF noticed that the airplane was climbing and asked the PF several times to descend. The latter then made several nose-down inputs that resulted in a reduction in the pitch attitude and the vertical speed, whose values nevertheless still remained excessive; the airplane then being near 37,000 ft and continuing to climb, without any intervention from the PNF. Although the REC MAX had been a permanent preoccupation before the AP disconnection, neither of the two copilots made any reference to it.

At around 2 h 10 min 34, the speed displayed on the left side became valid again and was then 215 kt; the speed on the ISIS was still incorrect. The airplane had then lost about 60 kt since the autopilot disconnection and the beginning of the climb, which is consistent with the increase in altitude of around 2,000 ft.

At 2 h 10 min 47, the thrust levers were slightly retarded to 2/3 of the IDLE/CLB (85% of N1) range. Two seconds later, the pitch attitude went down a little to 6°, the roll was controlled, the angle of attack was slightly below 5° and the THS was 3° nose-up. The vertical speed was then high at +1,100 ft/min. In the following seconds, the PNF tried to call back the Captain.

During this phase, at no time did either of the two copilots make any callouts on speed, pitch attitude, vertical speed or altitude. The Flight Directors not having been disengaged, the cross bars disappeared and reappeared several times without it being possible, at this stage of the investigation, to know what orders they may have indicated nor to establish if these orders influenced the actions of the PF.

At that moment, after a rapid increase in pitch attitude and altitude, resulting from the PF's inputs, the airplane's flight path seemed to have been mastered. The increase in initial pitch attitude and the vertical speed that resulted were excessive for this flight altitude and should have led to immediate callouts of the discrepancies by the PNF. The absence of specific training in manual aircraft handling at high altitude likely contributed to the inappropriate piloting inputs and surveillance.

The low level of synergy observed between the two copilots may have resulted from the absence of a clear attribution of roles by the Captain, as well as from the absence of any CRM training between two copilots, in a situation with a relief Captain.

Note: No regulations require such training or any criteria such as the capacity to take decisions when designating the relief Captain during flights made by reinforced crews.

➢ Phase 3

At 2 h 10 min 51, the stall warning triggered again, at an angle of attack of about 6°, which corresponds to the theoretical stall warning trigger threshold for the Mach which was then at 0.68. The PF continued to make a majority of nose-up inputs: pitch attitude increased from 6° to 13° and the angle of attack from 6° to 10°. The vertical acceleration recorded indicates the rapid appearance of vibrations that may have been *buffet*. Five seconds later, probably in reaction to the stall warning, the PF pushed the thrust levers towards the TO/GA detent and called it out. It was at about that time that the airplane exited its flight envelope.

Despite some nose-down inputs, the PF maintained nose-up inputs overall. Pitch attitude fluctuated between 11° and about 18° and the angle of attack between 11° and 23°. The THS began a movement that was consistent with the PF's inputs and reached 13° nose-up about a minute later. It should be noted that in *alternate* law, the auto trim is still active. On the other hand, it is difficult for the crew to know the trim position and there is no warning to the crew that it is moving.

At 2 h 11 min 06, after several attempts to call, the PNF was anxious again about the absence of the Captain. This anxiety probably increased the stress for the PNF who was faced with a situation that he didn't understand.

A second later, the speed on the ISIS became valid again. ADR 3 being selected on the right side PFD, the speed for the PF also became valid again. It was then 183 kt and the three displayed speeds were consistent. This brought no comment from the crew.

In the 30 seconds after the beginning of the stall warning, the speed fell from 205 to about 160 kt. The vertical speed progressively approached zero then became strongly negative (-4,000 ft/min). The maximum altitude of about 38,000 ft was reached at 2 h 11 min 10.

A little after 2 h 11 min 30, the PF said twice that he had lost control of the airplane. That could be explained by the difficulty that he had in controlling the roll, the airplane being banked to the right while he was maintaining his sidestick at the stop to the left. However, his few nose-down inputs caused a decrease in pitch attitude each time.

At 2 h 11 min 37, the PNF said "*controls to the left*", took over priority and made a brief left input to the stop; the PF took back the controls almost immediately without any callout and continued to fly the plane.

At around 2 h 11 min 42, the Captain came back into the cockpit, a very short time before the stall warning stopped. The airplane's parameters were then: altitude about 35,800 ft, vertical speed -9,100 ft/min, computed speed 100 kt and falling, pitch attitude 12° and engine N1 for both engines at 102%. Neither of the two copilots gave him a precise summary of the problems encountered nor of the actions undertaken, except that they had lost control of the airplane and that they had tried everything. In reaction, the Captain said several times *"take that"*, doubtless speaking of the FPV. The parameters show that the stall warning stopped because the three angle of attack values had become invalid.

Note: From 2 h 11 min 45, the speeds were no longer displayed in a continuous manner on the PFD.

At 2 h 12 min 04, the PF said that he thought that they were in an overspeed situation, perhaps because a strong aerodynamic noise dominated in the cockpit. Neither of the two analysed this hypothesis whereas it was inconsistent with the nose-up pitch attitude and the high vertical speed in descent.

Until the end of the flight, the angle of attack values became successively valid and invalid. Each time that at least one value became valid, the stall warning triggered, and each time that the angles of attack were invalid, the warning stopped. Several nose-up inputs caused a decrease in the pitch attitude and in the angle of attack whose values then became valid, so that a strong nose-down input led to the reactivation of the stall warning. It appears that the pilots then reacted by a nose-up input, whose consequences were an increase in the angle of attack, a decrease in measured speeds and, consequently, the cessation of the stall warning. Until the end of the flight, no valid angle of attack value was lower than 35°.

Neither of the two copilots formally identified the stall situation that the airplane was in, either via the aural warning, or by recognising the *buffet*, or by interpreting the high vertical speed and pitch attitude values. It should be noted that *buffet* is the only indication of the approach to stall at high altitude on other airplanes whose stall warning threshold does not vary with the Mach.

In the absence of relevant information from the copilots, reading the information available on the screens (pitch attitude, roll, thrust, vertical speed, altitude, etc…) was not sufficient in itself for the Captain to become rapidly aware of the airplane's situation. He did not then ask questions that could have helped him to understand the sequence of events.

The stall warning lasted 54 seconds continuously, during which time neither of the copilots made any reference to it. It is likely that the Captain heard this warning a few moments before coming back into the cockpit, but it is also likely that the multiple starts and stops added to the confusion and disturbed his diagnosis of the situation.

Despite several references to the altitude, which was falling, none of the three crew members seemed to be able to determine which information to rely on: for them, the pitch attitude, roll and thrust values could seem inconsistent with the vertical speed and altitude values.

3 - CONCLUSIONS

3.1 New Findings

- the composition of the crew was in accordance with the operator's procedures,
- the airplane's weight and balance were within operational limits,
- at the time of the autopilot disconnection, the Captain was taking a rest,
- the departure of the Captain was done without leaving any clear operational instructions, in particular on the role of each of the copilots,
- the crew had identified some echoes on the weather radar,
- the crew made a heading change of 12° to the left of its route,
- the AP disconnected while the airplane was flying at the upper limit of a slightly turbulent cloud layer,
- the copilots had not received any training, at high altitude, in the "Unreliable IAS" procedure and manual aircraft handling,
- there was an inconsistency between the speeds measured, likely following the blockage of the Pitot probes in an ice crystal environment,
- although having identified and called out the loss of the speed indications, neither of the two copilots called the procedure "Unreliable IAS",
- the invalidity of the speed displayed on the left PFD lasted for 29 seconds, that of the speed on the ISIS for 54 seconds,
- in less than one minute after the autopilot disconnection, the airplane exited its flight envelope following inputs that were mainly pitch-up,
- the Captain came back into the cockpit about 1 min 30 after the autopilot disconnection,
- throughout the flight, the movements of the elevators and the THS were consistent with the pilot's inputs,
- up to the exit from the flight envelope, the airplane's longitudinal movements were consistent with the position of the flight control surfaces,
- there was no explicit task-sharing between the two copilots,
- there is no CRM training for a crew made up of two copilots in a situation with a relief Captain,
- no standard callouts were made on the disparities in pitch attitude and vertical speed,
- the airplane's angle of attack is not directly displayed to the pilots,

- the approach to stall was characterised by the triggering of the warning then the appearance of *buffet*,
- neither of the pilots made any reference to the stall warning,
- neither of the pilots formally identified the stall situation,
- the stall warning was triggered continuously for 54 seconds,
- a short time after the triggering of the stall warning, the PF selected TO/GA thrust and made a nose-up input,
- the angle of attack is the parameter that allows the stall warning to triggered; if the angle of attack values become invalid, the warning stops,
- by design, when the measured speed values are lower than 60 kt, the 3 angle of attack values become invalid,
- each time that the stall warning triggered, the angle of attack exceeded the value of its theoretical trigger threshold,
- the engines functioned normally and always responded to the crew's inputs,
- no announcement was made to the passengers.

4 - SAFETY 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.

4.1 Recommendations on Operations

Training for Manual Aircraft Handling

The investigation brought to light weaknesses in the two copilots: the inappropriate inputs by the PF on the flight controls at high altitude were not noted by the PNF through an absence of effective surveillance of the flight path. The stall warning and the buffeting were not identified either. This was probably due to a lack of specific training, although in accordance with regulatory requirements. Manual airplane handling cannot be improvised and requires precision and measured inputs on the flight controls. There are other possible situations leading to autopilot disconnection for which only specific and regular training can provide the skills necessary to ensure the safety of the flight. Examination of their last training records and check rides made it clear that the copilots had not been trained for manual airplane handling of approach to stall and stall recovery at high altitude.

Consequently, the BEA recommends:

- **that EASA review the content of check and training programmes and make mandatory, in particular, the setting up of specific and regular exercises dedicated to manual aircraft handling of approach to stall and stall recovery, including at high altitude.**

Relief Captain

The investigation showed that an absence of training and practice for a crew consisting of two copilots does not guarantee a level of performance equivalent to a crew consisting of a Captain and a copilot when faced with a degraded situation. The absence of a hierarchy and of effective task-sharing in the cockpit strongly contributed to the low level of synergy. The anxiety generated by the absence of the Captain from the cockpit shows that the two copilots were not capable of resolving this emergency situation. This can be explained both by the absence of any appropriate training and a lack of decision-making practice on the part of the two copilots. Numerous events turned out favourably due to the presence of the Captain whose training and experience made possible a more solid analysis and more serene reactions to the situation.

Consequently, the BEA recommends:

- **that EASA define additional criteria for access to the role of relief Captain so as to ensure better task-sharing in case of relief crews.**

and

- **that, provisionally, the DGAC define additional criteria for access to the role of relief Captain so as to ensure better task-sharing in case of relief crews.**

4.2 Recommendations relating to Certification

Angle of Attack Measurement

The crew never formally identified the stall situation. Information on angle of attack is not directly accessible to pilots. The angle of attack in cruise is close to the stall warning trigger angle of attack in a law other than normal law. Under these conditions, manual handling can bring the airplane to high angles of attack such as those encountered during the event. It is essential in order to ensure flight safety to reduce the angle of attack when a stall is imminent. Only a direct readout of the angle of attack could enable crews to rapidly identify the aerodynamic situation of the airplane and take the actions that may be required.

Consequently, the BEA recommends:

- **that EASA and the FAA evaluate the relevance of requiring the presence of an angle of attack indicator directly accessible to pilots on board airplanes.**

4.3 Recommendations relating to Flight Recorders

Analysis of the FDR parameters and audition of the CVR provide information that is essential to an understanding of the event. However, it is difficult to reconstruct the indications that were available to the crew on their instrument panel, especially the instructions given by the Flight Director crossbars when they reappear. It is also impossible to see whether there have been any attempts to re-engage the autopilot. A view of the instrument panel would complete the information provided by the FDR and the CVR and would make it possible to confirm the indications that were available to the crew and the actions that they made. Numerous recommendations have already been made on this subject over the past ten years without any real progress having been made.

Consequently, the BEA again recommends:

- **that ICAO require that aircraft undertaking public transport flights with passengers be equipped with an image recorder that makes it possible to observe the whole of the instrument panel ,**

and

- **that at the same time, ICAO establish very strict rules for the readout of such recordings in order to guarantee the confidentiality of the recordings.**

Today, the regulation requires recording of the flight parameters displayed on the left side. Some parameters essential to the analysis of the conduct of the flight are lacking, in particular those displayed to the pilot in the right seat: speed, altitude, attitudes, position of the flight director crossbars, etc. In addition, airplanes are equipped with complex systems whose functional analysis is limited and delayed by the absence of a recording of all of the data sources that they use.

Consequently, the BEA recommends:

- **that EASA and the FAA make mandatory the recording:**
    - **of the position of the flight director crossbars,**

- **of the parameters relating to the conduct of the flight displayed on the right side, in addition to those displayed on the left side,**

and

- **that EASA and the FAA evaluate the relevance of making mandatory the recording of the air data and inertial parameters of all of the sources used by the systems.**

4.4 Recommendations relating to Transmission of Flight Data

In its Interim Report n°2, the BEA issued safety recommendations on increasing the duration and the range of Underwater Locator Beacon (ULB)'s, regular transmission of data and the installation of deployable recorders. These recommendations were based on the conclusions of an international government-industry working group[12] led by the BEA in the framework of the safety investigation into the accident to flight AF-447, which has since studied the feasibility of triggered transmission of flight data. This concept consists of real time analysis of onboard flight parameters in order to detect emergency situations. In these cases, the transmission of flight data is triggered to facilitate the localisation of an airplane in an emergency situation. The results[13] of the working group show that it is technically feasible to define reliable criteria based on flight parameters allowing emergency situations to be detected, while limiting false alarms. The group also concluded that it is technically feasible to obtain an impact position with enough precision, even in accidents where the airplane in an unusual position. In addition, the group's work showed that the in-flight activation of next generation emergency locator transmitters (ELT) using the same emergency detection criteria is feasible, thus allowing localisation of wreckage within 5 km.

On the basis of this work, the BEA recommends:

- **that EASA and ICAO make mandatory as quickly as possible, for airplanes making public transport flights with passengers over maritime or remote areas, triggering of data transmission to facilitate localisation as soon as an emergency situation is detected on board;**

and

- **that EASA and ICAO study the possibility of making mandatory, for airplanes making public transport flights with passengers over maritime or remote areas, the activation of the emergency locator transmitter (ELT), as soon as an emergency situation is detected on board**

[12] This group brought together representatives from investigation authorities, ICAO, Airbus, Boeing, Air France, Iridium, Inmarsat and Cospas-Sarsat.
[13] Available on the BEA website:
http://www.bea.aero/en/enquetes/flight.af.447/triggered.transmission.of.flight.data.pdf

5 - CHANGES MADE AFTER THE ACCIDENT

5.1 Air France

5.1.1 Aircraft maintenance and equipment

A330/A340 Pitot probes

- Acceleration of the replacement of the Thales “AA” probes by “BA” probes started on 27 May 2009. By 11 June 2009, all the probes had been replaced.

- Following the issuing of an Airworthiness Directive by EASA, Thales “BA” probes replaced by Goodrich probes in positions 1 and 3, from 4 to 7 August 2009.

- As a result of an Air France internal decision, Thales “BA” probes replaced by Goodrich probes in position 2 between 18 January and 8 February, 2010.

5.1.2 Changes to the reference documents

Strengthening the role of copilots

- Change to the rules governing relief duties in March 2010: the relief copilot is designated by the Captain; sits in the left seat and is the PNF.

- On-going implementation of a new decision-making method: the copilot expresses his or her opinion first, prior to the final decision being made by the Captain (optimisation of the decision-making process, enhancing the copilot's responsibilities).

5.1.3 Crew training

Training in a flight simulator

Additional session entitled “Unreliable IAS”:

- Summer 2009 (A320, A330/340)
- Booklet and briefing from the session: key technical points, HF and TEM (Threat and Error Management) considerations
- Revision of emergency manoeuvres, at take-off and in cruise.
- High altitude flight in alternate law
- Approach to stall, with triggering of the STALL warning
- Landing without airspeed measurement information
- Associated briefings (all cockpit crew):
    - Weather radar
    - Ice crystals

Note1: This information has been integrated into the type ratings.

Note 2: The stall procedures were modified following the modification of the STALL procedures by the manufacturer, as indicated in 1.18.

Reinforced crew and relief captain

- Creation of a DSAC*/airlines working group
- Definition of new rules
- Specific mid-AEL session
- Exercises during ECP (periodic training and checking), then integrated into three-yearly training
- Design of a self-learning module for reinforced crew
- Design of a self-learning module for captains

5.2 Airbus

Review of the"Unreliable IAS" procedure

- EASA carried out a review in Autumn 2009 to evaluate the manufacturer's procedure. It resulted in confirmation of the existing procedure.

- FOT of 9 September 2009 recommending a high altitude simulator training session in normal and alternate laws including:

    - Manual airplane handling
    - Performance of the UNRELIABLE SPEED INDICATION / ADR CHECK PROC procedure.

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Appendix 1

FDR / CVR Summary Table

Symbols

The CVR transcript extracts are noted in the history of the flight with the following colour codes:

- Captain (green)
- Copilot in the left seat (PNF) using the Captain sideslick (blue)
- Copilot in the right seat (PF) using the copilot sideslick (red)
- Warnings, comments and various noises (black)

Glossary

UTC Time	UTC time obtained from FDR recording
SV	Synthetic Voice
Cricket	Sub sound sequence of the stall warning. It is made of several multi-frequency pulses and lasts 700 ms. Cricket end time is indicated in the transcript when this subsequence is incomplete (ex: warning end)
(…)	Words or groups of words not relevant to the conduct of the flight
( )	Words or groups of words that are doubtful. The " / " symbol expresses the different possibilities
(*)	Words or groups of words not understood

The aircraft FDR parameters at the start of the recording, then at 2 h 10

	0 h 09 min 14	2 h 10
Standard altitude (ft)	34.992	35.044
Computed airspeed (kt) / Mach	275 / 0.80	282 / 0.82
Ground speed (kt)	481	468
Pitch attitude (°) [>0 nose-up]	2.8	1.8
Angle of attack 1 / 2 / 3 (°)	2.5 / 2.8 / 2.8	2.1 / 3.2 / 3.2
Magnetic heading (°) / True route (°)	47 / 24	35.5 / 15
Roll angle (°) [>0 right turn]	-0.4	-1.8
True N1 Engine 1 / engine 2 (%)	98 / 98	100.4 / 99.8
Configuration	Clean	Clean
Static temperature (°C)	-43.5	-38.8
Total weight (tonnes) / Centre of gravity (%MAC)	218 / 27.5	205 / 28.7
Trim tank fuel quantity (tonnes)	5.0	4.9
Inner left / right tank fuel quantity (tonnes)	22.8 / 22.6	16.3 / 16.2
Outer left / right tank fuel quantity (tonnes)	2.7 / 2.8	2.8 / 2.8
THS Position [>0 nose-down] (°)	-3.0	-2.8

The CVR recording started at 0 h 09 min 14.

UTC Time	Altitude (ft) ISIS Altitude (ft)	FDR Parameters	Extracts from the CVR transcript

Phase 1: from the beginning of the CVR recording → 2 h 10 min 05

1 h 35 min 49		Copilot's ND scale changes from 320 NM to 160 NM.	
1 h 50 min 35		The radar display mode changes from WXR ONLY to WXR+TURB. The Captain's ND scale changes from 160 NM to 40 NM.	
1 h 55 min 57			Well we just have to wake him up, eh? Er flight rest
2 h 00 min 17		Copilot's ND scale changes from 160 NM to 80 NM.	
2 h 00 min 33			Well the little bit of turbulence that you just saw we should find the same ahead we're in the cloud layer unfortunately we can't climb much for the moment because the temperature is falling more slowly than forecast So what we have is some REC MAX a little too low to get to three seven
2 h 03 min 44			The inter-tropical convergence there well we're in it between SALPU and TASIL
2 h 06 min 54		Note: no change in the nacelle anti-ice parameters.	Minus forty-two we won't use the anti ice that's a plus
2 h 07			See, we're really on the edge of the layer (*)
2 h 08 min 07			You can maybe go a little to the left I agree that we're in manual, eh?
2 h 08 min 12		The lateral mode changes to HDG. The magnetic heading selected decreases to 34°.	

2 h 08 min 19			What I call in manual er no we’re in computed
2 h 09 min 30 → 2 h 10		The roll angle varies between 2.8° right and 4.6° left.	
2 h 09 min 53		Copilot’s ND scale changes from 80 NM to 40 NM.	
2 h 09 min 54			There I’ve taken it down a bit
2 h 09 min 58		Speed handling changes from managed to selected. The selected Mach is 0.8.	
2 h 10		Pitch attitude decreases from 1.8° to 0° in 3 seconds. In 8 seconds, the N1 commanded and the N1 change from 100 % to 84 %.	
2 h 10 min 03		The nacelle anti-ice switches for the engines change to ON. Note: the parameters are recorded every 4 seconds. The engine 1 nacelle anti-ice parameter is recorded ON at 2 h 10 min 05, but usually the two selections are simultaneous.	Do you want it to be on ignition start?

Phase 2: 2 h 10 min 05 → 2 h 10 min 51

2 h 10 min 05	35,024	The A/P2 disconnects. The roll angle changes from 0 to 8.4° in 2 seconds whereas the sidestick is at neutral. The pitch attitude is 0°.	Cavalry charge (Autopilot disconnection warning)
2 h 10 min 06		The flight control law changes from normal to alternate.	I have the controls
2 h 10 min 07 → 2 h 10 min 18		• The copilot sidestick is positioned: - nose-up between neutral and ¾ of the stop position - to the left in half-travel position then to the right in half-travel position and twice, alternatively left to the stop position then right to the half-travel position (Period of 4 seconds). • The pitch attitude increases to 11°. • The vertical acceleration varies between 0.9 g and 1.6 g. • The roll angle fluctuates between 11° right and 6° left. • The vertical speed increases to 5200 ft/min.	

2 h 10 min 08		The FD 1 and 2 become unavailable. The A/THR disengages and the THR LK mode is activated. The N1 are at 83 %. The CAS changes from 274 kt to 156 kt. The CAS ISIS changes from 275 kt to 139 kt then goes back up to 223 kt. The Mach changes from 0.80 to 0.26.	
2 h 10 min 09	34,664 34,900	The CAS is 52 kt. The CAS ISIS stabilises at 270 kt for 4 seconds.	Ignition start
2 h 10 min 10		The stall warning is triggered. The angles of attack 1, 2, and 3 values are respectively 2.1°, 4.9° and 5.3°.	02 h 10 min 10,4 : SV : “Stall, stall” (without cricket)
2 h 10 min 11	minimum (local) of 34,636 ft		What is that?
2 h 10 min 12		The CAS ISIS changes from 270 kt to 73 kt in 4 seconds while the CAS is 55 kt.	
2 h 10 min 13		The ‘Master Warning’ is activated. The angles of attack 1, 2, and 3 values are respectively 2.1°, 4.6° and 4.9°. The TCAS TA ONLY parameter changes to TA ONLY (for 10 seconds).	SV : “Stall, S”
2 h 10 min 14			We haven’t got a good … We haven’t got a good display…
2 h 10 min 17	34,976	The FD 1 and 2 become available again; the active modes are HDG/ALT CRZ*. The selected heading is 37°. The CAS is 80 kt and the CAS ISIS is 92 kt.	We’ve lost the the the speeds so… engine thrust A T H R engine lever thrust
2 h 10 min 18		The ‘TLU 1 availability’ and ‘TLU 2 availability’ parameters become NOT AVAILABLE.	… of speed
2 h 10 min 18 → 2 h 10 min 25		• The copilot sidestick is positioned: - nose-up to ¼ of the stop position - left to ¾ of the stop position then right to the half-travel position twice. • The pitch attitude varies from 11° to 13°. • The THS is stable at around -3°. • The roll angle varies between 8° right and 5° left. • The vertical speed increases to 6,700 ft/min.	

2 h 10 min 21		The FD 1 and 2 become unavailable. The CAS is 93 kt and the CAS ISIS is 83 kt. The Mach is 0.29.	
2 h 10 min 22			Alternate law protections (law/low/lo)
2 h 10 min 23		The THR LK mode is de-activated, the thrust levers remain on the CLB detent. The N1 start to increase and reach around 104 % in 12 seconds.	
2 h 10 min 24			Wait we're losing…
2 h 10 min 25	35,856	The 'wing anti-ice' switch is ON.	Wing anti-ice
2 h 10 min 26		The FD 1 and 2 become available again (HDG and V/S modes). The vertical speed reached the maximum value of 6,900 ft/min.	
2 h 10 min 27 → 2 h 10 min 31		• The copilot sidestick is positioned: - nose-down to about the half-travel position - right to one third of the stop position then left to 4/5 of the stop position then again right to 4/5 of the stop position. • The pitch attitude varies from 12° to 10°. • The roll angle varies between 9° left and 1° right. • The vertical speed decreases to 5,600 ft/min. The angle of attack 1 is stable at 2.1°. The angle of attack 2 changes from 3.9° to 3.2° while the angle of attack 3 changes from 4.2° to 3.2°.	Watch your speed Watch your speed Okay, okay okay I'm going back down Stabilise Yeah Go back down
2 h 10 min 33			According to the three you're going up so go back down
2 h 10 min 34		The CAS increases from 105 kt to 223 kt in 2 seconds. The CAS ISIS is 115 kt.	
2 h 10 min 35			Okay
2 h 10 min 36	37,124	The FD 1 and 2 are unavailable.	You're at Go back down It's going we're going (back) down
2 h 10 min 39 → 2 h 10 min 46		The 'AIR DATA' selector then the 'ATT/HDG' selector are positioned on "F/O on 3".	I'll put you in in A T T (*)…

2 h 10 min 42		The FD 1 and 2 become transitionally available (HDG/VS modes). The selected heading is 36°. The vertical speed is 1,900 ft/min and the vertical speed selected is 1,300 ft/min.	We are in yeah we are in climb
2 h 10 min 47		The FD 1 and 2 become available again (modes HDG/ VS). The selected heading is 34°. The vertical speed is 1,500 ft/min. The thrust levers are moved back to 33° (2/3 of the IDLE / CLB range). The N1 decrease to 85% in 4 seconds.	
2 h 10 min 49	37,512	The CAS is 216 kt and the CAS ISIS is 121 kt. The Mach is 0.68. The pitch attitude is 5.6°. The THS is at -3.1°. The angles of attack 1, 2 and 3 values are respectively 2.1°, 4.6° and 4.9°. The roll angle is 0.4° left. The vertical speed is 1,100 ft/min.	(…) where is he er?

Phase 3: 2 h 10 min 51 → end

2 h 10 min 51		The stall warning is triggered. The angle of attack 1 is 2.1° while the angles of attack 2 and 3 are 6.0°. The Mach is 0.68. The vertical speed is 750 ft/min.	**SV : "Stall, stall" + cricket continuously**
2 h 10 min 51 → 2 h 10 min 57	The altitude changes from 37,500 ft to 37,596 ft.	• The copilot sidestick is positioned: - nose-up to two-thirds of the stop position - slightly to the left then to the right. • The pitch attitude changes from 6° to 13°. The THS varies from -3.2° to -3.6°. • The angles of attack 2 and 3 change from 6.0° to 10.2°. The angle of attack 1 changes from 2.1° to 7.4°. • The roll angle varies between 2.8° to the left and 1.4° to the right.	
2 h 10 min 54		The thrust levers are positioned on the CLB detent.	
2 h 10 min 56		The thrust levers are positioned on the TOGA detent. The N1 increase progressively and reach 103% at 2 h 11 min 02.	(TOGA)

2 h 10 min 58 → 2 h 11 min 22		• The copilot sidestick is positioned: - between the half-travel position nose-down and ¾ of the stop position nose-up with a nose-up position on average - between 4/5 of the stop position to the left and 4/5 of the stop position to the right. • The pitch attitude fluctuates between 17.9° and 10.5° (Period of 5 seconds). • The THS varies from -3.8° to -8.3°. • The roll angle fluctuates between 8.8° to the left and 4.9° to the right (Period of 5 seconds). • The angle of attack 1 increases from 7.4° to 18.3° while the angles of attack 2 and 3 increase from 10.9° to 22.9°. • The CAS decreases from 207 kt to 161 kt and the Mach decreases from 0.66 to 0.51. • The vertical speed changes from +2272 ft/min to -3904 ft/min. • The normal load factor decreases from 1.13 g to 0.75 g (at 2 h 11 min 03) then goes up and stabilises at 0.85 g.	
2 h 11			Above all try to touch the lateral controls as little as possible eh
2 h 11 min 03			I'm in TOGA eh
2 h 11 min 06			(…) is he coming or not?
2 h 11 min 07		The CAS ISIS changes from 129 kt to 183 kt. The CAS is at 184 kt.	
2 h 11 min 10	maximum (global) of 37,924 ft		
2 h 11 min 21			But we've got the engines what's happening (…)?
2 h 11 min 22 → 2 h 11 min 35		• The copilot sidestick is positioned: - mainly nose-up between the neutral and the half-travel position, with two nose-down inputs (half-travel position for one second) at 2 h 11 min 22 and at 2 h 11 min	

		30. - left from neutral to the stop position. • The pitch attitude is stabilised at 16° then decreases to 13°. • The THS varies from -8.3° to -11.5°. The roll angle varies between 0° and 26° to the right. • The angles of attack 2 and 3 continue to increase to 29.9°. • The vertical speed changes from -3 900 ft/min to -6 800 ft/min. The Mach changes from 0.51 to 0.42. • The CAS changes from 161 kt to 133 kt while the CAS ISIS changes from 164 kt to 128 kt.	
2 h 11 min 32			(…) I don't have control of the airplane any more now I don't have control of the airplane at all
2 h 11 min 35 → 2 h 12 min 18		• The copilot sidestick is: - positioned nose-up, reaches the stop position after 6 seconds and stays there until 2 h 12 min 15 - maintained in stop position to the left. • The THS changes from -11.5° to -13.5°. • The pitch attitude reaches a maximum of 14.8° at 2 h 11 min 45 then decreases to reach a minimum of 9° nose-down before increasing to 0°. • The roll angle varies between 16° and 40° to the right.	
2 h 11 min 38		The pilot in the captain's seat takes over the controls. The Captain sidestick is positioned left in stop position.	Controls to the left
2 h 11 min 40	36,068	The FD 1 and 2 become unavailable. The angles of attack 1 and 2 become invalid (NCD status) while the angle of attack 3 is 33°. The CAS is 106 kt and the CAS ISIS 112 kt. The pilot in the copilot seat takes over the controls for 6 seconds. The copilot sidestick is positioned: - left in stop position - nose-up to two thirds of the stop position.	
2 h 11 min 41			I have the impression (we have) the speed

2 h 11 min 43		The thrust levers are moved from TOGA to MCT. The N1 are stable at around 102 %.	**Sound of cockpit door opening** Er what are you (doing)? What's happening? I don't know I don't know what's happening
2 h 11 min 45	35,372	The 3 angles of attack are invalid (NCD status). The last valid value of angle of attack 3 is reached at 2 h 11 min 44 and is 41.5°. The stall warning stops. The pitch attitude is 15°. The roll angle is 32° right increasing. The vertical speed is no longer calculated by the IR (Inertial reference) but by the ADR. It is about -10,000 ft/min.	**End of "Stall, stall" warning + cricket**
2 h 11 min 47		The thrust levers are moved to IDLE. The N1 of the two engines decrease to around 58 % in 20 seconds. The normal load factor decreases then stabilises at around 0.75 g.	
2 h 11 min 52			Well look take take that
2 h 11 min 53		Only the angle of attack 3 is temporarily valid at around 41°. The stall warning is triggered. The vertical speed reaches - 14,800 ft/min.	SV : "Stall, stall" + incomplete cricket
2 h 11 min 55		The angles of attack 1 and 2 become temporarily valid again with values close to 40°. The stall warning is triggered.	SV : "Stall, stall" + incomplete cricket
2 h 11 min 58		The vertical speed is around - 15,300 ft/min.	I have a problem it's that I don't have vertical speed indication Okay I have no more displays
2 h 12 min 04 → 2 h 12 min 07		The airbrakes are controlled and deployed.	I have the impression that we have some crazy speed no what do you think?
2 h 12 min 07	29,736	The angle of attack 2 is temporarily valid at 41°. The stall warning is triggered.	No above all don't extend (the) SV : "Stall, stall"
2 h 12 min 10		The thrust levers are positioned on the CLB detent. The N1 change from 58 % to 105 % in about 10 seconds. The angle of attack 3 is temporarily valid at 40.4°. The stall warning is triggered.	SV : "Stall, stall" + incomplete cricket

2 h 12 min 13			What do you think about it what do you think what do we need to do?
2 h 12 min 15 → 2 h 12 min 19		The ‘AIR DATA’ and ‘ATT-HDG’ selectors are positioned on “CAPT on 3”.	There I don’t know there it’s going down
2 h 12 min 16		The pilot in the copilot seat takes over the controls.	
2 h 12 min 17			SV : “Priority right”
2 h 12 min 19		The copilot sidestick is positioned nose-down to one third of the stop position. The pitch attitude changes from 3.2° to 1.8° in 4 seconds.	
2 h 12 min 19 → 2 h 12 min 45		The copilot sidestick is positioned alternatively in stop position right then left three times. The left inputs last on average 3 seconds while the right inputs last on average 1 second. The roll angle fluctuates between 12° left to 17° right (period of 7 seconds).	That’s good we should be wings level, no it won’t (not) The wings to flat horizon the standby horizon The horizon (second)
2 h 12 min 20 → 2 h 12 min 33		• The copilot sidestick is positioned nose-up between the half-travel and the stop position with a nose-down input of less than one second. • The pitch attitude starts to increase and reaches 7°. • The THS stabilises at -13.6°.	
2 h 12 min 26		The angle of attack 3 is temporarily valid at 43.6°.	The speed?
2 h 12 min 27		The stall warning is triggered.	You’re climbing SV : “Stall, stall” You’re going down down down
2 h 12 min 30			Am I going down now? Go down
2 h 12 min 32		The pitch attitude is about 5° nose-up. The engine N1 are about 106%.	No you climb there
2 h 12 min 33		The copilot sidestick is at stop position nose-down (2 seconds). The thrust levers are positioned in TOGA. The N1 change from 106 to 110 %.	I’m climbing okay so we’re going down

2 h 12 min 34		The angle of attack 3 is temporarily valid at 43.2°. The stall warning is triggered.	SV : "Stall, stall" + incomplete cricket
2 h 12 min 35 → 2 h 12 min 42		The copilot sidestick is positioned between the neutral and the half-travel position nose-down. The pitch attitude changes from 8° nose-up to 2° nose-down.	
2 h 12 min 39		The ISIS CAS and the CAS start to increase. (The CAS was NCD and the ISIS CAS was at 0).	Okay we are in TOGA
2 h 12 min 40		The angle of attack 3 is temporarily valid at 38.7°. The stall warning is triggered.	**SV : "Stall, stall" + CRC**
2 h 12 min 41 → 2 h 12 min 44		The 3 angles of attack are valid (non-NCD status).	
2 h 12 min 42	20,412	The N1 change from 110% to 105% in 2 seconds then stabilise again at 110%.	What do we have in alti?
2 h 12 min 43 → 2 h 12 min 52		• The copilot sidestick is positioned nose-up and nose-down between the neutral and the third of the stop position. • The pitch attitude increases to 6° nose-up then decreases again to 7° nose-down. • The CAS reaches a maximum of 153 kt at 2 h 12 min 43 then decreases to become NCD before increasing again and reaching a maximum of 127 kt at 2 h 12 min 53. • The ISIS CAS reaches a maximum of 159 kt at 2 h 12 min 43 then decreases to freeze at 0 before increasing again and reaching a maximum of 134 kt at 2 h 12 min 52.	
2 h 12 min 44	20,028		(…) it's impossible
2 h 12 min 45			On alti what do we have?
2 h 12 min 45 → 2 h 13 min 04		• The copilot sidestick is to the left in stop position. • The roll angle changes from 12° right to 41° right in 3 seconds then fluctuates between about 20° and 40° right (period of 10 seconds).	What do you mean on altitude? Yeah yeah yeah I'm going down, no? You're going down yes Hey you're in … get the wings horizontal Get the wings horizontal That's what I'm trying to do Get the wings horizontal

2 h 12 min 46			**End of the "Stall, stall" warning + cricket**
2 h 12 min 49		The angle of attack 2 is temporarily valid at 40.8°. The stall warning is triggered.	**SV: "Stall, stall" + cricket**
2 h 12 min 50 → 2 h 13 min 36		The engine 1 N1 is stable at 110 %. The engine 2 N1 fluctuates between 100 and 110 %.	
2 h 12 min 51 → 2 h 12 min 56		The 3 angles of attack become valid again (non-NCD).	
2 h 12 min 52		The FD 1 and 2 become available again (HDG V/S modes). The selected vertical speed is -6,000 ft/min. The selected heading is 197°.	
2 h 12 min 52 → 2 h 12 min 57		• The copilot sidestick is positioned nose-up between the neutral and the half-travel position. • The pitch attitude changes from 7.4° to 6.0° nose-down. • The CAS changes from 127 kt to 56 kt. • The ISIS CAS changes from 134 kt to 15 kt.	
2 h 12 min 57			**End of "Stall, stall" warning + cricket**
2 h 12 min 58		The FD 1 and 2 become unavailable again.	
2 h 12 min 59		The Captain sidestick is positioned: - left at ¾ of the stop position - nose-up at 1/5 of the stop position.	I'm at the limit … with the roll The rudder bar
2 h 12 min 59 → 2 h 13 min 40		• The copilot sidestick is positioned nose-up on average at the half-travel position. From 2 h 13 min 36, the copilot sidestick is positioned nose-up in stop position. • The pitch attitude changes from 6° nose-down to 13° nose-up in 11 seconds then stabilises at about 11° nose-up. • The CAS becomes invalid (NCD status). • The ISIS CAS becomes invalid (FW status). • The angles of attack become invalid (NCD status).	

2 h 13 min 02 → 2 h 13 min 46		The rudder-bar is positioned left at ¼ displacement then to right to ¼ displacement for 4 seconds. It is then positioned slightly right (between 1.4° and 6.1°).	
2 h 13 min 04 → 2 h 13 min 17		• The copilot sidestick is positioned right in stop position, then to left in stop position for 4 seconds. It is then positioned to the right between neutral and one third of the stop position, then left in stop position for 3 seconds. • The roll angle fluctuates between 15° right and 3° left (period of 7 seconds).	
2 h 13 min 17 → 2 h 13 min 40		• The copilot sidestick is positioned alternatively left at 3/4 of the stop position then right to the half-travel position with mostly left inputs. • The Captain sidestick is positioned: - left at ¾ of the stop position then right to the half of the stop position then left again at ¾ of the stop position - alternatively nose-up and nose-down (between 4° nose-up and 3° nose-down) - at neutral from 2 h 13 min 24. • The roll angle fluctuates between 17° right and 10° left. (period of 7 seconds) • The DUAL INPUT parameter is activated twice.	At 2 h 13 min 23: SV : "Dual input"
2 h 13 min 25			What is… how come we're continuing to go right down now?
2 h 13 min 28			Try to find what you can do with your controls up there The primaries and so on
2 h 13 min 32	10,092	The 'AIR DATA' selector is positioned on "NORM".	* at level one hundred
2 h 13 min 35 → 2 h 13 min 37		The FCPC1 FAULT and FCSC1 FAULT parameters change on FAULT.	
2 h 13 min 36	9,332		Nine thousand feet
2 h 13 min 38			Careful with the rudder bar there

2 h 13 min 39			Climb climb climb climb
2 h 13 min 40 → 2 h 14 min 07		• The Captain sidestick inputs are nose-up between the neutral and half-travel position and nose-down between the neutral and stop position. They are mostly nose-down (in particular sidestick positioned nose-down for 15 consecutive seconds). • The copilot sidestick is at stop position nose-up then neutral twice. • After increasing slightly, the pitch attitude changes from 12° nose-up to 4° nose-down then increases and stabilises at around 15° nose-up. • From 2 h 13 min 55 to 2 h 14 min 02, the angle of attack 2 is no longer NCD. It decreases from 39.4° to 37.3° then increases to 42.5°. The 'Stall warning' is activated again. The CAS is no longer NCD. It changes from 53 kt to 89 kt then decreases to 30 kt. • The Captain sidestick is positioned left between the neutral and stop position. The stop position is held for 5 consecutive seconds. • The copilot sidestick is positioned mainly left between the neutral and ¾ of the stop position. • The roll angle fluctuates between 23.2° right and 10.2° left. • The DUAL INPUT parameter is activated 5 times.	2 h 13 min 41 : SV : "Dual input" 2 h 13 min 43 : SV : "Dual input" 2 h 13 min 45 : SV : "Dual input" 2 h 13 min 47 : SV : "Dual input"
2 h 13 min 40			But I've been at maxi nose-up for a while No no no don't climb So go down
2 h 13 min 45			So give me the controls the controls to me Go ahead you have the controls we are still in TOGA eh

2 h 13 min 48		The thrust levers are moved back to the CLB detent. The engine 1 N1 changes from 106% to 100%.	
2 h 13 min 55		The angle of attack 2 is temporarily valid to 39.4°.	**SV: "Stall, stall" + cricket**
2 h 13 min 57		The FD 1 and 2 become temporarily available again. The selected vertical speed is 1900 ft/min. The selected heading is 280°.	
2 h 14 min 03		The 3 angles of attack are invalid (NCD status).	**End of the "Stall, stall" warning + cricket**
2 h 14 min 05	4,024	The pitch attitude is 14°.	Watch out you're pitching up there I'm pitching up? Well we need to we are at four thousand feet
2 h 14 min 07 → 2 h 14 min 26		• The Captain sidestick is positioned nose-up between the neutral and stop position. • The copilot sidestick is at neutral until 2 h 14 min 17, then in stop position nose-up. • The pitch attitude changes from 15° to 18° nose-up then decreases to 3.5° nose-down before increasing again to 16° nose-up. • At 2 h 14 min 19, the CAS is no longer NCD. It changes from 30 kt to 60 kt then decreases to 32 kt. • At 2 h 14 min 21, the angle of attack 2 is no longer NCD for one second and is 41.1°. The stall warning is triggered. • The Captain sidestick is positioned alternatively to the right then left with mainly right inputs. • The copilot sidestick is at neutral until 2 h 14 min 18 then positioned left to the half-travel position. • The roll angle fluctuates between 9° right and 18° left.	
2 h 14 min 09		The thrust levers are positioned on IDLE for 2 seconds then are moved forward to 21°. The engine N1 change from 100% to 55% in 8 seconds.	
2 h 14 min 17	RA=2,140 ft		SV : "Sink rate" SV : "Pull up" (3x)

2 h 14 min 18 → 2 h 14 min 21		The thrust levers are moved forward in two stages to TOGA. The N1 increase to 105%.	Go on pull Let's go pull up pull up pull up
2 h 14 min 21 → fin		The pilot in the copilot seat takes over the controls.	SV : "Pull up" (4x)
2 h 14 min 26 → end		The Captain sidestick is positioned nose-down and right. The copilot sidestick is in stop position nose-up and around neutral in lateral.	(Ten) degrees pitch attitude

2 h 14 min 28,4 **End of recordings**

Last values recorded on the FDR

Standard altitude (ft)	204
Radio altitude (ft)	71
Computed airspeed (kt) / ISIS speed (kt)	NCD / FW
Ground speed (kt)	107
Pitch attitude (°) [>0 nose-up]	16.2
Roll angle (°) [>0 right turn]	-5.3
Magnetic heading (°)	270
True N1 engine 1 (%)	98.6
True N1 engine 2 (%)	100.9
Configuration	Clean
Nx (g)	-0.17
Ny (g)	-0.10
Nz (g)	1.012
Vertical speed (ft/min)	-10912
Static temperature (°C)	24.3
Gross weight (tonnes) / Centre of gravity (%MAC)	205 / 29.1
Position THS [>0 nose-down] (°)	-13.8

Appendix 2

Operational instructions for crews

3.2. ANNONCES STANDARD

L'ensemble des annonces et leurs modalités de mise en œuvre sont détaillés dans le MANEX B, y compris les annonces spécifiques au type avion. Un certain nombre d'annonces standard sont utilisées sur tous les avions de la flotte, certaines sont présentées sur le tableau ci-dessous :

Annonce	Emetteur	Objet
"DECOLLAGE - V1 xxx kt"	CDB	Décision de décollage
"STOP"	CDB	Décision d'interrompre le décollage
"ON CONTINUE"	CDB	Décision de poursuivre le décollage en cas d'anomalie au décollage Décision de poursuivre l'approche au passage de la DA/MDA/DH
" VARIO POSITIF "	PNF	Lorsque le vario est vérifié positif
" TRAIN SUR RENTRE "	PF	Ordre
" TRAIN RENTRE VERROUILLE "	PNF	Après vérification de la position du train
"ACCELERATION"	PNF	Franchissement de la ZAC au décollage en cas de panne moteur Franchissement de l'altitude d'accélération en remise de gaz N-1
" VOLETS "	PF	Ordre
" VOLETS "	PNF	Après vérification de la position des volets
"1000 ft AVANT"	PNF	1000 ft avant l'altitude ou le niveau de vol autorisé
"LOC ACTIF"	PNF	Décollage butée localizer
"GLIDE ACTIF"	PNF	Décollage butée glide
"TRAIN SUR SORTI"	PF	Ordre
"TRAIN SORTI X VERTES"	PNF	Après vérification de la position du train
"COHERENCE ALTIMETRE SONDE"	PNF	Vérification de la cohérence des altimètres lors du Call Out 2500 ft ou 2000 ft AGL
"ONE THOUSAND" OU "FIVE HUNDRED"	PNF ou CALL OUT	Au franchissement du plancher de stabilisation ***Note :*** *Si le CALL OUT est indisponible ou inadapté (topographie), le PNF annonce le passage du plancher*
"STABILISE"	CDB	Formalisation de la stabilisation au passage du plancher de stabilisation en approche
"500, 400, 300"	PNF ou CALL OUT	A 500, 400 et 300 ft lus sur la sonde
"+ 100"	PNF ou CALL OUT	Altitude / Hauteur de décision + 100 ft
"DECISION" ou "MINIMUM "	PNF ou CALL OUT	Altitude / Hauteur de décision
"ON CONTINUE"	CDB	Altitude / Hauteur de décision
"REMISE DE GAZ"	Tous PNT	Ordre de remise de gaz (CDB), déclenchement de la remise de gaz (PF), demande de remise de gaz (tous PNT)
" LE … NE PASSE PAS "	PNF	Défaut d'inverseur
" LES SPOILERS NE SORTENT PAS "	PNF	Défaut de spoilers
" ..X.. KT "	PNF	A la vitesse de retour d'inversion
"A TOI LES COMMANDES" "J'AI LES COMMANDES"	PF PNF	Passage de commande au PNF Prise de commande par PNF (après demande PF ou décision CDB PNF)
"ASSIETTE"	PNF	Assiette hors plage normale (Cf. MANEX B)
"VITESSE"	PNF	Montée initiale et remise de gaz : vitesse inférieure de plus de 5 kt à la vitesse cible Autres phases : écart hors plage - 5 kt / + 10 kt par rapport à la vitesse cible, ou approche des VMO/VFE/VLE Manoeuvre du train et des hypersustentateurs : vitesse supérieure à VFE/VLO
"VARIO"	PNF	Vario négatif en montée initiale ou en remise de gaz Vario en descente > 1000 ft mn sous 1000 ft AAL
"INCLINAISON"	PNF	Inclinaison > 5° entre le plancher de stabilisation et le sol

TDM
LP
MAJ
ABC
TDM

Appendix 3

OSV Info

Air France Page 1 06/11/2008

info OSV

Sécurité des vols

Airbus A340 / A330

ANOMALIES ANEMOMETRIQUES

A330- A340

Un **nombre significatif d'incidents** rapportés par ASR (6) sont **survenus en croisière** sur nos A330-340.
Ce type d'incidents a été identifié chez d'autres opérateurs sur le même type d'avion, caractérisés par :
-des **pertes d'indications anémométriques**.
-de **nombreux messages ECAM**
-parfois des **alarmes de configuration**

Les principaux faits sont :

➢ **Environnement** :
- Zone de givrage prévue ou observée.
- Turbulence faible à modérée
- 2 cas de turbulences fortes (avec application de la procédure MSS /Turbulence)

➢ **Technique** :
- A330 et A340
- APRS sans items relatifs aux ATA : Auto-flight, Flight controls, Navigation

➢ **Paramètres de vol et Configuration** :
- Vol en haute altitude
- Mach 0.80 à 0.82
- A/P ON et ATHR ON

Ce document est uniquement destiné aux PNT A340/330
Abbès DAOUD-ALMADOWAR - OA.PN – abdaoudalmadowar@airfrance.fr- 06 71 92 44 11 – (01 41 5) 6 36 52

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<u>Chronologie des anomalies : (</u>Ce paragraphe est une synthèse des éléments rapportés par ASR et /ou ATL. Seuls les paramètres et messages apparents sont repris)

1. Indications IAS sur 1 ou 2 PFD erronées (400kt – VLS-50)
2. Ecarts significatifs entre 2 PFD et/ou stand by instruments.
3. Message ECAM : - NAV IAS Discrepancy/ NAV ADR Disagree
   - F/CTL PRIM Fault
   - NAV…xx V/S Det fault
4. Passage en ALTN LAW
5. Dégagement de l'A/P et /ou des ATHR
6. Annonce furtive ou persistante « STALL »

Durant cette phase dont la durée est de plusieurs minutes environ, les équipages ne déclarent **aucune sensation d'overspeed** (vibrations, accélérations) ou **d'approche de décrochage** (assiette, incidence, référence à l'horizon).malgré l'apparition de l'alarme « STALL »

Ces incidents ont conduit la division A330/340 par le biais du BIT à un suivi particulier en relation avec la Maintenance et Airbus.
Les **investigations sont en cours.**
Elles ont fait l'objet de communication lors de la 15e conférence Flight Safety Airbus en octobre 2008 , et de procédures spécifiques reprises à Air France par RCT du 27/10/08 A330/A340.

SOYONS VIGILANTS DANS DES CONDITIONS SIMILAIRES DE VOL
(Haute altitude, givrage, turbulence)

<u>Recommandations aux équipages</u> :

1. **.Lisons attentivement le RCT en vigueur.**
2. **Sachons contenir l'effet de surprise.**
3. **Identifions et confirmons la situation.**
4. **En cas de reprise de contrôle manuel de l'avion, Procédons par faibles corrections.**

Ce document est uniquement destiné aux PNT A340/330
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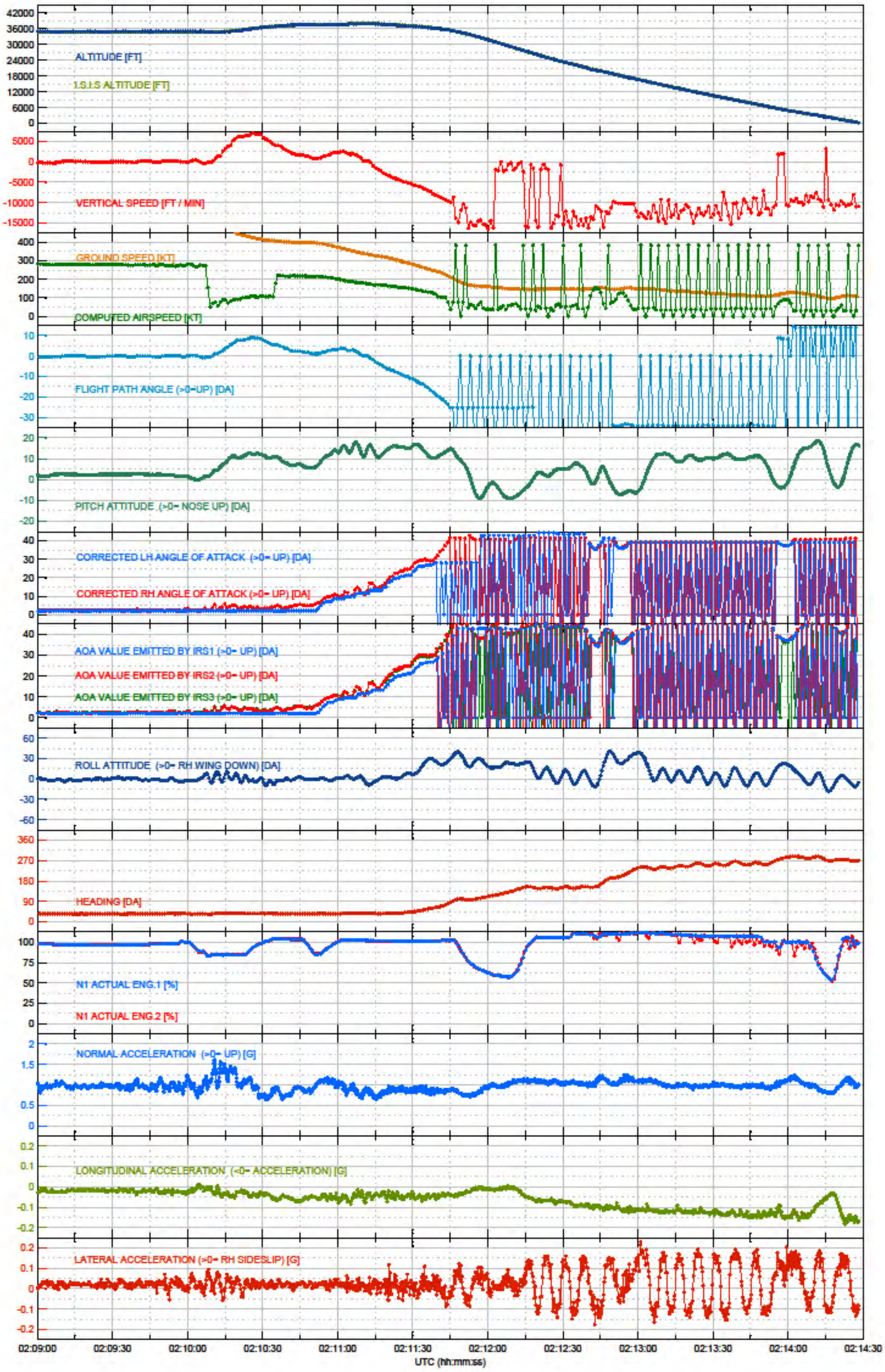
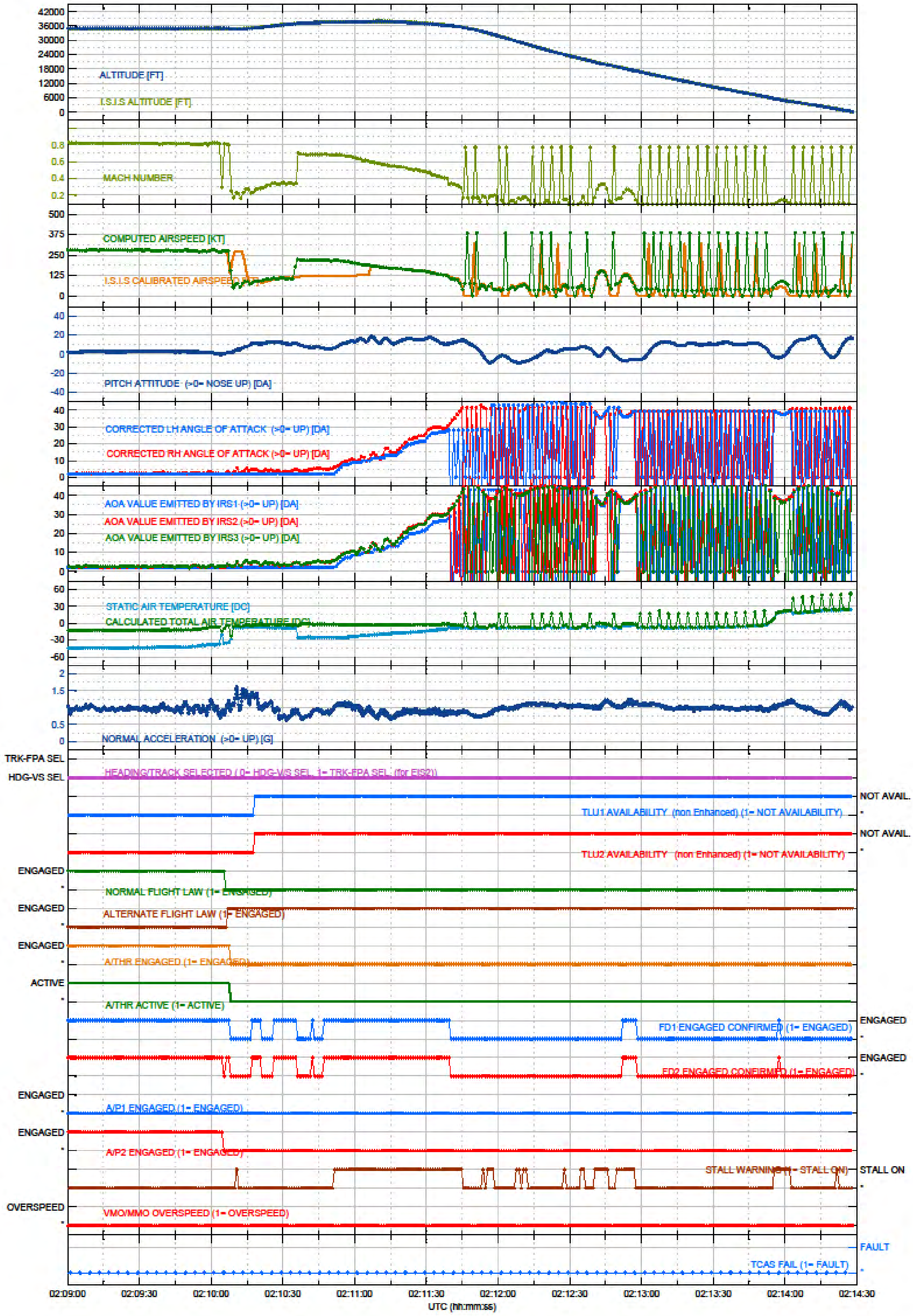
Appendix 4

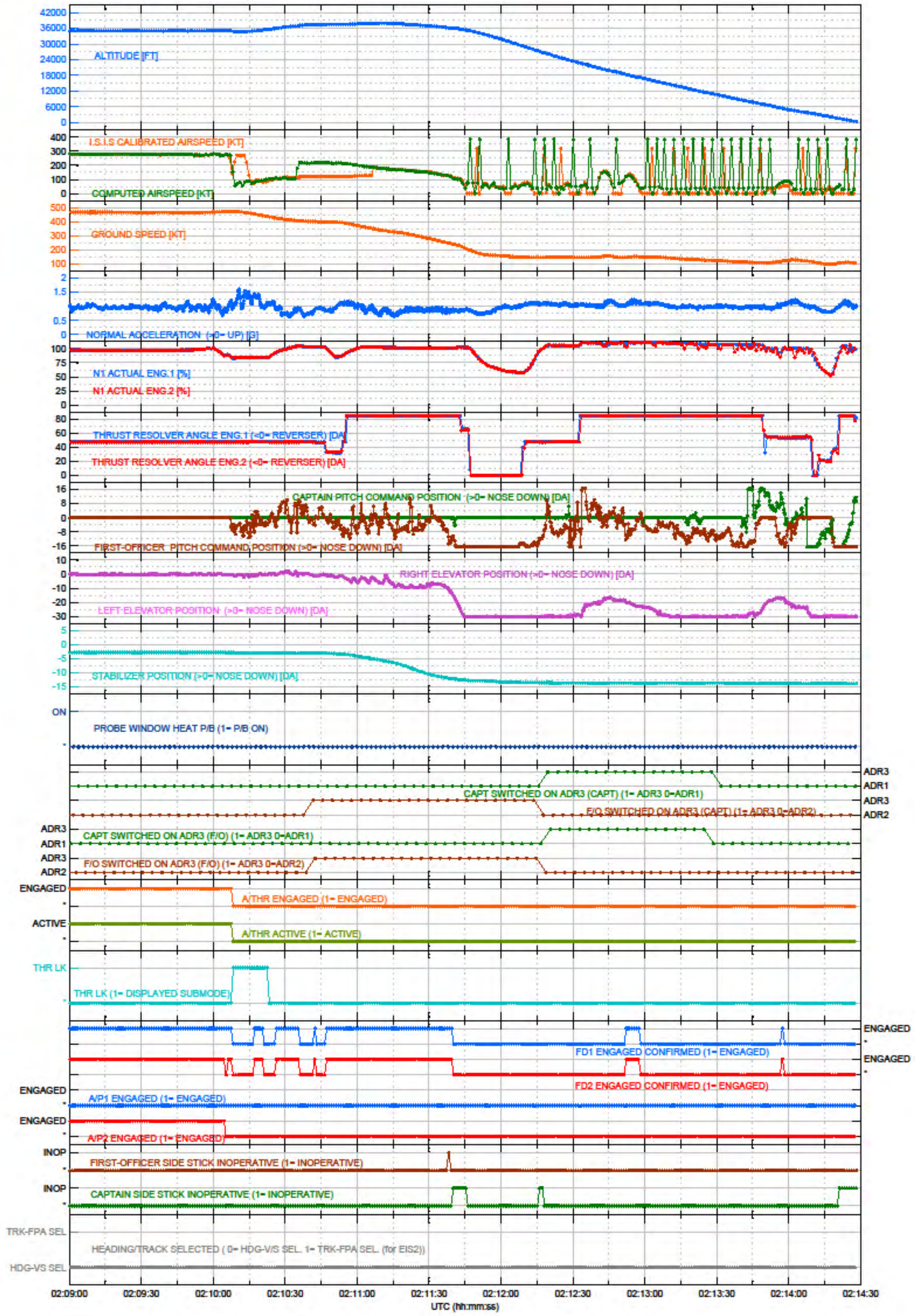
Graphs of flight parameters



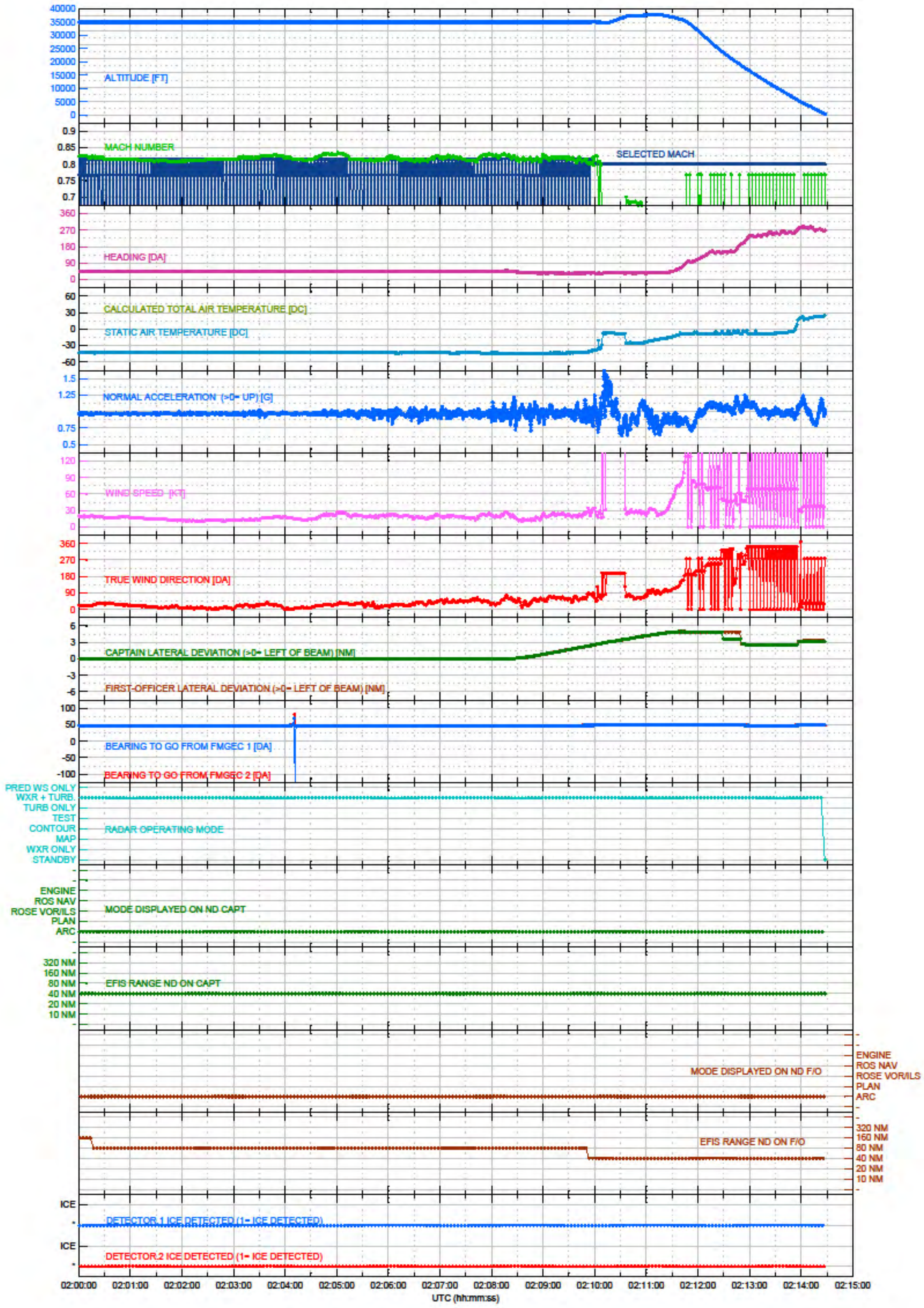
General parameters



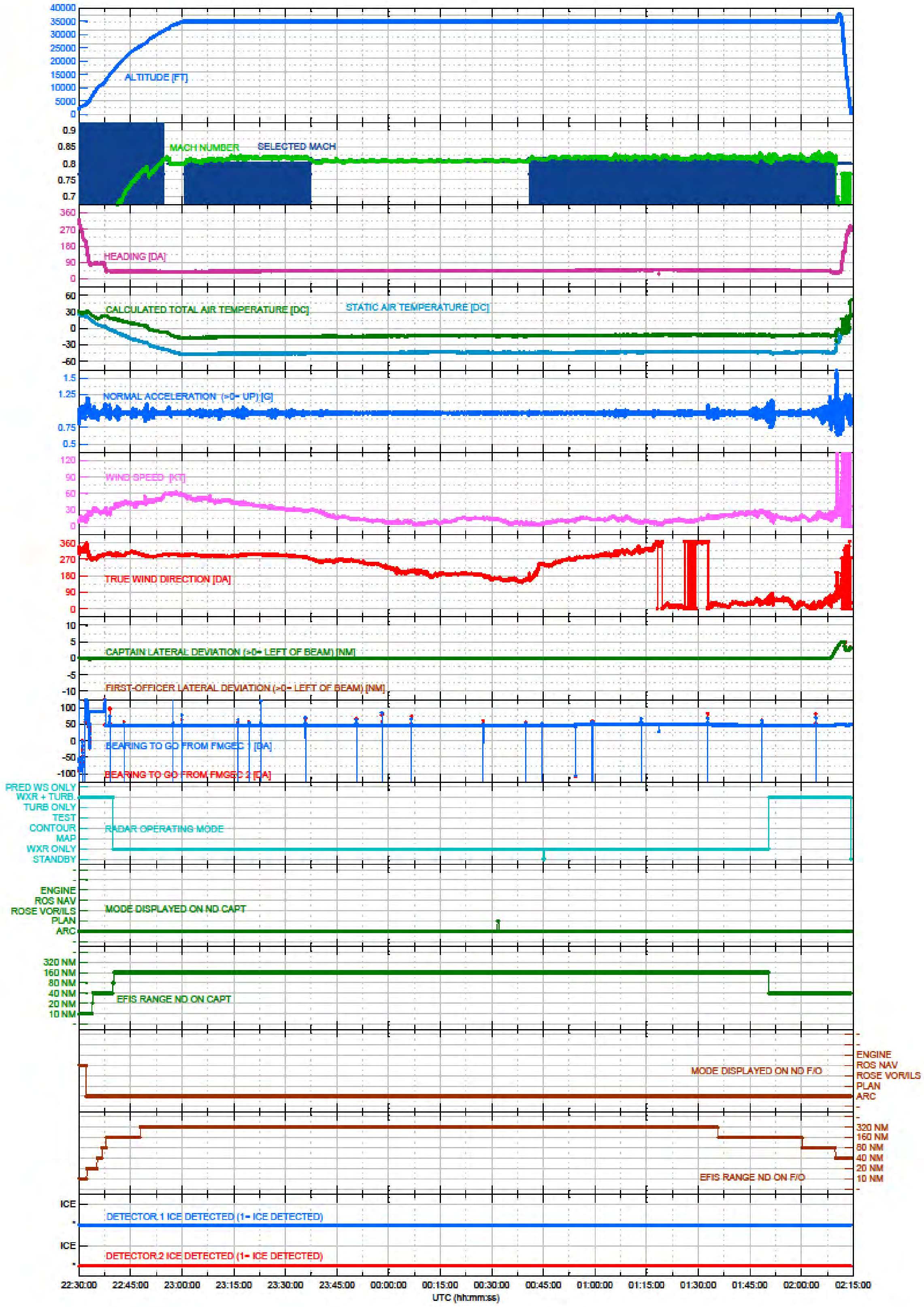
UAS 1 parameters



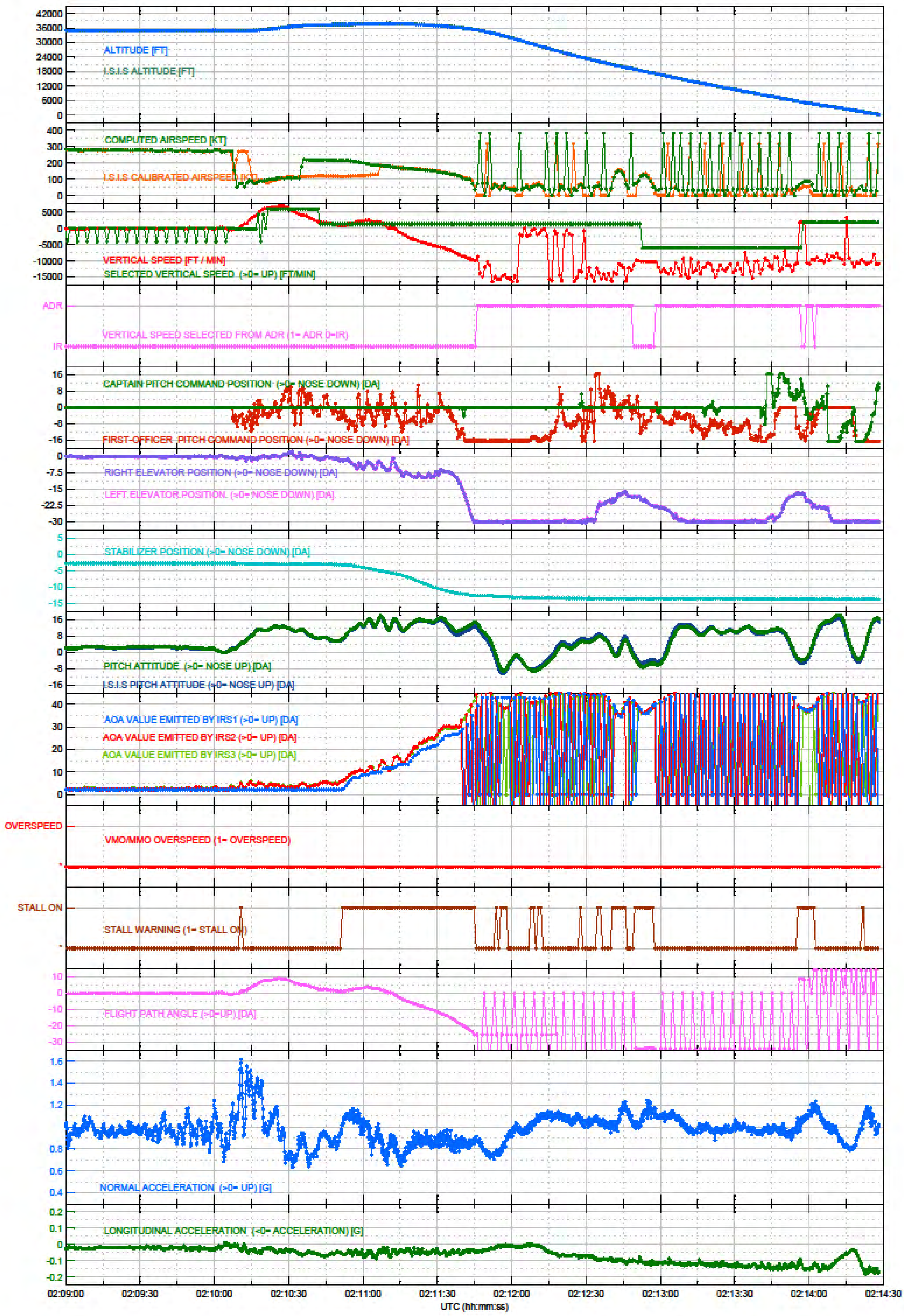
UAS 2 parameters



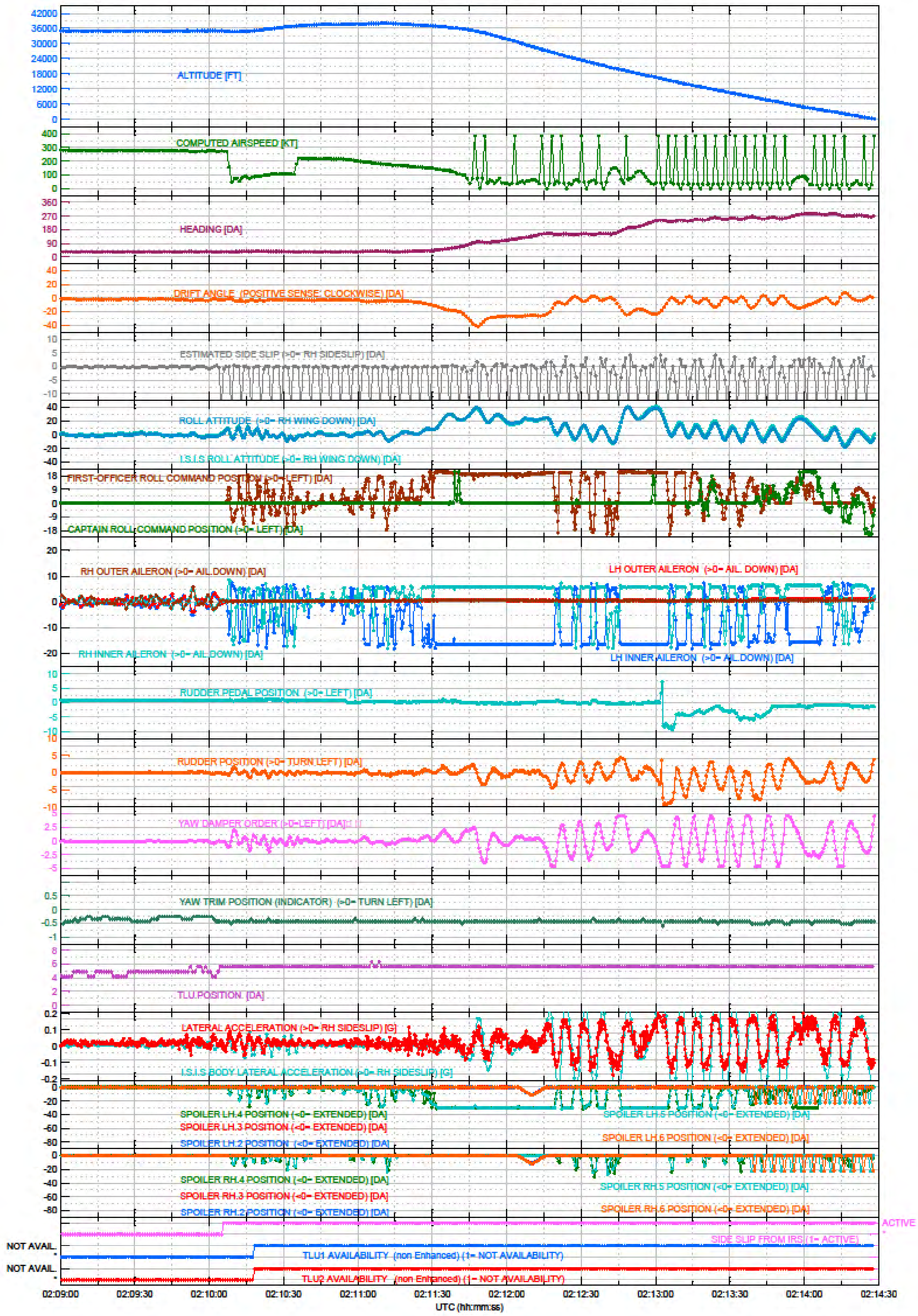
Navigation parameters



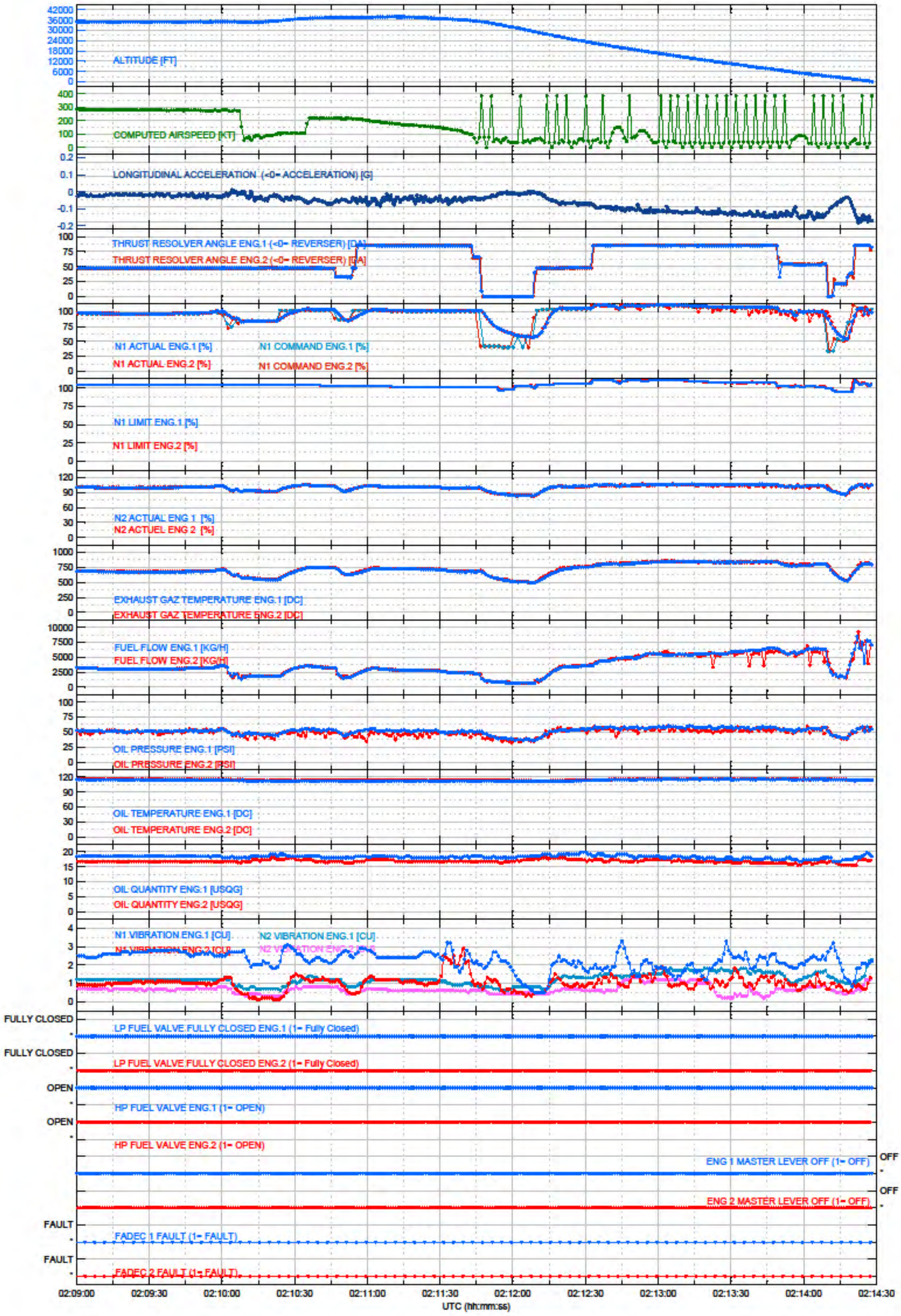
Navigation parameters (complete flight)



Longitudinal parameters



Lateral parameters



Engine parameters

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