MINISTERE DE L'EQUIPEMENT,
DES TRANSPORTS ET DU DESENCLAVEMENT

COMMISSION D'ENQUETE SUR LES ACCIDENTS ET INCIDENTS D'AVIATION CIVILE

REPUBLIQUE DU MALI
UN PEUPLE – UN BUT – UNE FOI

FINAL REPORT

Accident
on 24 July 2014
near Gossi (Mali)
to the McDonnell Douglas DC-9-83 (MD-83)
registered EC-LTV
operated by Swiftair S.A.

Approved on 22 April 2016

N'Faly CISSE

Foreword

The aim of the safety investigation into civil aviation accidents and incidents is to establish the facts, the conditions and the circumstances of the accident or incident to determine the probable causes and the factors that caused it in order to be able to take the appropriate steps to prevent another accident or incident from occurring.

In accordance with Annex 13 to the Convention on International Civil Aviation, the safety investigation is intended neither 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 or incidents.

SPECIAL FOREWORD TO ENGLISH EDITION

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

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GLOSSARY

AAIB	Air Accident Investigation Board (United Kingdom)
ACC	Area Control Centre
AOA	Angle of Attack
AOC	Air Operator Certificate
AP	Autopilot
ATC	Air Traffic Control
BEA	Bureau d'Enquêtes et d'Analyse pour la sécurité de l'aviation civile (French Safety Investigation Agency)
CIAIAC	Comisión de Investigación de Accidentes e Incidentes de Aviación Civil (Spanish civil aviation accident and incident investigation commission)333
CRM	Crew Resource Management
CSMU	Crash Survivable Memory Unit
CVR	Cockpit Voice Recorder
DFGC	Digital Flight Guidance Computer
DGAC	Direction Générale de l'Aviation Civile (French Civil Aviation Administration)
EASA	European Aviation Safety Agancy
EGT	Exhaust Gas Temperature
EPR	Engine Pressure Ratio
ETOPS	Extended-range Twin-engine Operation Performance Standards
FAA	Federal Aviation Administration (USA)
FAR	Federal Aviation Regulation
FCL	Flight Crew Licensing
FCOM	Flight Crew Operations Manual
FD	Flight Director
FDR	Flight Data Recorder
FGCP	Flight Guidance Control Panel
FIR	Flight Information Region
FL	Flight Level
FMA	Flight Mode Annunciator
FMS	Flight Management System
GPS	Global Positioning System
ICAO	International Civil Aviation Organisation
ITCZ	Inter-Tropical Convergence Zone
LMC	Last Minute Change
MEL	Minimum Equipment List
METAR	METeorological Aerodrome Report
MLW	Maximum Landing Weight
MMO	Mach Max Operating
NASA	National Aviation and Space Administration
ND	Navigation Display
NM	Nautical Mile
NTSB	National Transportation Safety Board (USA)
P/N	Part Number
PFD	Primary Flight Display
PNC	Personnel Navigant Commercial
QNH	Altimeter sub-scale setting to obtain elevation when on the ground,
RPM	Revolution Per Minute
S/N	Serial Number
SAFA	Safety Assessment of Foreign *Aircraft*
SAR	Search And Rescue
SAT	Static Air Temperature
SIB	Service Information Bulletin

SIGMET	Significant Meteorological Information
STC	Supplemental Type Certificate
TAF	Terminal Area Forecast
TAT	Total Air Temperature
THS	Trimmable Horizontal Stabilizer
TRP	Thrust Rating Panel
UTC	Universal Time Coordinated
VMO	Maximum Operating Limit Speed

SYNOPSIS

Aircraft	MD-83[1] registered EC-LTV
Date and time	24 July 2014 at 1 h 47[2]
Operator	Swiftair S.A.
Place of accident	80 km south-east of Gossi, Mali
Type of flight	International public transport of passengers flight AH5017 Ouagadougou (Burkina Faso) – Algiers (Algeria)
Persons on board	Captain; copilot; 4 cabin crew; 110 passengers
Consequences and damage	116 fatalities; aircraft destroyed

The aeroplane took off at night from Ouagadougou airport at about 1 h 15 bound for Algiers. During the climb, the crew made several heading changes to avoid a stormy area before reaching cruise level FL 310. A few minutes later, the aeroplane's speed, piloted by the autothrottle, decreased due to the obstruction of the pressure sensors on the engine nose cones, likely by ice crystals. The autopilot then progressively increased the aeroplane's pitch attitude to maintain the altitude, until the aeroplane stalled. The aeroplane's stall was not recovered.

The aeroplane maintained its nose-up attitude and left bank while the control surfaces remained mainly deflected in a pitch-down attitude and with a right bank. The aeroplane struck the ground at high speed.

The accident resulted from a combination of the following events:

- non-activation by the crew of the engine's anti-icing system ;
- obstruction of the PT2 pressure sensors, likely by ice crystals, leading to erroneous EPR values that caused the autothrottle to limit the thrust delivered by the engines below the level of thrust required to maintain FL310 ;
- the crew's late reaction to the decrease in speed and to the erroneous EPR values, possibly linked to the workload associated with avoiding the convective system and to the difficulties in communicating with air traffic control ;
- the crew's lack of reaction to the appearance of buffet, the stickshaker and the stall warning ;
- the absence of appropriate flight control inputs by the crew to recover from the stall situation.

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[1]Although the official designation is McDonnell Douglas DC-9-83, for reasons of brevity the term MD-83 will be used throughout this report.
[2]Except where otherwise indicated, the times given in this report are expressed in Universal Time Coordinated (UTC), which was also the official time in Mali on the day of the accident.

On 10 July 2015, the Malian commission of Inquiry and the BEA addressed 3 safety recommendations to EASA and to the FAA relating to information for crews on the risk of icing on the Pt2 sensors and its consequences.

The final report contains ten additional safety recommendations relating to:

- Studying a permanent engine anti-icing system for the MD80 Pt2 sensors
- Modification the criteria for activation of the anti-ice systems on MD80 engines
- Information and training for crews on the specific features of stall during cruise on MD80
- Representative conditions for the approach to stall at altitude on the MD80 flight simulators
- Studying a modification of the MD80 autopilot so that it disengages on approach to stall
- The maintenance check procedure for CVRs on MD80
- Setting up coordination plans for « SAR » operations in Burkina-Faso, Mali and Niger

ORGANISATION OF THE INVESTIGATION

On Thursday 24 July 2014, with no news from flight AH5017 since 1 h 44, the Niamey area control centre (ACC) broadcast an ALERFA message at 3 h 30 then a DETRESFA message at 4 h 38. Aerial search aircraft identified the wreckage of the aeroplane at 18 h 23 on 24 July 2014.

Crisis cells were immediately set up in Algeria, Burkina Faso, Spain, France and Mali. The high authorities of several of these states travelled to Gao or to the accident site with the assistance of the French armed forces or of the MINUSMA, present in the region. Of note were:

- the visit of His Excellency Ibrahim Boubacar KEITA, President of the Republic of Mali;
- the visit of His Excellency Blaise COMPAORE, President of Burkina Faso;
- the joint visit of the Minister of Transport of Algeria, the Minister of Infrastructure, Transport and Development of Mali and the Minister of the Interior and Security of Mali;
- the visit of the Minister of Infrastructure, Transport and Development of Burkina Faso.

In accordance with Annex 13 to the Convention on International Civil Aviation, a Safety Investigation was initiated by Mali, the State of Occurrence, which set up a Commission of Inquiry which associated:

- an accredited representative from the NTSB (United States), the aeroplane being of American design and manufacture and with American engines. This made it possible to benefit from the assistance of technical advisors from Boeing and Pratt & Whitney;
- an accredited representative from CIAIAC (Spain), the aeroplane being registered in Spain and operated by a Spanish airline;
- an accredited representative from Algeria;
- an accredited representative from Burkina Faso;
- an accredited representative from Lebanon;
- an expert from the AAIB (United Kingdom), in accordance with article 5.27 of Annex 13;
- an accredited representative from the BEA (France), which the President of the Commission asked to provide technical assistance.

The President of the Malian Commission of Inquiry sent four field investigators to the accident site. In addition, investigators from the Spain and France, under the protection of the French military authorities, arrived at the accident site on the morning of 26 July. The geopolitical context made it impossible for the other accredited representatives to go there. The mission to the accident site involved the recovery of the two flight recorders, examination of the wreckage, as well as of the accident site.

In the days following the accident, the recorders were transferred by the Malian authorities to the BEA to be read out and analysed in France. This work was undertaken in the presence of the NTSB accredited representative and an investigator from the CIAIAC.

Following this work, a first meeting of the Commission was held with the accredited representatives of Algeria, the USA and Burkina Faso present. The President of the Malian Commission of Inquiry formed three working groups in the following areas: *Aircraft, Operations and Systems*. Investigators from various countries participated actively in the work of these groups. They met several times at the BEA headquarters. The President decided on the publication of an interim report which was published on 20 September 2014.

The work continued and the first conclusions were shared in January 2015 with the European Aviation Safety Agency (EASA) and through that organisation with the American authorities (FAA). They were the subject of a briefing published on 2 April 2015. They were used for the publication of an SIB (Safety Information Bulletin) issued by EASA and for 3 Safety Recommendations issued jointly by the Mali Commission of Inquiry and the BEA addressed to EASA and to the FAA. All of the work by the investigation groups was included in a draft Final Report, addressed for consultation to the parties involved in the investigation in accordance with the provisions of Annex 13 and the European Regulation on investigations and the prevention of aviation accidents and incidents, which came into effect in October 2012.

Integration of the comments received and the writing and then the publication of the Safety Investigation Final Report on 22 April 2016.

1 - FACTUAL INFORMATION

1.1 History of Flight

Note: the following elements are based on data recorded on the FDR, radio communications and witness statements. No useable data was recovered from the CVR (see 1.11.3).

On 24 July 2014, the MD-83 registered EC-LTV was programmed to operate flight AH 5017 from Ouagadougou bound for Algiers. One hundred and ten passengers and six crew members were on board.

The flight plan filed planned a departure via Niamey (NY), then ROFER via route UM608.

At 1 h 02 min 20, the crew was cleared to start up for a departure from active runway 22.

At 1 h 10 min 14, the crew was cleared to taxi to runway 22 and said that they wanted flight level FL 330 for cruise, then changed their minds and requested FL 310 initially, because the aeroplane’s weight was too high for FL 330.

At 1 h 13 min 05, the controller cleared the crew to perform the departure via EPEPO, towards FL 310, with a turn to the right after takeoff. The controller had prepared for a departure of this flight via GAO through the EPEPO point, through which the aeroplane had passed at the time of its arrival at Ouagadougou from Algiers.

At 1 h 15 min the crew took off, then turned to the right and flew 023° heading. At an altitude of about 10,500 ft, the left side autopilot was engaged[3], the autothrottle having been active since takeoff.

Nine minutes after takeoff, the crew said that they were passing through FL 145 and that they estimated EPEPO point at 01 h 38, and Algiers at 05 h 06.

At 1 h 28 min 09, climbing through FL 215, the aeroplane was transferred to the Ouagadougou ACC to which the crew said that they were turning to the left on heading 356° due to an avoidance manoeuvre[4]. The total air temperature was then 9°C[5].

During the climb towards FL 310, the crew made three heading alterations to the left (of 28°, of 4° and then of 8°), then an alteration to the right of 36° to return to heading 019°, close to the initial heading. The TAT reached 6°C at 01 h 31 min 11

At 1 h 37 min 28, the aeroplane levelled off at FL 310 at Mach 0.740. The autopilot then maintained the aeroplane’s altitude and heading, while the speed was controlled by the autothrottle. At the same time, the aeroplane was transferred to the Niamey ACC. The Total Air Temperature was then -5°C.

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[3] This means that the Captain was likely the Pilot Flying (PF)
[4] The precise message from the pilot was as follows: « we are turning left heading 356 to avoid ».

[5] L'aéronef est équipé d'une sonde RAT (Ram Air Temperature) et la documentation du MD80 utilise cette terminologie. Cependant, tout au long du rapport, le terme température totale, plus communément utilisé, est préféré.

In the two minutes following level-off, the aeroplane's speed increased.

From 1 h 38 min 34, and for about 30 seconds, the autothrottle was in MACH ATL[6] mode. The engines' EPR[7] stabilised around 1.92 and the Mach changed from 0.758 to 0.762. The autothrottle then returned to MACH mode and the aeroplane continued to accelerate up to Mach 0.775.

At 1 h 39 min 36, the aeroplane's speed started to decrease. At 1 h 40 min 10, the autothrottle changed to MACH ATL and for about thirty seconds this mode alternated with MACH mode. At 1 h 40 min 46 the autothrottle changed back to MACH ATL mode while the Mach was 0.752. Following that and until 1 h 45, the altitude remained stable, pitch and EPR increased progressively, while the engines' N1[8] remained stable and the speed continued to decrease.

Between 1 h 41 min 38 and 1 h 44 min 29, the Niamey ACC and flight AH5017 tried to get in contact, but did not manage to do so. Flight RAM543K offered to act as the intermediary. The crew of flight AH5017 announced, at 1 h 44 min 29, that they were at FL 310 on an avoidance manoeuvre. The Niamey ACC heard this radio exchange and then asked them to squawk the 3235 transponder code. He also asked them to call back passing GAO and to transmit estimates for MOKAT point.

No answer or any other messages from flight AH5017, reached the Niamey ACC and the transponder code used by flight AH5017did not change.

At 1 h 44, EPR and N1 fluctuations on both engines appeared for about 45 seconds.

Then, for about twenty seconds, the EPR increased then decreased on two occasions from 1.6 to about 2.5. The N1s increased up to 91% during the first oscillation and remained between 83 and 87% during the second. Some roll oscillations between 4° to the left and right appeared. The autothrottle was disengaged between 1 h 45 min 02 and 1 h 45 min 06[9]. This disengagement occurred between the first and second EPR variations.

At 1 h 45 min 06, the calibrated airspeed was 203 kt, the Mach 0.561, the angle of attack was 9° and the aeroplane started to descend. Pitch increased until it reached 10° at 1 h 45 min 17, and then decreased slightly while the deflection of the elevators and the position of the trimmable horizontal stabilizer (THS) continued pitching up. The EPR and the engines' RPM started to decrease towards values corresponding to idle. The roll oscillations continued and the speed continued to decrease.

At 1 h 45 min 35, the autopilot disengaged. The altitude had fallen by about 1,150 ft in relation to cruise flight level, the calibrated airspeed was 162 kt, the Mach 0.439, the angle of attack was 25° and both engines were almost at idle. The aeroplane's pitch began to decrease and bank was increasing to the left.

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[6] MACH ATL: see paragraph ~~1.6.5.3.3~~ (1.6.5.4.3)for a system description.
[7]Ratio between total pressure at the engine outlet and that at the inlet.
[8]The N1 parameter represents the rotation speed of the engine low pressure rotor, expressed as a percentage of a reference speed.
[9] Autothrottle modes are only recorded every 4 seconds.

The aeroplane's pitch and bank was then subject to significant changes. They reached, respectively, 80° nose-down and 140° bank to the left. The aeroplane was pitched nose-down and banked to the left until it struck the ground. The flight control surfaces remained mainly deflected pitch-up and in the direction of a bank to the right. Around twenty seconds before the impact, the flight control surfaces pitch-up deflection decreased, then the engine speed increased again and reached values close to maximum thrust.

The last values were recorded at 1 h 47 min 15:

- Pressure altitude: 1,601 ft, (in relation to the 1013 hPa isobar)
- Calibrated airspeed: 384 kt
- Pitch: 58° nose-down
- Bank: 10° to the left
- Magnetic heading: 099°

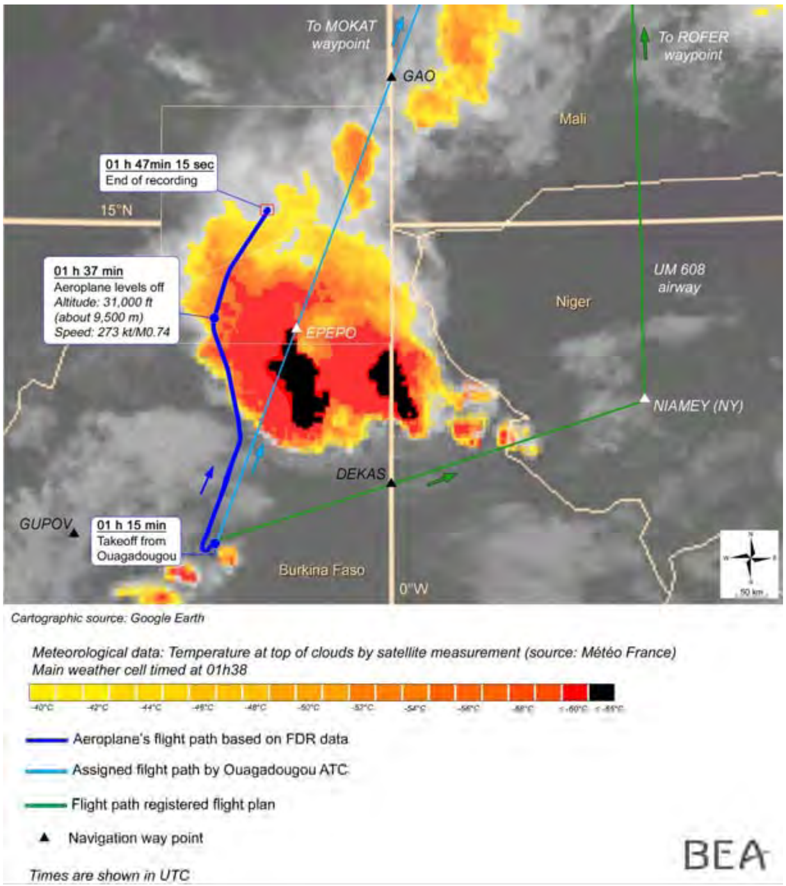


Figure 1 - Overall flight path

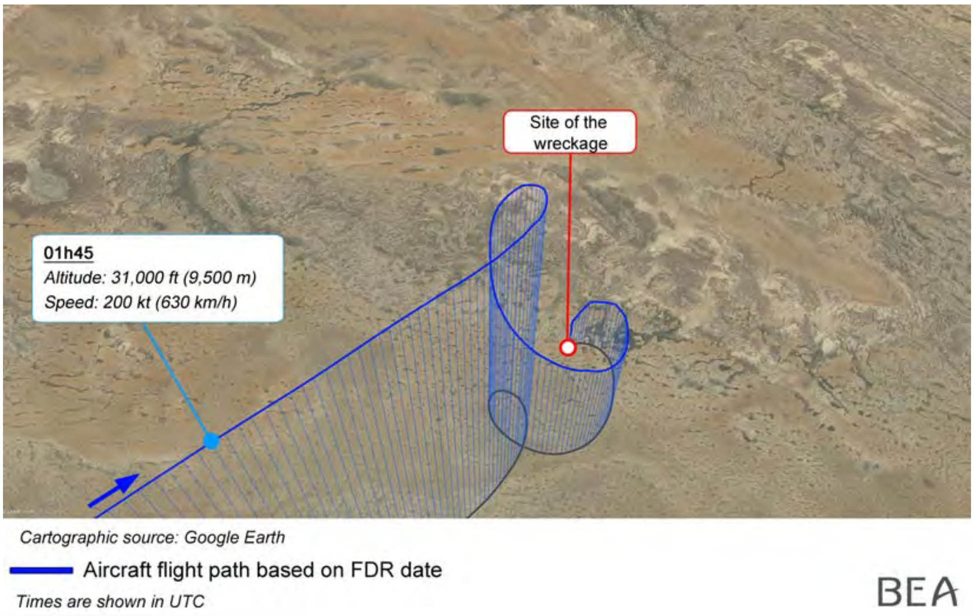


Figure 2 – Final flight path

1.2 Injuries to Persons

	Injuries		
	Fatal	Serious	Slight/none
Crew members	6	-	-
Passengers	110	-	-
Other persons	-	-	-

1.3 Damage to Aircraft

The aeroplane was destroyed.

1.4 Other Damage

Not applicable.

1.5 Personnel Information

1.5.1 Flight Crew

1.5.1.1 Captain

Male, aged 47

- Air transport airline pilot's license ATPL(A) issued on 17 March 2000 by the Spanish civil aviation authority, valid until 30 April 2015;
- Commercial Pilot's License CPL (A) issued on 15 December 1989;
- Private Pilot's License PPL (A) issued on 24 November 1986;
- DC9/MD-80 type rating valid until 30 April 2015;
- TRI (instructor) qualification for DC9/MD-80 valid until 23 January 2015;
- TRE (examiner) qualification for DC9/MD-80 valid until 4 October 2015;
- Medical certificate (Class 1) valid until 20 September 2014.

Experience

- Total: 12 988 flying hours including 8 689 as captain;
- On type: 10 007 flying hours of which 6,445 as captain.

Aviation career details

- From 1989 to 1994 : general aviation pilot
- From 1994 to 1996: copilot on MD-80 with Centennial (CNA)
- From 1997 to 2012: copilot then captain on MD-80 with Spanair
- 15 June 2012: joined Swiftair S.A. as captain on MD-80

Flying experience in Africa

- Between 1997 and 2012 the captain, as co-pilot then captain at Spanair, had flown to various airports located in Africa including the one at Ouagadougou.
- From 12 July 2012 to 1 October 2013, he had totalled 456 flying hours in Africa for the UN, as captain on MD80. He was based in Khartoum (Sudan).
- Since 20 June 2014, date of the start of operations with Air Algérie, the captain had carried out 45 flights and 100 flying hours including in particular
    - 30 flights from or to aerodromes in North Africa (Oran, Casablanca, Tlemcen, Bejaïa, Batna)
    - on 30 June 2014 one Algiers – Niamey flight
    - on 1 July 2014, the return Niamey - Algiers flight
    - on 21 July one Algiers - Ouagadougou flight
    - on 22 July one Ouagadougou - Algiers flight
    - on 23 July one Algiers - Ouagadougou flight

1.5.1.2 Copilot

Female, aged 42

- Air transport airline pilot's license ATPL(A) issued on 10 May 2002 by the Spanish aviation authority, valid until 31 May 2015;
- Commercial Pilot's License CPL(A) issued on 16 June 1993;
- Private pilot's license PPL(A) issued on 19 June 1992;
- DC9/MD-80 type rating valid until 31 May 2015;
- Airbus A320 type rating valid until 31 March 2015;
- Medical certificate (Class 1) valid until 16 July 2015.

Experience

- Total: 7,016 flying hours including 6,180 flying hours as a co-pilot on MD80.

Since 20 June 2014, date of the start of operations with Air Algérie, the copilot had carried out 43 flights and 93 flying hours including in particular:

- on 21 July one Algiers - Ouagadougou flight
- on 22 July one Ouagadougou - Algiers flight
- on 23 July one Algiers - Ouagadougou flight

Aviation career details

- From 1995 to 1998 : dispatcher at Spanair;
- From 1998 to 2012 : copilot on MD-80 at Spanair;
- On 1 June 2013: joined Swiftair S.A. as copilot on MD 80.

Flying experience in Africa

- Between 1998 and 2012 the copilot, as copilot with Spanair, had flown to various aerodromes located in Africa, including the one at Ouagadougou.
- Since 20 June 2014, date of the start of operations with Air Algérie, the copilot had carried out the same flights as the captain, except for the Niamey roundtrip flight, which corresponds to 43 flights and 93 flying hours.

Details of recurrent training and checks on the flight crew are included in paragraph 1.17.1.9.

1.5.2 Cabin Crew

The licenses, qualifications medical certificates of the four cabin crew members were up to date.

1.6 Aircraft Information

General

The McDonnell Douglas MD-83 is a variant of the MD-80 airliner manufactured by the American aircraft manufacturer McDonnell Douglas. The MD-80 is itself an improved version of the McDonnell Douglas DC-9.

The first MD-80, certified by the FAA in August 1980, entered service in October 1980. Five different models were developed: the MD-81, MD-82, MD-83, MD-87 and MD88.

McDonnell Douglas was taken over by Boeing in 1997.

The MD-80 family of aircraft was produced in Long Beach by the commercial aircraft division of Boeing until December 1999.

1.6.1 Airframe

1.6.1.1 Characteristics (data supplied by Swiftair SA)

Manufacturer	McDonnell Douglas (Boeing)
Model	MD-83
Serial number	53190
Year of manufacture	1996
Registration	EC-LTV
Certificate of registration (validity)	25/10/2015
Airworthiness examination certificate (validity)	27/12/2014
Owner	Balcargo S.L
Operator	Swiftair S.A.
Lessor	Avico
Charterer	Air Algérie
Maximum Operational Passenger Seating Configuration (MOPSC)	172
Passenger seat configuration	165, single class
Operational Empty Weight (OEW)	83,917 lb (38,064 kg)
Maximum Zero Fuel Weight (MZFW)	122,000 lb (55,338 kg)
Maximum Landing Weight (MLW)	139,500 lb (63,276 kg)
Maximum Take-Off Weight (MTOW)	160,000 lb (72,574 kg)
Total aircraft flying time[10]	38,362 hrs 55 min

[10]Before the accident flight.

Total aircraft flight cycles	32,390
Last maintenance check	19/06/2014 (Check 1A)
Last maintenance service	23/07/2014
Last weigh-in	07/10/2012

1.6.1.2 Aircraft history

<table>
<tr><th>Date</th><th>Note</th><th>Registration</th><th>Operator</th><th>Owner</th></tr>
<tr><td>23/08/1996</td><td>Delivery to Heliopolis Airlines</td><td rowspan="2">SU-ZCA</td><td rowspan="2">Heliopolis</td><td rowspan="2">AWAL[11]</td></tr>
<tr><td>06/12/1997</td><td>Deleted from the Egyptian register</td></tr>
<tr><td>09/12/1997</td><td>Registered with the US register</td><td rowspan="2">N190AN</td><td rowspan="2">AWAS[12]</td><td rowspan="5">Wilmington Trust Company</td></tr>
<tr><td>10/02/1998</td><td>Deleted from the US register</td></tr>
<tr><td>13/02/1998</td><td>Registered with the Columbian register</td><td rowspan="2">HK-4137X</td><td rowspan="2">Avianca</td></tr>
<tr><td>11/08/2000</td><td>Deleted from the Colombian register</td></tr>
<tr><td>17/08/2000</td><td>Registered with the US register</td><td rowspan="3">N190AN</td><td rowspan="3">AWAS</td></tr>
<tr><td>21/12/2006</td><td>Sold to AWAS</td><td rowspan="6">AWAS</td></tr>
<tr><td>16/01/2007</td><td>Deleted from US registry</td></tr>
<tr><td>19/01/2007</td><td>Registered with the Argentinian register</td><td rowspan="2">LV-BHN</td><td>Austral</td></tr>
<tr><td>02/2012</td><td>Deleted from the Argentinian register</td><td rowspan="3">AWAS</td></tr>
<tr><td>30/03/2012</td><td>Registered with the US register</td><td rowspan="2">N190AN</td></tr>
<tr><td>10/2012</td><td>Deleted from the US register</td></tr>
<tr><td>24/10/2012</td><td>Registered with the Spanish register</td><td>EC-LTV</td><td>Swiftair S.A.</td><td>Balcargo S.L</td></tr>
</table>

[11] Ansett Worldwide Aviation Limited
[12] Ansett Worldwide Aviation Service

1.6.2 Engines

The aeroplane was equipped with two Pratt & Whitney JT8D-219 engines. They are two-spool engines, with a medium bypass ratio. The first engine of the D-200 Series was certified on 22 June 1979. The JT8D-219 was certified on 22 February 1985.

	Engine #1	Engine #2
Manufacturer	Pratt & Whitney	
Model	JT8D-219	
Serial number	708184	728104
Total time	44,779 hrs 04 min	26,161 hrs 55 min
Total cycles	27,728	22,012
Time since last check	183 hrs 55 min	3,956 hrs 55 min
Cycles since last check	100	2,043
Last overhaul	20/03/2013	07/05/2010

1.6.3 Monitoring of Maintenance Operations

1.6.3.1 General

Daily and weekly checks are carried out. They help ensure preventive maintenance tasks and to correct problems reported after the flight by crews.

Type A checks include routine maintenance operations. On the MD-83, there are 3 types:

- 1A check carried out every 450 flying hours;
- 2A check carried out every 900 flying hours;
- 4A check carried out every 1,800 flying hours.

1.6.3.2 Last maintenance operations

The last three type A checks were carried out:
- On 20/06/2014 for type 1A and 2A inspections by Swiftair;
- On 06/01/2014 for the type 4A inspection by MyTechnic[13].

Concomitantly with the type 4A check, on 06/01/2014, MyTechnic carried out parts of type 1C checks (3,600 flight hours or 18 months), type 3C (10,800 flight hours or 54 months) and type 30M (30 months).
These checks were carried out in accordance with the operator’s maintenance programme, developed from the manufacturer's recommendations (maintenance programme) and approved by the Spanish authorities.

[13]Part 145 AMO, located in Istanbul, Turkey.

The last maintenance operations concerning the EPR system were the following:

- On 21 July 2013, intermittent failures on the autothrottle led to replacement of the EPR transmitter on No. 2 engine.
- On 19 October 2013, the No. 1 engine EPR indicator was faulty (no display of values) and the display was replaced.
- On 2 March 2014, the autothrottle actuator was replaced. During the recommissioning process, the "*EPR LH*" failure message was displayed. The left-hand EPR transmitter was therefore also replaced.

In addition, on 27 June 2014, an engine surge resulted in a rejected take-off at about 80 kt. Engine n° 1 was replaced.

The examination by the investigation team of the maintenance documents, of the maintenance programme and of the aircraft's airworthiness dossier did not reveal any element likely to have contributed to the accident.

1.6.3.3 Condition of the aeroplane before departure

According to the flight records for maintenance staff made available to the investigation, all the equipment included in the Minimum Equipment List (MEL) was in working order at the time of the departure from Ouagadougou.

1.6.4 Weight and Balance

During flight preparation, the weight calculated by the crew was 151,697 lb (68,808 kg). The weight was distributed as follows:

- an operating empty mass of 86,924 lb (39,428 kg);
- a passenger mass (99 adults and 12 children) of 19,239 lbs (8,726 kg);
- a cargo mass (baggage[14]) of 6,034 lb (2,736 kg);
- a fuel mass of 39,500 lb (17,916 kg).

The estimated fuel weight for taxiing was 500 lb. The estimated take-off weight was then 151,197 lb (68,581 kg). The regulated takeoff weight (RTOW) in the conditions on the day, taking into account the runway in use, airport altitude, temperature, wind and flaps setting was 152,557 lb (69,197 kg).
The maximum authorized take-off weight (MTOW) was 160,000 lb (72,574 kg).

A last minute change resulted in a correction of the final load sheet to account for the absence of a passenger. The aeroplane thus took off with 110 passengers on board.

The weight and balance at take-off determined by the crew of the aeroplane were within the limits set by the manufacturer. These calculations were checked by the investigation team.

[14] The load sheet indicated there was no cargo on board the flight.

In addition the aircraft performance calculations made by the manufacturer, for the purposes of the investigation, specifically on the basis of the load sheet, confirm that the balance of the aeroplane remained within operational limits during the flight.

1.6.5 Systems Description

1.6.5.1 Description of thrust control

The thrust of a turbojet can be measures from the ratio between the total pressure of the air at the jet outlet (P_{t7} and the total pressure at the inlet (P_{t2}). These pressures are measured through sensors placed respectively at the engine outlet and inlet. The ratio of these two pressures, outlet over inlet, is called EPR (Engine Pressure Ratio).

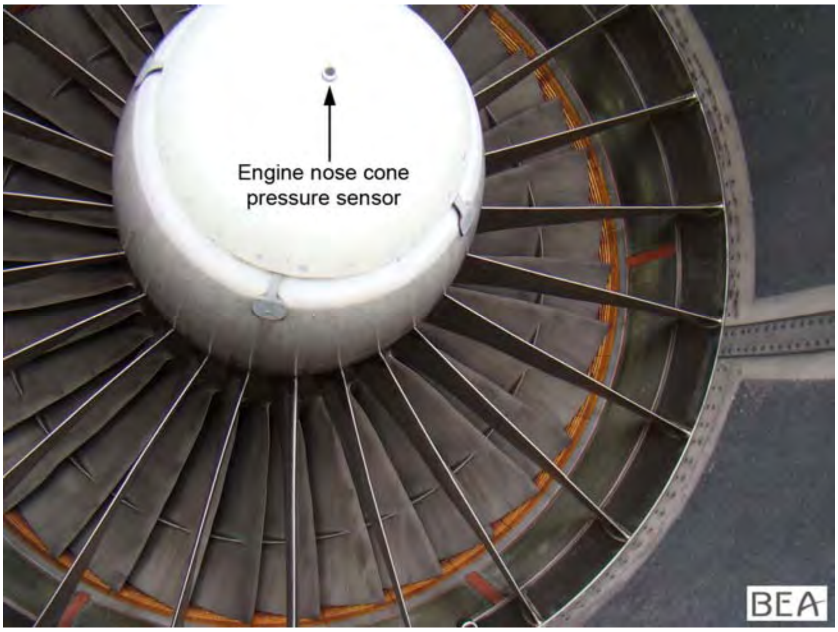


Figure 3 – Nose cone

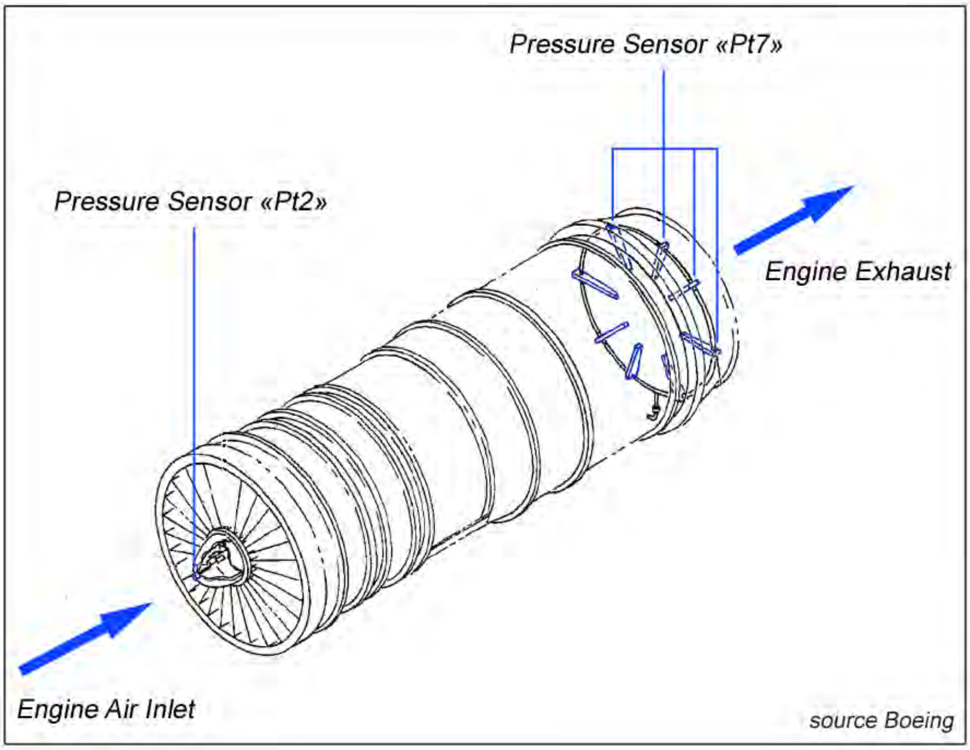


Figure 4 – Position of pressure sensors

On the MD-83 equipped with PW JT8D engines, the EPR is the parameter used to control and command the engine thrust. The thrust can be commanded manually by the crew through inputs on the throttle levers until the desired EPR value is displayed, or through the autothrottle which will automatically make inputs on the throttle levers to reach the EPR value calculated by the automatic systems. The autothrottle has one servocontrol to control the position of both throttle levers, consequently the action of the autothrottle is identical on both levers.

The thrust can also be linked to the low pressure system rotation speed. This parameter is known as N1 and is expresses as a percentage of the engine rotation reference setting. The values of the EPR and N1 on both engines are displayed in the cockpit on the engine control instruments and there is, in normal operation, a direct correspondence between the variations of the EPR and N1 when the commanded thrust varies.

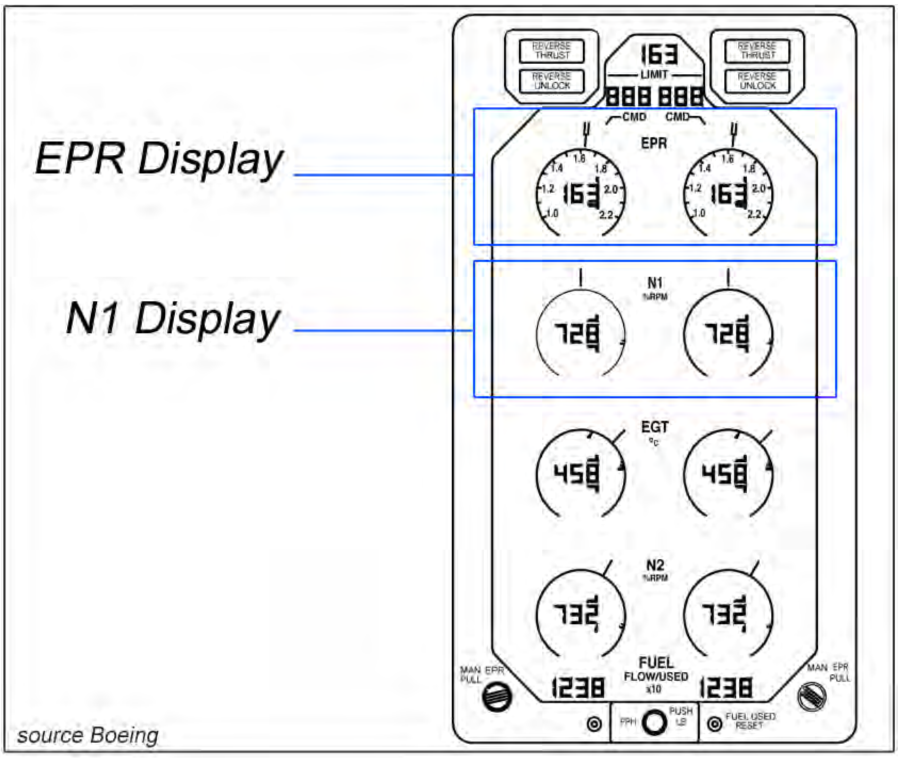


Figure 5 – Engine instruments

1.6.5.2 Description of the EPR data system

For each engine, a transmitter calculates the value of the EPR from the total pressure measurements Pt_7 and Pt_2. This value is then transmitted:

- to the two Digital Flight Guidance Computers (DFGC) that control guidance and autopilot;
- to the engine instrument panel to be displayed in the cockpit;
- to the Flight Data Acquisition Unit (FDAU) which formats it and sends it to the FDR for recording.

Electrical supply to the EPR 1 and the EPR 2 data systems is dissociated.

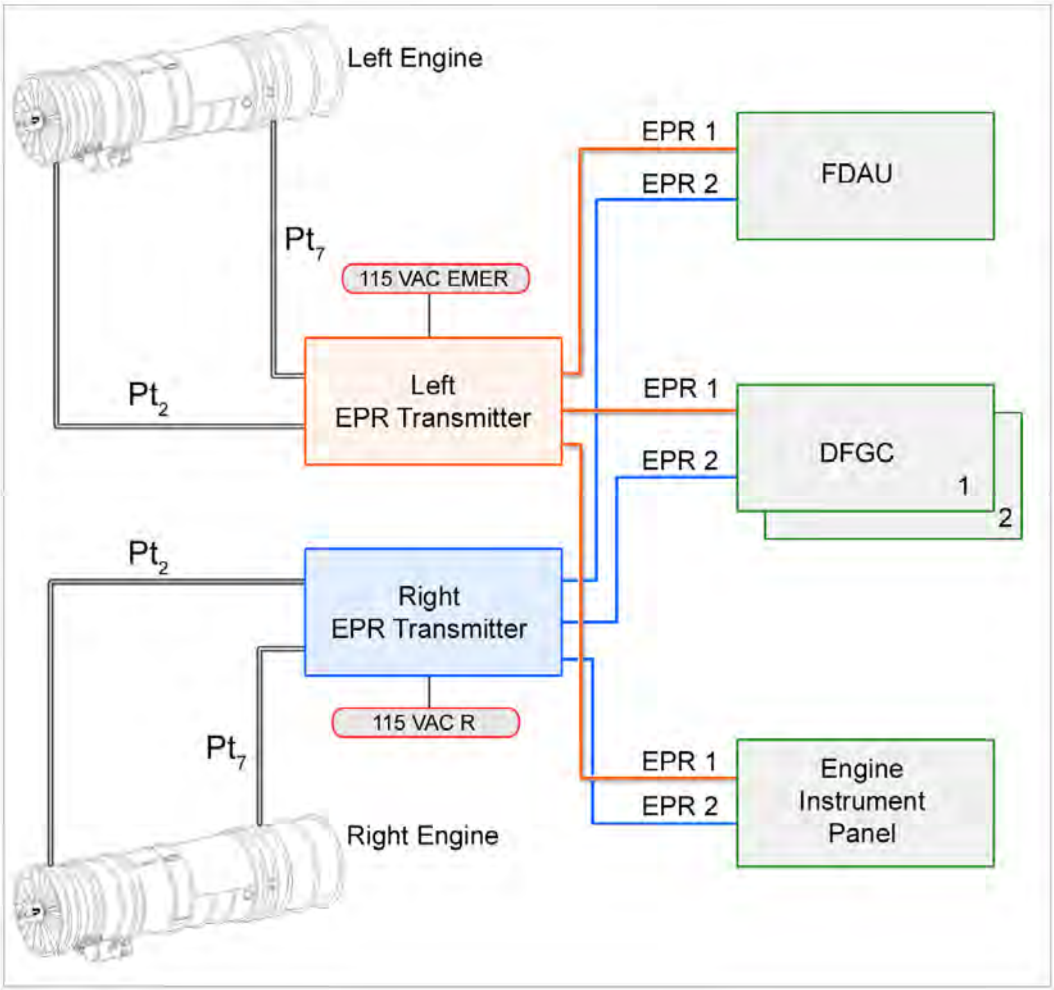


Figure 6 - Diagram of the EPR data system

An obstruction of Pt_2sensor will result in a decrease of the measured pressure value and thus an increase in the EPR value. In this case, the aeroplane's systems use a measured EPR value greater than the true value of this parameter.

1.6.5.3 Icing protection systems

1.6.5.3.1 General

The MD83 anti-icing system includes the following functions:

- anti-icing of the inlet guide vanes, the nose cone including Pt2 pressure sensor, and the inlet duct of each engine is provided by hot air bled from the compressor;
- anti-icing of the leading edge slats, stabilizer panels (*strakes*) located on the front of the fuselage and of the outside air intake for air conditioning is provided by hot air bled from the compressor ;
- de-icing the leading edge of the trimmable horizontal stabilizer is provided by hot air bled from the compressor;
- anti-icing of the pitot probes, angle of attack sensors, static pressure taps and temperature sensors is provided electrically;
- anti-fogging and anti-icing of the windshields is provided electrically.

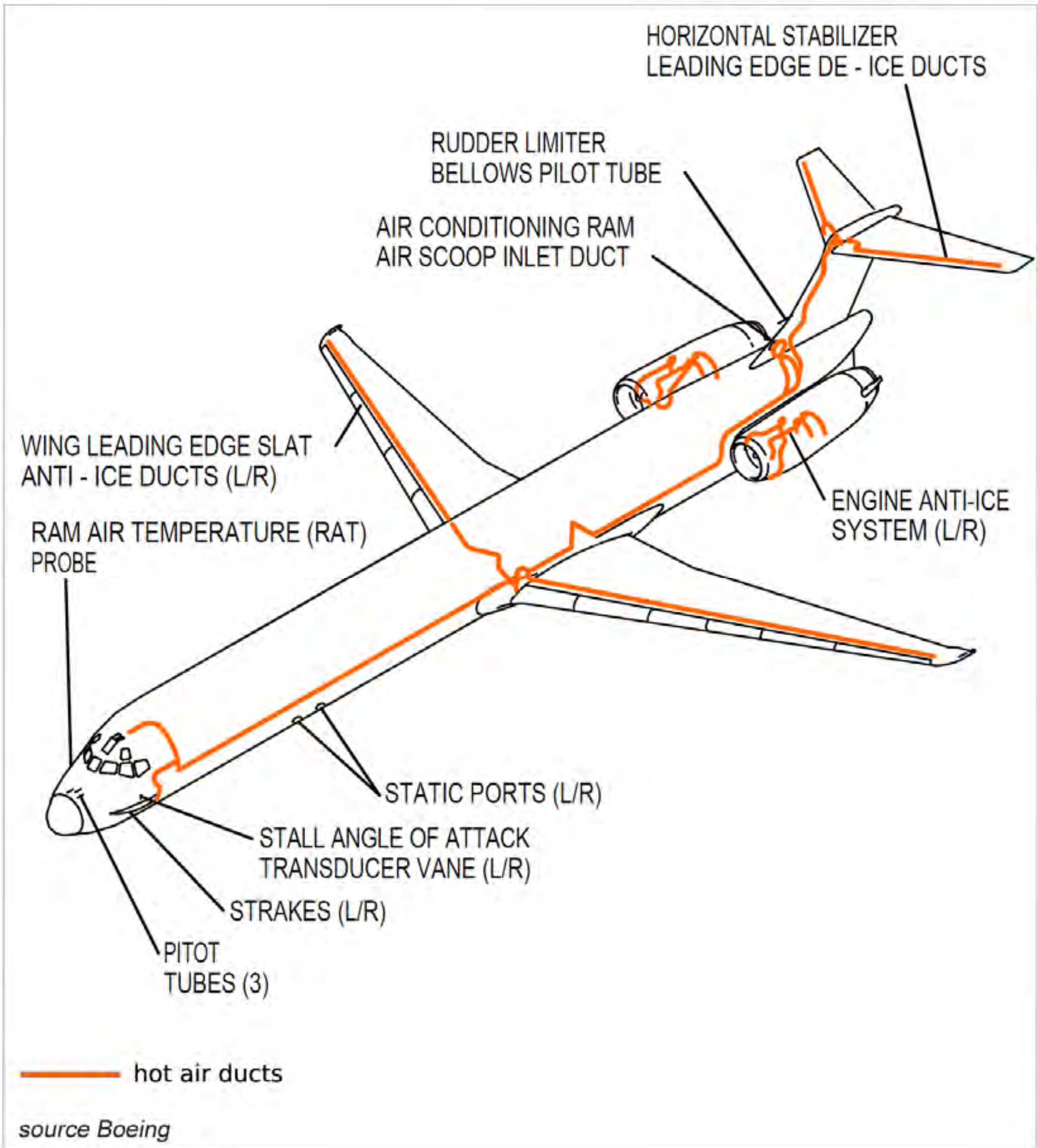


Figure 7 - Overview of the anti-icing system

Note: an anti-icing system acts pre-emptively to prevent the accumulation of ice. A de-icing system acts in a curative manner by removing the accumulation of ice.

The anti-icing system on each engine can be activated by the crew using the corresponding command, "*ENG L*" or "*ENG R*", located on the top panel. Airframe and stabilizer anti-icing is activated using the "*AIRFOIL*" command. Protection of the windshields is ensured by the "*ANTI-FOG*" and "*ANTI-ICE*" controls. The "*METER SEL & HEAT*" switch manages the heating of the various sensors.

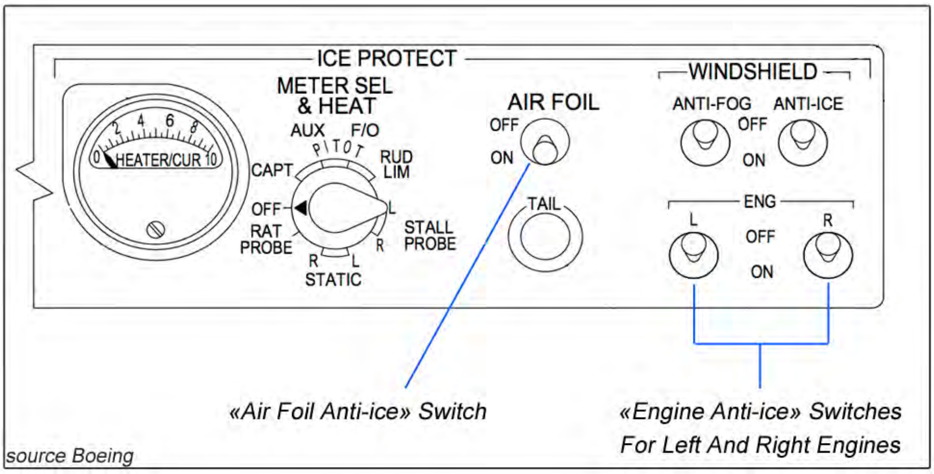


Figure 8 - Ice Protection Panel

1.6.5.3.2 P_{t2} sensor heating

The Pt2 pressure sensor located on the engine nose cone is heated by hot air bled from the engine. This air is sent to the nose cone and circulates around the pressure sensor. When the "*ENG L*" or "*ENG R*" button is in the ON position, the engine anti-icing valves on the corresponding engine open and the heating operates.

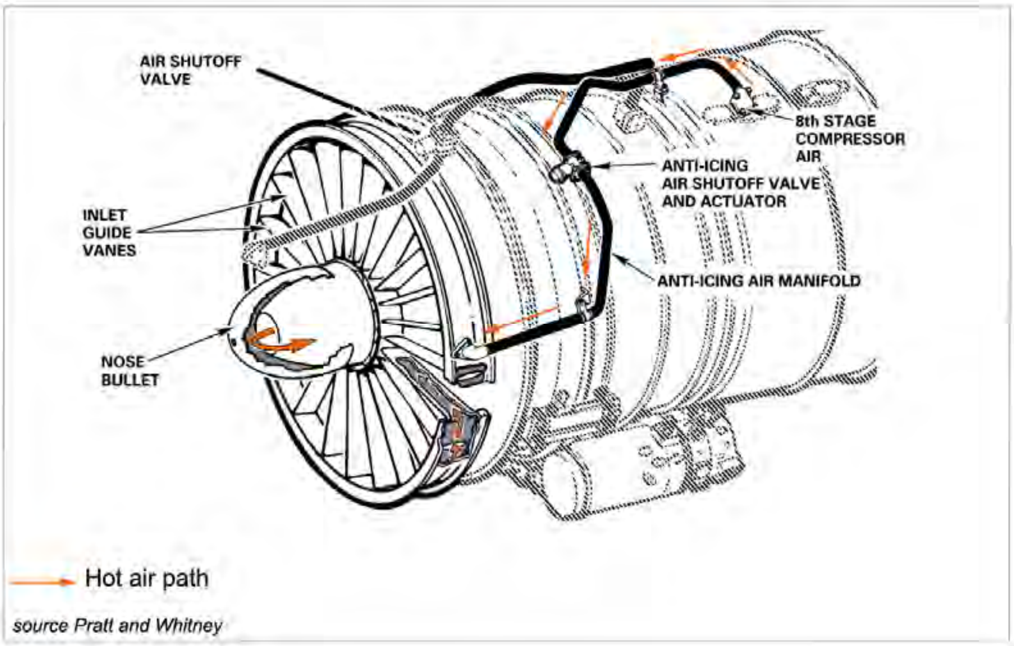


Figure 9 - General diagram of the heating system on the nose cone

1.6.5.4 Description of automated systems

1.6.5.4.1 General

The MD-83 is equipped with two Digital Flight Guidance Computers (DFGC) that process the data necessary for the following specific functions:

- flight directors (FD);
- autopilot (AP);
- autothrottle;
- thrust calibration.

In normal operation, the DFGC1 processes the commands of the Flight Director (FD) displayed on the left-hand Primary Flight Display (PFD) and the DFGC2 processes the commands displayed on the right PFD. For the FD commands to be displayed on a PFD, the corresponding "*FD*" command, located on the Flight Guidance Control Panel (FGCP) must be in the FD position. The active modes are then displayed on the corresponding Flight Mode Annunciator (FMA).

When the autopilot is engaged, the crew can select AP1 (left side) or AP2 (right side) by means of a control on the FGCP.

Figure 10 - MD-83 FGCP

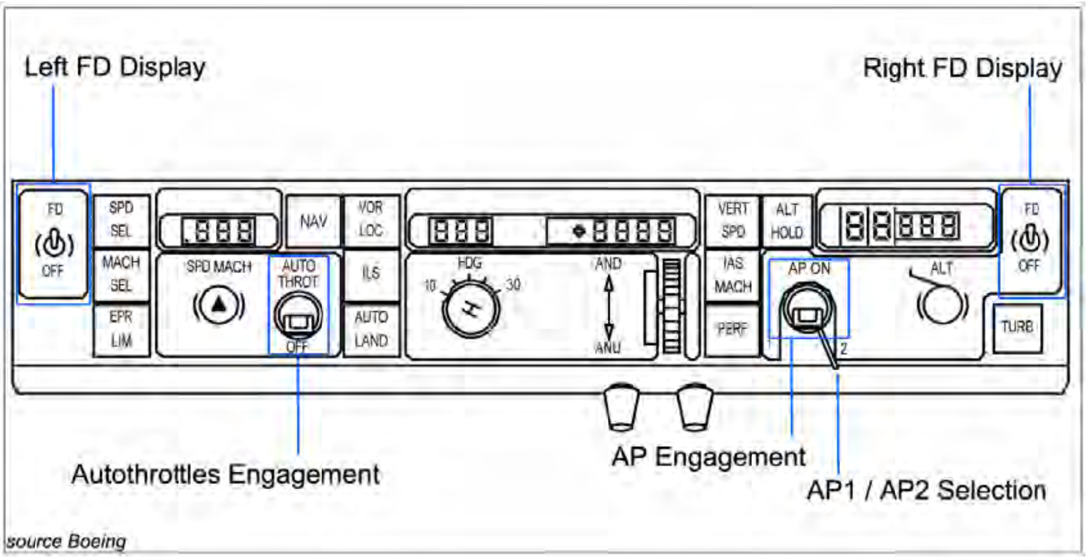


Figure 11 - FGCP (Source: Swiftair S.A. FCOM)

Figure 12 – FMA

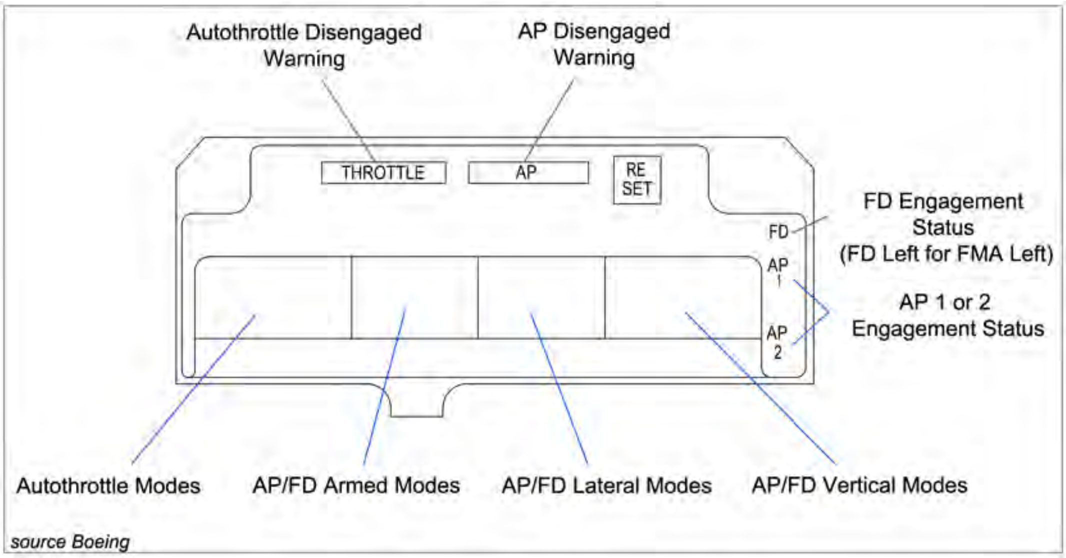


Figure 13 – FMA (*Source: Swiftair S.A. FCOM*)

1.6.5.4.2 Autopilot

The autopilot is engaged by moving the "*AP ON*" control located on the FGCP to the AP ON position. This command remains in the AP ON position as long as the conditions for engaging the autopilot are met. The autopilot can be disengaged manually or automatically in case of malfunction. The autopilot can be manually disengaged by:

- moving the AP ON switch from the ON position, or
- moving the "*AP 1-2*" switch to the opposite position, or
- pressing one of the "*AUTOPILOT REL*" switches located on the pilot control columns, or
- making an input on the main horizontal compensation control, or
- pushing one of the TO/GA switches on the throttle levers if the flaps and slats are not in the landing configuration, or
- making a flight control input by exerting a force ranging between 175 and 225 Newton in roll and approximately 97 Newton in pitch.

The autopilot can also disengage automatically in one of the following cases:

- Loss of electrical power loss for more than 200 ms;
- Fault or system failure detected by the DFGC;
- Internal failure of the DFGC.=

In the case of manual or automatic disengagement, the autopilot engagement control automatically resumes the rest position and the red "*AP Warning*" light flashes on the left and right FMAs. Except in automatic landing mode, no aural warning is issued. Pressing one of the "*AUTOPILOT REL*" buttons turns off the light.

The table below gives the main modes used by the crew.

Lateral mode	HDG SEL	This mode maintains the heading selected on the FGCP. The heading select button must be pulled for this mode to be engaged. The set point is maintained by acting on the roll axis.
	VERT SPD	The vertical speed management mode keeps the vertical speed displayed on the FGCP. The set point is maintained by acting on the pitch axis
Longitudinal modes	ALT HLD	The altitude hold mode. The AP maintains the altitude at which this mode was engaged. If the altitude select knob on the FGCP is pulled, the AP is activated (ALT mode) to recapture and maintain the altitude displayed. The set point is maintained by acting on the pitch axis.
	IAS/MACH	The speed/MACH hold mode. The AP maintains the speed or current MACH when it was engaged. The set point is maintained by acting on the pitch axis. In this case the autothrottle is in EPR LIM mode (see 1.6.5.4.3) and maintains thrust.

In cruise, if the airspeed falls 13.5% below a reference speed called the "*Alpha Speed*[15]", the display on the FMAs of the longitudinal mode alternates between the active mode and the indication "*SPD LOW*" in order to alert the crew to the low speed situation. This indication is inhibited if the autothrottle is engaged in a mode other than the CLMP Mode (CLAMP mode, which translates as a fixed position of the throttle levers in certain flight phases, the crew always being able to position them manually). For this reason, the SPD LOW indication was inhibited during the event until disengagement of the autothrottle (see 1.16.9).

1.6.5.4.3 Autothrottle

The autothrottle is engaged by setting the "*AUTO THROT*" switch on the FGCP to the AUTO THROT position. This control remains in the AUTO THROT position as long as the conditions for engaging the autothrottle are met.

[15]The Alpha speed is calculated by the DFGC to maintain a margin in relation to the stall speed of the aeroplane in the current configuration

The autothrottle can be disengaged manually or automatically in case of malfunction. To disengage the autothrottle manually, it is necessary to:

- Move the "*AUTO THROT*" switch from the AUTO THROT position, or
- Move the "*AP 1-2*" switch to the opposite position, or
- Press one of the autothrottle disconnect buttons on the throttle levers, or
- Engage the TURB (turbulence) mode by pressing the "*TURB*" button of the FGCP, or
- With the aeroplane on the ground, apply the thrust reversers.

The autothrottle can also be disengaged automatically in one of the following cases:

- Loss of power to the DFGC for more than 200 ms, or
- Fault detected by the DFGC, or
- Internal failure of the DFGC, or
- in EPR LIM mode, exceeding VMO/MMO or the speed limits the flaps and slats if these are extended.
-

In the case of manual or automatic disengagement, the AUTO THROT control automatically resumes the OFF position and the red "THROTTLE" indication lights up on the left and right FMAs. Pressing the autothrottle disconnect buttons located on the throttle levers, or re-engagement of the autothrottle position turns off the light.

Three main modes can be selected by the crew on the FGCP: SPD SEL, MACH SEL and EPR LIM. So-called "*secondary*" modes are activated automatically, including the MACH ATL mode. These modes are briefly described below.

SPD SEL and MACH SEL	The SPD SEL and MACH SEL modes can be engaged by pressing the SPD SEL button or the MACH SEL in every phase of flight except take-off. When the autothrottle is in one of these modes, it maintains the speed or Mach selected by the crew and is displayed in the SPD MACH window of the FGCP unless the selected value is less than the "*Alpha Speed*[16]". In this case, the autothrottle maintains this speed and the FMA indicates ALFA SPD. When the selected altitude is captured, the autothrottle automatically switches from EPR LIM captured, the autothrottle automatically switches from EPR LIM mode to SPD SEL mode or MACH SEL mode, unless the TO FLX or GA thrust has been selected on the TRP. When the autothrottle automatically switches to SPD SEL or SEL MACH mode, it maintains the target speed or Mach displayed in the SPD MACH window of the FGCP.
EPR LIM	This mode is engaged by pressing the EPR LIM button on the FGCP either during take-off or a go-around. In this case, the autothrottle maintains a thrust corresponding to the EPR limit value output by the EPR system, selected by the crew on the Thrust Rating Panel (TRP).
MACH ATL	This mode automatically engages when the autothrottle is engaged in MACH mode and the thrust needed to achieve the Mach target displayed on the FGCP is greater than the thrust corresponding to the EPR limit value displayed on the centre panel. In this case, the controlled thrust is that of the EPR limit value. As soon as this condition ceases to apply, the autothrottle reverts to the mode that preceded the activation of the MACH ATL mode.

[16]The Alpha speed is calculated by the DFGC to maintain a margin in relation to the stall speed of the aeroplane in the current configuration

1.6.5.4.4 Engine Thrust Rating System

The Engine Thrust Rating System enables the crew to select a maximum level of EPR corresponding to a given phase of flight. This selection is made by the crew via the Thrust Rating Panel (TRP). Possible modes are TO (Take Off), TO FLX (Take Off Flex), GA (Go Around), MCT (Maximum Continuous Thrust), CL (Climb) and CR (Cruise). The DFGC then calculates the EPR limit value based on the total temperature, altitude, and bleed air from the engines. This value is displayed on the centre panel and, where appropriate, used by the autothrottle based on the active mode.

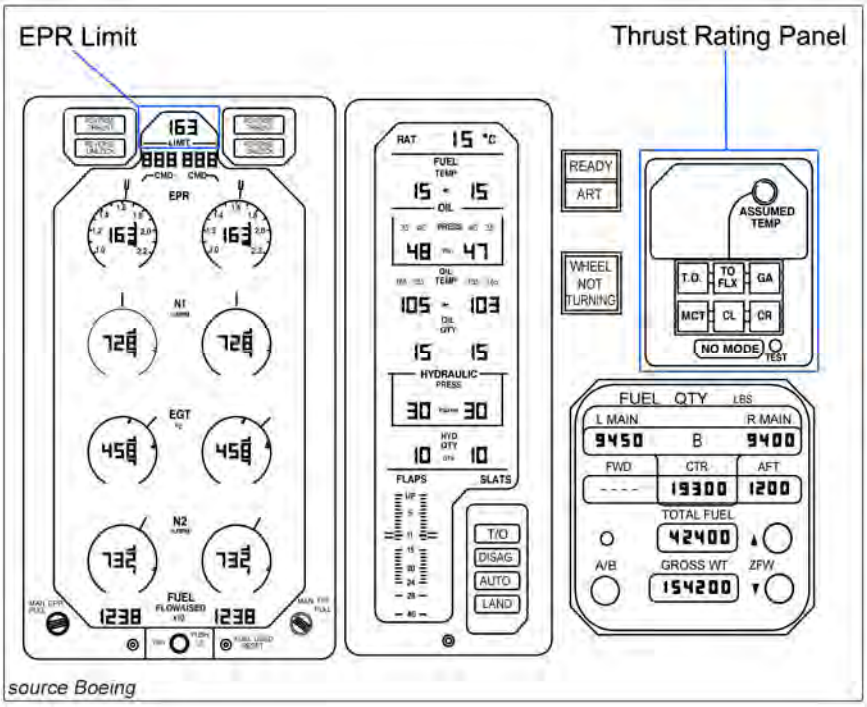


Figure 14 – Central Instrument Panel

1.6.5.5 Airspeed indicator

The MD83 cockpit is equipped with two Mach-airspeed indicators, one on the captain side, and the other on the co-pilot side. In addition to the needle indicating the current speed of the aircraft:

- a red striped needle indicates the maximum speed (VMO);
- three digits show the Mach of the aeroplane;
- A bright orange triangular index shows the speed selected by the crew on the FGCP (see 1.6.5.4.1). When the speed needle is aligned to the triangular index, the airplane’s current airspeed corresponds to the speed selected by the flight crew on the FGCP;
- other indexes can be positioned by the crew on the reference speed (250 kt, approach airspeed, for example);
- an "A/S" flag alerts the crew when the speed information is unusable.

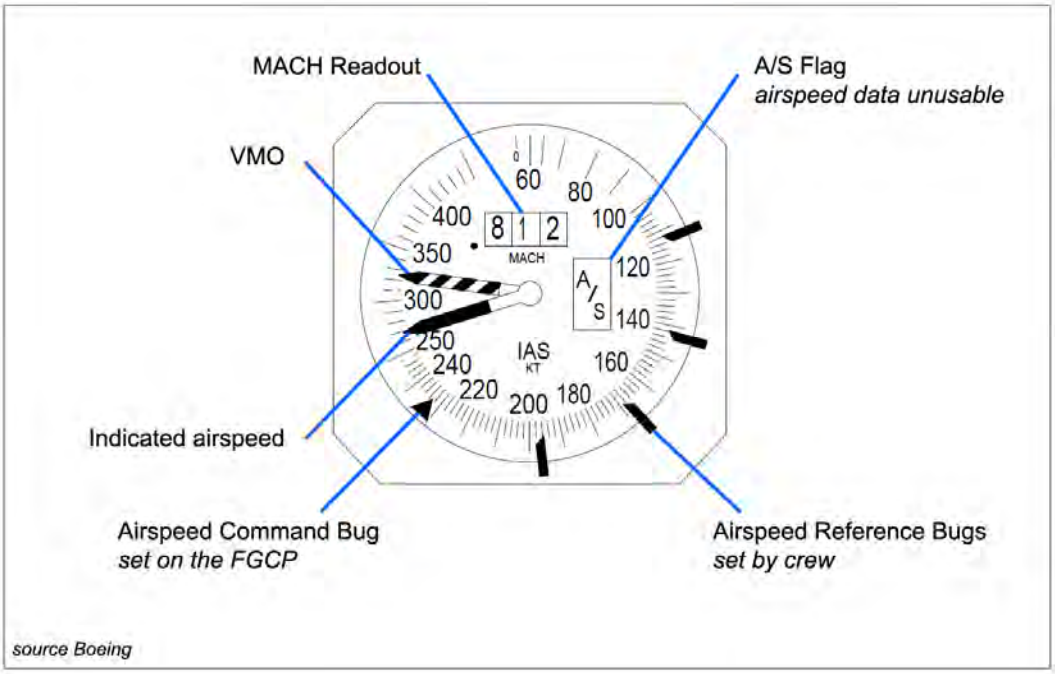


Figure 15 – **Mach-a*irspeed indicator***

The following illustration shows the location of the primary flight instruments.

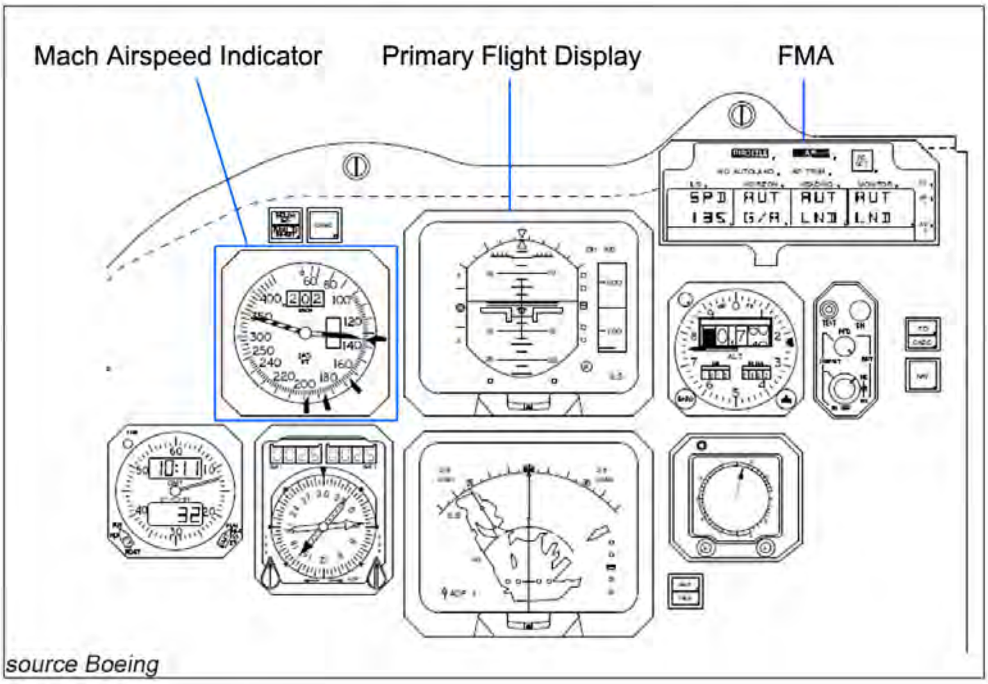


Figure 16 – Primary Flight Instrument Panel

Speed information is also supplied on the PFD by the "Fast/Slow" indicator. This indicator, commanded by the DFGC, is specifically centred when the Mach set point displayed on the FGCP is reached. The high and low stops correspond to a gap of about 10 kt in relation to the set point.

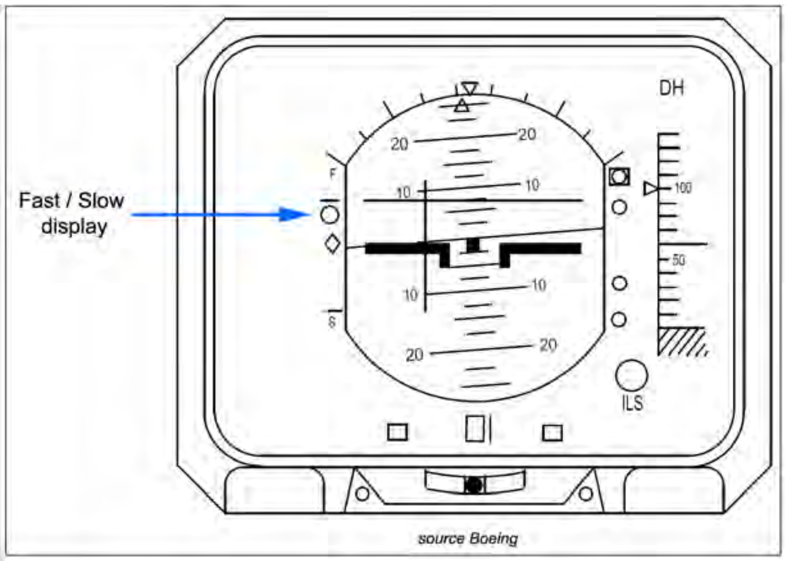


Figure 17 – PFD

The aeroplane’s speed is also indicated on a standby instrument, located on the instrument centre panel. This instrument also displays the aeroplane’s altitude.

1.6.5.6 Stall warning and stall recovery assistance systems

On the MD83, the system which activates the devices warning the crew of the approach to stall mainly consists of the following:

- two AOA sensors arranged on either side of the forward fuselage;
- two *Stall Warning Computers* (SWC);
- two stickshakers, located respectively on the captain’s control column and on the co-pilot's control column;
- An actuator ensuring the stick-pusher function, called the *stick-pusher*.

Each SWC receives:

- the value measured by the AOA sensor that is attached to it (left sensor for the SWC 1, right sensor for the SWC 2);
- the position of the left flap for the SWC 1, and that of the right flap for the SWC 2;
- the position of the left and right slats transmitted via the Proximity Electronic Switch Unit and the slats and flaps control in the cockpit;
- the position of the trimmable horizontal stabilizer.

It then produces a signal, which in clean configuration actuates the following two devices:

- the two stickshakers;
- a stall warning consisting of a flashing red "*STALL*" light, an aural warning consisting of a "horn" lasting one second and a synthesized voice calling out "*Stall*". The “*STALL”* lights are located on the upper instrument panel in front of each pilot.

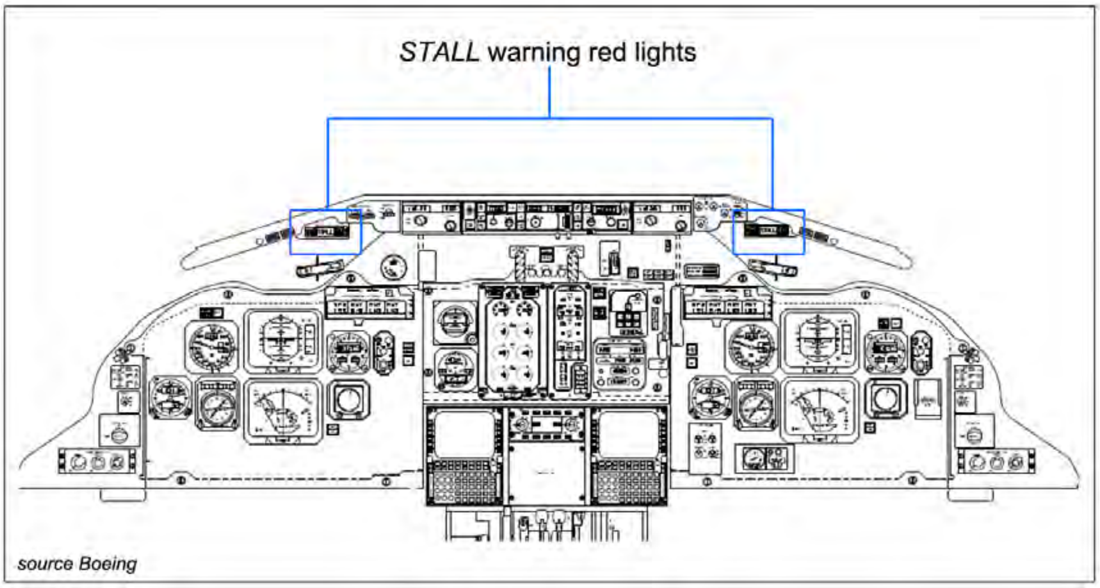


Figure 18 – Stall warning lights location

If either of the two SWCs detects the approach to stall, these devices are activated.

In clean configuration, their triggering threshold depends only on the value of the angle of attack and its rate of change. These thresholds are independent of the Mach number (see Section 1.16.6.2 for the associated consequences in cruise).

Once triggered, the stickshakers and the stall warning stay activated as long as the angle of attack stays above their respective threshold.

The stickshaker is designed to signal the approach to stall, while the stall warning is triggered when a stall situation is identified. In practice, this translates to a stickshaker triggering threshold lower than that of the stall warning.

Each SWC monitors the status of the system's component elements and the operation of the other SWC. If the angle of attack measured by the left sensor and that measured by the right sensor:

- differ by more than 3.3°, the Stall Indication Failure indicator lights up and the aural warning is inhibited;
- differ by more than 2.75° but less than 3.3°, the Stall Indication Failure indicator lights up but the aural warning is not inhibited.

The *"STALL"* lights are not inhibited.

When the slats are extended, there are two additional devices to assist with stall recovery:

- automatic deployment of the slats to their full extension;
- a stick-pusher, which generates a nose-down input on both control columns.

The aeroplane being in clean configuration at the time of the event, neither of these two devices was active.

EPAS – Elevator Power Augmentation System

On the MD83, each elevator is controlled by a tab, activated by the movement of the control columns. When the aeroplane is in a stall situation there may be a decrease in the effectiveness of tabs which can no longer sufficiently deflect the elevators to recover from the stall.

For this reason each elevator is equipped with a hydraulic actuator which, when activated, ensures full movement of the elevators.

This system is activated when the nose-down command to the stick is such that the tabs are turned 10° relative to the position of the elevator. In this case, all the hydraulic power contained in the actuator is applied so that the elevators are in the maximum nose-down position.

1.6.5.7 Other warnings

In addition to the stall warning and autopilot disconnect warning described in the preceding paragraphs, other audible warnings may have been triggered during the flight and are described below.

Movement of the trimmable horizontal stabilizer:

- when the movement of the trimmable horizontal stabilizer, controlled manually or by the autopilot, exceeds 0.5°, a buzzer sounds and repeats every 0.5° of additional movement;
- when the movement of the trimmable horizontal stabilizer, controlled by the autopilot, is more than 2° in less than 30 s, the synthesized voice "*Stabilizer Motion*" calls out and is repeated until the movement of the trimmable horizontal stabilizer stops.

Altitude warning:

When the altitude of the aeroplane deviates by more than 250 ft from the altitude selected after the latter has been captured, the altitude warning is triggered:

- the amber light on the altimeter flashes;
- the aural warning consisting of a "*C Chord*" sound signal lasting one second alternates with a synthesized voice calling out "Altitude".

This alarm is active as long as the selected altitude is not captured again and can be cancelled by pressing the altitude knob.

Overspeed warning:

When the indicated airspeed exceeds VMO (340kt up to 27,300 ft) or when the Mach exceeds MMO (0.84), the overspeed warning is triggered. It consists of an aural warning called a *clacker* lasting one second alternating with a synthesized voice calling out "*Overspeed*".

1.6.5.8 Management of priorities for aural warnings

On the MD83, when several aural warnings are active at the same time, they are transmitted one after the other in the same manner on the loudspeakers on the captain's and copilot's sides. When a new aural warning is triggered it is transmitted immediately and interrupts the previous sequence. The aural warnings then start again with a new sequence including a new warning.

In the case of the stall warning, operation is different. The captain's and copilot's sides are then dissociated:

- when the SWC1 detects the approach to stall and triggers the "stall" warning , the loudspeaker on the captain's side only transmits this warning and no other possible warnings;
- when the SWC2 detects the approach to stall and triggers the "stall" warning, the loudspeaker on the copilot's side includes this warning in the sequence, as described at the start of the paragraph above.

When the two SWCs detect the approach to stall, each loudspeaker broadcasts its own warning sequence. The crew then hear both types of aural sequences at the same time.

1.6.6 Airborne Weather Radar

The aircraft was equipped with a Collins airborne weather radar, model 622-5135-001. The information output by this radar is displayed on the ND (Navigation Displays) when in ARC mode (this display mode gives an indication of the distances and headings) or MAP mode (this mode displays the aeroplane on its environment and the route followed).

The display scale of the radar information ranges from 10 to 320 NM depending on the scale of the ND. The weather radar is designed to detect water in liquid form (rain or wet hail) by measuring the rate of precipitation. Depending on the detected rate of precipitation and the selected gain, echoes with different colours are displayed on the ND. Areas with a higher density of precipitation are shown in red, areas with an average density of precipitation in yellow and areas with a lower density of precipitation are shown in green. When "WX - T" mode is selected on the radar control box, areas of turbulence are shown in magenta within a maximum radius of 50 NM.

It has difficulty detecting water in solid form, such as ice crystals or dry snow.

The tilt setting (tilting the radar beam up and down) determines the area crossed by the radar beam and therefore the echoes that are detected and displayed on the ND. By adjusting the gain, the radar can adapt to the reflectivity of the precipitation encountered. Depending on the tilt setting, clouds situated in front of the aeroplane but not crossed by the beam are not visible on the radar.

These settings are not recorded in the FDR; it is therefore not possible to determine the image seen by the crew on the weather radar.

Below, as an example, is a photo of EC-LTV's ND taken a few days before the accident. On it can be seen the returns of the colours from the weather radar as well as some navigation information.

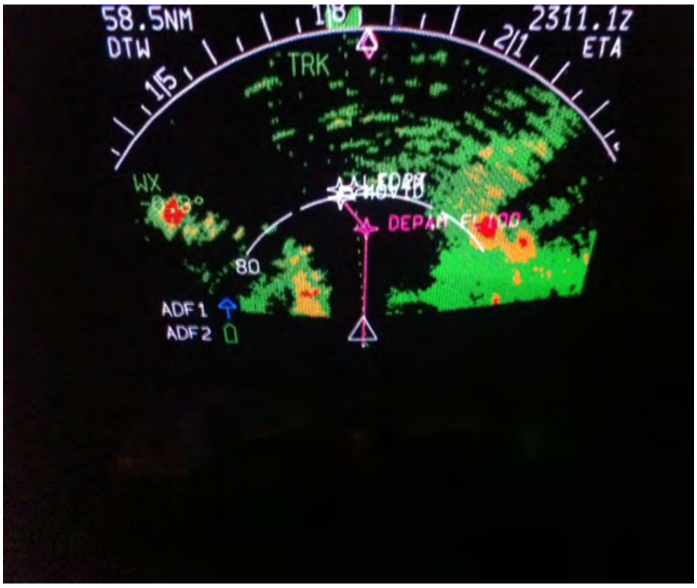


Figure 19 – EC-LTV's ND during a previous flight

1.7 Meteorological Information

1.7.1 General Situation

Between May and October, latitude navigation over Africa generally implies crossing the intertropical front. This front is an area of conflict between the masses of dry air over the Sahara and the masses of moist air from the Atlantic. The contrast causes development of thick convective clouds of the cumulonimbus type and heavy rainfall (monsoon rains).

Over West Africa, the monsoon is often associated with violent squall lines as well as vast cloud formations that extend over several degrees of latitude and longitude. These disturbances cross the continent from east to west at intervals of three to five days. This phenomenon is called the easterly wave. The activity of these waves is subject to diurnal variations. They develop between 12h00 and 18h00, and are at a maximum at the start of the night, weakening between 3h00 and 9h00.

The size of the thermal contrasts and the quantity of moisture generate storm cells whose horizontal dimension can be hundreds of kilometres and whose vertical development extends throughout the atmosphere, often exceeding 15,000 metres.

1.7.2 Situation on the Day of the Accident

In the evening and night of 23 July 2014, the intertropical front was positioned north of Mali. A talweg, T1 (area of low pressure), combined with an easterly wave reached the west coast. It was followed by a second talweg, T2, located north of the intertropical front. The presence of these waves explains the wet front over Burkina Faso towards the north of Mali.

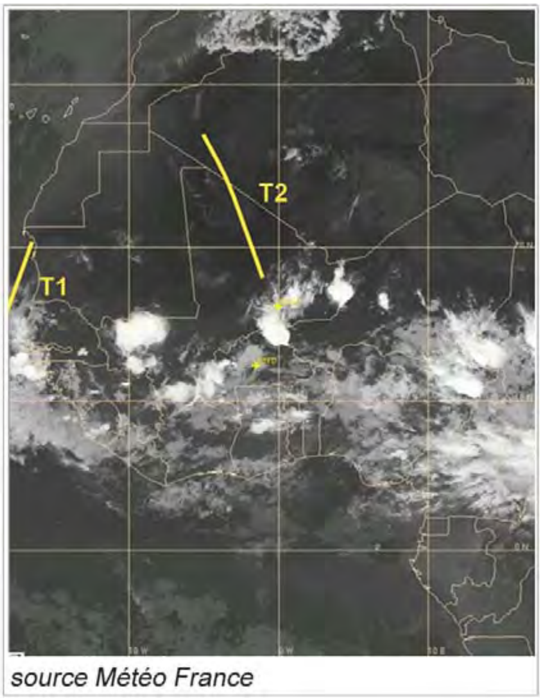


Figure 20 - INFRA RED channel image dated 24/07 at 0 h 00 UTC with the positioning of the two talwegs (T1 and T2) corresponding to the average atmosphere dynamics (FL140) Wet front along from 0°W and 10°W indicated by cloud clusters

Instability, heavy moisture in low layers, dry air between 500 and 600 hPa, raised cloud base and significant instability are favourable conditions for generalised convection in a line over Burkina Faso and Mali.

It should be noted that in this sector there was a considerable shortage of water in 2014, causing great aridity on the ground and a drying of the lower layers of the atmosphere. This situation would not be exceptional were it not for the high dust content combined with convection over the northern area of the Sahel. This concentration of dust may affect the quantity and concentration of condensation nuclei in cumulonimbus.

1.7.3 Items Brought to the Crew's Attention

A file including the meteorological data in force at 22h30 was handed to the crew on their arrival.

It included, among other items:

- the meteorological conditions on the ground in Ouagadougou;
- wind charts at various altitudes up to FL340, indicating a north-north-east sector wind with an average of 10 kt;
- the TAF and METAR of the aerodromes en-route;
- a satellite IR chart of the meteorological situation (see Appendix 4);
- a SIGMET message valid from 23 July 20h30 to 24 July at 1h30, issued by Niamey FIR indicating embedded cumulonimbus moving west south-west, in an area ranging from Niger to Senegal and encompassing the Gossi region, en route to its destination.

1.7.4 Meteorological Conditions in the Aeroplane's Flight Sector

Satellite observations on the night of 23-24 July showed an area of convection which was developing from 20h00 over the north of Burkina Faso moving towards the south-west. In the image below, the two black areas represent the coldest areas, therefore the highest and most dynamic. In these two areas the cloud peaks reached altitudes of between 46,000 ft and 59,000 ft (14 to 18 km). Temperatures there were -43°C to -73°C. These two areas correspond to the location of the most numerous lightning strikes.
At the time of the accident, there was no moon.

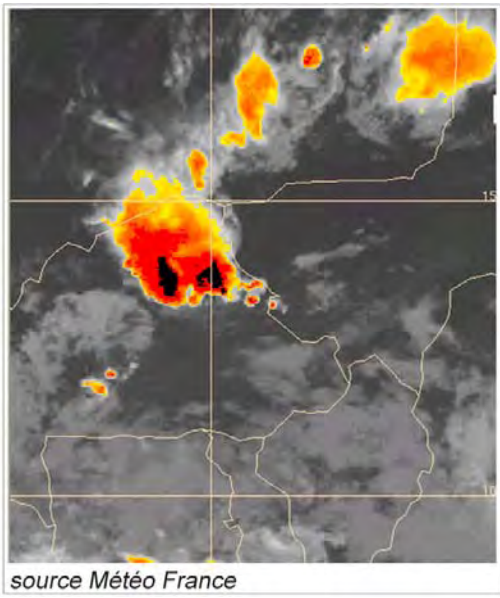
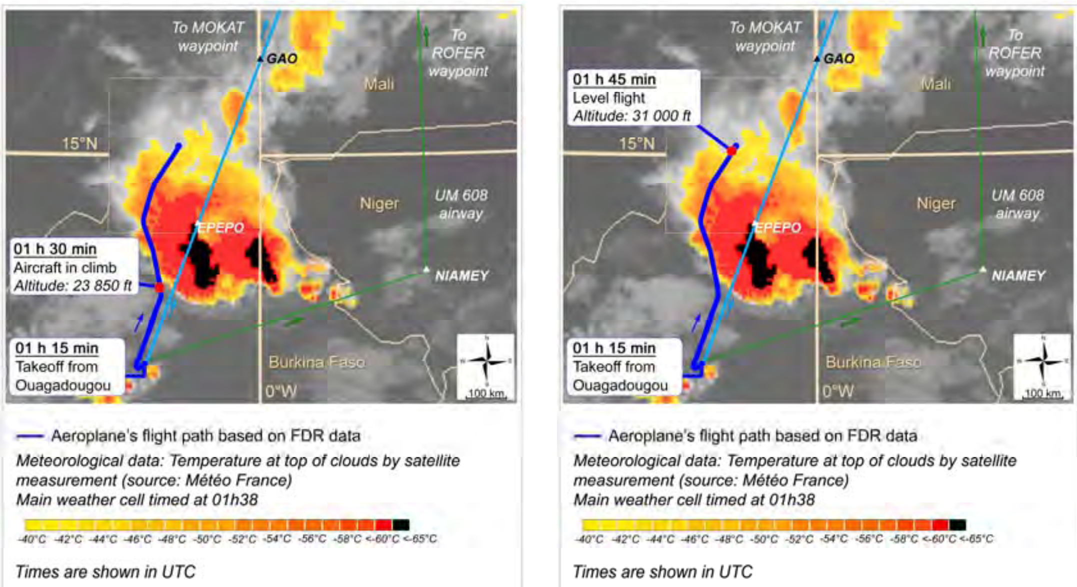


Figure 21 - MSG channel infra-red satellite image, 24 July at 1h30 UTC (threshold at -66°C)

To the east, three storm cells grew quickly from 00h00 onwards.
The images below represent infra-red images with the aeroplane flight path superimposed at 01h30 and 01h45. The aeroplane’s position at these two moments is shown by a red dot.



1h30, aeroplane altitude: 23,850 ft **1h45, aeroplane altitude: 31,028 ft**

Figure 22 - Infra-red images and superimposed flight path

These satellite observations show that the meteorological situation encountered was in accordance with the information supplied to the crew before departure.

1.7.5 Different Types of Icing

In a convective cell environment, an aeroplane may encounter two types of icing:

- icing caused by supercooled water;
- icing caused by ice crystals.

1.7.5.1 Icing caused by supercooled water

In this type of icing, the supercooled water surrounding the aeroplane freezes on contact with the airframe. This phenomenon is mainly encountered at the centre of the cell when the air temperature is between -7°C and -20°C, but may be present at lower temperatures, as low as -30°C. In the latter case, icing is often accompanied by strong turbulence.

1.7.5.2 Icing caused by ice crystals

In an article published at the beginning of 2014, relating to a study on the presence of ice crystals at high altitude, the CNRS (the French National Centre for Scientific Research) indicated that, among others:

- Since the 1990s incidents on aeroplane jet engines and anomalies in measuring aerodynamic speed and temperature have occurred at high altitude and low temperature. Detailed analysis by aircraft manufacturers of parameters recorded during these events showed that the temperatures recorded were mainly lower than -40°C and that no ice deposit had been detected on the structure. Studies have led researchers to believe that this was not standard icing by ice formation from the impact of supercooled water droplets, which is taken into account in the context of aircraft certification rules, but a different phenomenon[17].

This phenomenon occurs most frequently in a mass of tropical air, hotter than the standard atmosphere. However, the meteorological scientific community has yet to determine the nature of the development of the high ice water content regions of clouds that results in ice crystals. One theory is that in the presence of high cloud, water vapour contained in the air condenses directly into ice crystals on the particles in the air. An ice crystal results from the gradual crystallisation of water vapour in the air without going through a liquid phase. Areas of ice crystals are mainly found around storm systems or in its stratiform sections (anvils). They are not visible or barely visible on the weather radar equipping current aircraft.

A High Altitude Ice Crystal and High Ice Water Crystal (HAIC-HIWC) International Field Campaign was conducted from Darwin (Australia) from January to March 2014. The primary objective was to acquire atmospheric in-situ data in deep convective cloud systems to better characterize the ice crystal phenomenon. It also aimed at developing flight deck recognition of HIWC cues.

17http://www.insu.cnrs.fr/node/4731

However, information gathered from participants in this campaign led the investigation team to conclude that the presence and the density of ice crystals in the vicinity of convective areas and their level of detection, are still insufficiently known today.

The ice crystal icing events reported to Boeing have only occurred in areas of high concentrations of ice crystals that are found in mesoscale convective systems, in close proximity to or within the coldest cloud tops, as detected by IR satellite imagery.

It should be noted all the aeroplane anomalies mentioned in the CNRS report (jet engine, equipment measuring aerodynamic speed and temperature) are associated with heated airplane components. The PT2 probes are only heated when engine anti-ice is activated by the flight crew. Due to their geometry, PT2 probes, when unheated, may be obstructed by ice crystals, even if the crystal concentration is not exceptionally high.

A US NCAR study[18] indicated that in the last 20 years about 150 cases of icing caused by ice crystals were recorded around the world. They were characterised by:

- crews' not detecting ice on the airframe;
- reported light to moderate turbulence;
- no hail;
- no lightning;
- no or little echo on the onboard radar with the tilt set to horizontal.

1.7.6 Situation Likely Encountered by the Aeroplane

As the available observed data only consists of satellite images, it is impossible to determine precisely the amount or forms of water contained in the air mass in which the aeroplane was flying.

After takeoff from Ouagadougou the aeroplane's change of heading would cause it to fly on the west edge of the convection area, without it being possible to determine whether or not the aeroplane was flying in a cloud layer. The temperatures encountered during the climb (from -16°C to -32°C) could be conducive to icing by supercooled water. However, analysis of the satellite imagery evolution did not indicate supercooled water was present. Additionally, the absence of significant turbulence on FDR data suggests that no updraughts that might have carried supercooled water were present on the aircraft flight path. The cell was in the "mature stage" when the aeroplane passed. The anvil cloud was then well developed and the updraughts in the cell core fed this anvil with ice crystals. Thus, the presence of ice crystals within the anvil cloud was very likely. These crystals could have spread under the anvil or be transported downwind from the cell, to the area that the aeroplane was flying in.
These elements led the investigation to consider icing caused by ice crystals more likely than icing caused by supercooled water. The concentration of ice crystals encountered is unknown.

[18] US National Center for Atmospheric Research

Figure 22 - **Photo of a cumulonimbus and its anvil**

1.8 Aids to Navigation

No malfunctions in the ground radio-navigation equipment involved in the departure procedures described in paragraph 1.10 were reported on the day of the event.

1.9 Telecommunications

Flight AH 5017 was successively in radio contact with Ouagadougou tower and approach, grouped together on the 118.1 Mhz frequency, then the Ouagadougou CCR on the 120.3 Mhz frequency, and the Niamey ACC on the 131.3 Mhz frequency.

The VHF 126.1 MHz frequency allocated to the flight control sector that was undertaking control of flight AH5017 between GAO and MOKAT was out of service following the destruction of the relay station in Mali. The HF 8894 frequency, one of the two frequencies dedicated to this sector, used to attempt to contact flight AH5017 after it disappeared was, in addition, subject to jamming.
This situation linked to the geopolitical context had existed for some time.

The transcript of the radio-telephone exchanges is in appendices 2 and 3.

1.10 Aerodrome Information

1.10.1 Characteristics of Ouagadougou Aerodrome

Ouagadougou aerodrome has two parallel runways:

- A main runway 04L/22R made of tarmac, 3,000 m long and 45 m wide;
- A secondary runway 04R/22L, made of laterite, 1,900 m and 30 m wide.

The aerodrome's reference altitude is 316 m, that's to say 1,038 ft.
On the day of the accident, runway 22R was active.

1.10.2 Ouagadougou Aerodrome Departure Procedures

IFR departures are omnidirectional. For IFR departures towards the north, two routes are possible:

- Route G 854 towards DEKAS then NIAMEY (NY)
- Route G 859 towards EPEPO then GAO.

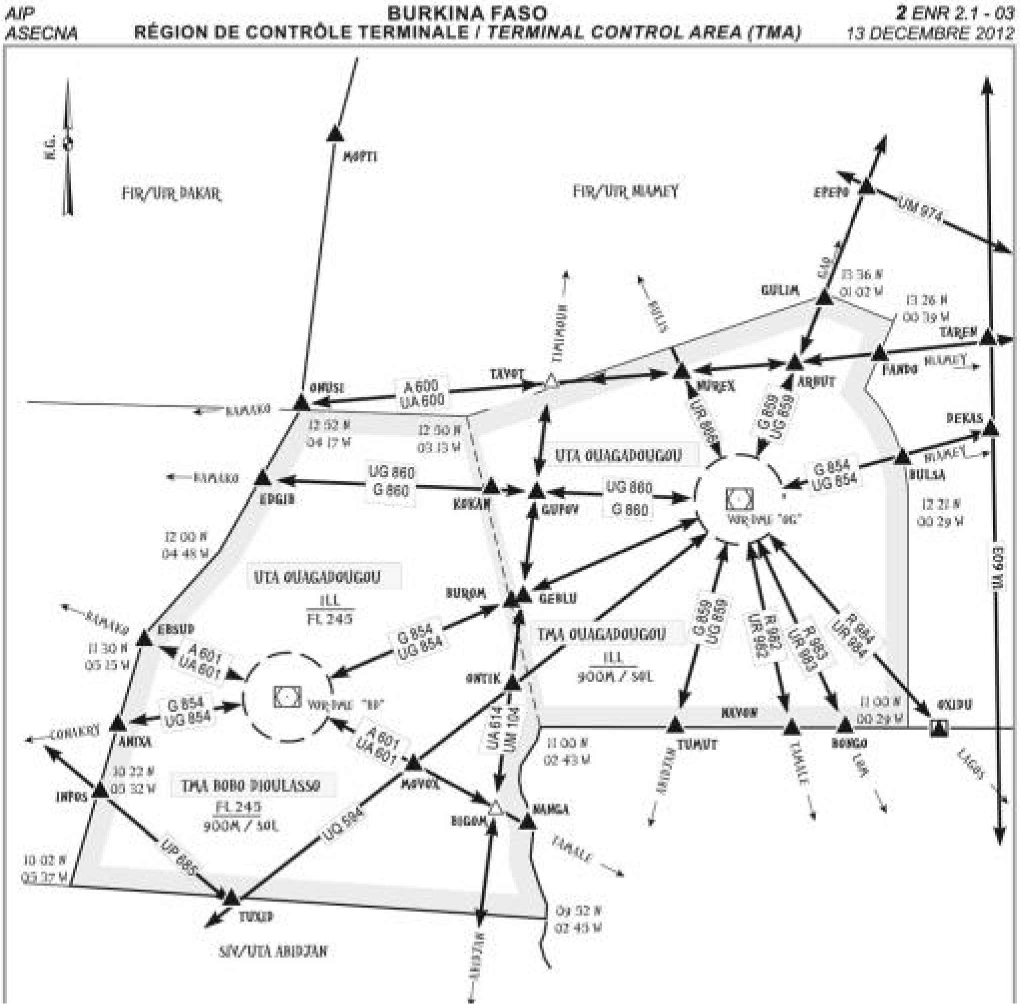


Figure 23 - Aerial routes on departure and arrival at Ouagadougou

1.11 Flight Recorders

1.11.1 Flight Recorder Opening and Readout Operations

The two regulatory recorders were sent to the BEA by the judicial authorities of Mali and France on 28 July 2014.

Figure 24 **- FDR protected module (on the left) and CVR (on the right)**

Flight Data Recorder (FDR)

- Make: Honeywell
- Model: 4700
- Type number (P/N): 980-4700-001[19]
- Serial number (S/N): 5139[20]

Only the protected module (CSMU) was sent to the BEA. This module contains the electronic card that records the flight data. The protected casing was separated from its frame and the underwater locator beacon (ULB) was not present. It was slightly damaged and showed some signs of impacts.

The protected module was opened and the various internal protection layers were removed. The memory card was extracted, and its protective layer was removed.

[19] Information uncheckable on the equipment
[20] Information uncheckable on the equipment

Figure 25 - **Electronic card in the CSMU**

Figure 26 - Electronic card with the protective layer

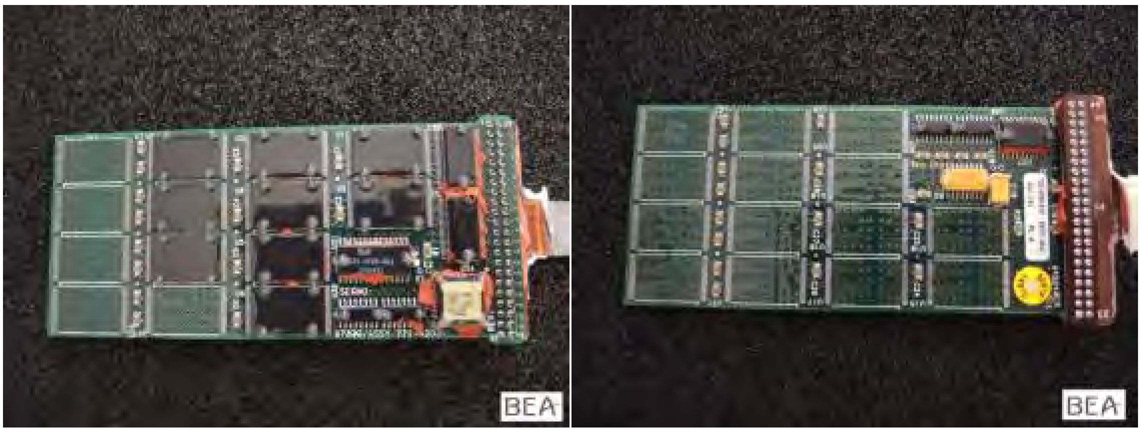


Figure 27 **- Electronic card without the protective layer**

The electronic card was checked and then connected to the BEA read-out chassis. Data readout was carried out with the official equipment provided by the manufacturer, Honeywell (RPGSE). The raw file downloaded contained about 52 hours of flight data, including those relating to the event flight.

Cockpit Voice Recorder– CVR

- Make: Fairchild
- Model: A100
- Type number (P/N): 93-A100-80
- Serial number (S/N): 54154

The CVR was seriously damaged. The recorder had been compressed and deformed during the accident. However it had not been exposed to fire.

Figure 28 - Initial condition of the CVR

Given the condition of the recorder, access to the protected memory module via a standard opening operation was not possible. The chassis had to be cut open.

Figure 29 - Opening the chassis

Visual examination of the protected module showed that it had been damaged during the accident.

Figure 30 - Protected module after extraction

Figure 31 - Data carrier heat protection

After opening the protected module and taking out the heat protection, visual inspection showed that the tape mechanism was destroyed and that the magnetic tape was damaged. The tape was broken in several places.

Figure 32 - Magnetic tape mechanism after

Figure 33 - Close-up - magnetic tape mechanism extraction

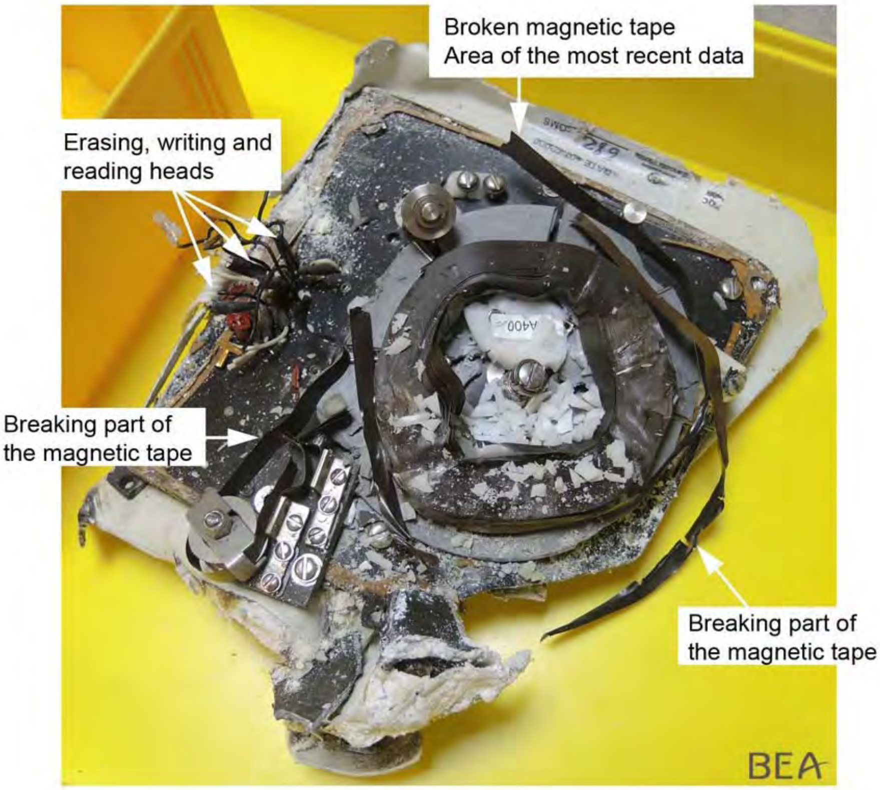


Figure 34 - Magnetic data carrier

The various sections of magnetic tape were identified and numbered. In order to read out the magnetic tape in its entirety, repair operations were required. These operations consisted of reinforcing the magnetic tape in the places where there was the most severe damage.

Figure 35 - Sections of magnetic tape recovered during the opening operations

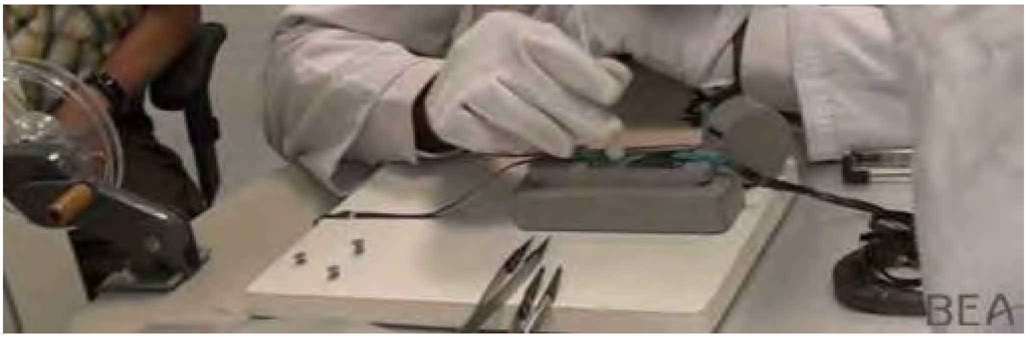


Figure 36 - Magnetic tape reconstruction operations

Once the tape had been reconstructed, readout was performed on a dedicated system. Analogue data on the magnetic support was scanned. Readout of the tape made it possible to recover the data contained on the four tracks of the tape. Four audio files of 31 minutes and 54 seconds were generated.

1.11.2 FDR data readout

The data contained in the FDR raw file were decoded using documents provided by the operator and aeroplane manufacturer. The FDR data were synchronised with the radio communications between the flight crew and the Ouagadougou and Niamey control centres, using the VHF keying recorded on the FDR.

1.11.2.1 Decoding the angle of attack

As the decoding functions in the documents supplied by the manufacturer and the operator did not provide valid results for this event, additional research was carried out by the manufacturer to obtain applicable decoding functions for this aeroplane.

From the same raw recorded value the first function provides the local angle of attack as measured by the sensor. This angle of attack is generally different to the aeroplane angle of attack because of local disturbance of the airflow around the sensor and its alignment in relation to the aeroplane axis. That is why the recorded local angle of attack in cruise is negative. However, it is this angle of attack that should be compared to the activation thresholds for the stick shaker and the stall warning to estimate the time they were triggered.

The second function makes it possible to obtain, from the same raw data, the aeroplane angle of attack which was used to estimate the situation of the aeroplane in relation to the aerodynamic stall.

1.11.2.2 Decoding the positions of the control columns

The positions of the control columns and rudder pedals are additional parameters added via the STC (Supplemental Type Certificate) ST09949SC issued in 2002 by the FAA to SIP Technical Services. According to information available to the investigation team, this company is no longer in business. In addition, the operator was not able to provide any documents to decode these parameters.

Consequently, for every parameter, an approximate function was developed from the value recorded when the controls were neutral as well as minimum and maximum values recorded during flight control tests carried out on the ground by the crew before each flight. By default, a linear function was chosen but it is possible that the conversion determined by the STC was different. The value of these parameters is therefore indicative but as they are consistent throughout the flight with the corresponding flight control position, it is possible to find out the direction of the crew input and to have an idea of its amplitude.

The graphs of these parameters are in Appendix 1.

1.11.2.3 Recorded engine parameters

The following engine parameters were recorded on the FDR:

- EPR (Engine Pressure Ratio): ratio between pressure at the engine outlet and pressure at the inlet, a unitless quantity;
- N1: rotational speed of the low pressure engine rotor, expressed as percentage of a reference speed;
- N2: rotational speed of the high pressure engine rotor, expressed as percentage of a reference speed;
- Fuel flow, expressed in kg/h;
- EGT (Exhaust Gas Temperature): gas temperature at the engine outlet, in degrees Celsius.

The position of the throttle levers was not recorded.

1.11.2.4 Recorded Vertical Modes

From 1 h 45 min 04 until the end of the flight, the recorded autopilot's longitudinal mode was "VNAV CAPTURE «when a longitudinal mode was active. This mode is a vertical flight path track mode for which the aircraft was not equipped. The investigation was unable to determine why the VNAV CAPTURE mode was recorded. It can be noted that when this mode was recorded on the FDR, the conditions for the SPD LOW activation were met.

1.11.2.5 VHF Keying Activation

Activations of the VHF keying were recorded on the FDR (see the VHF keying parameters on the parameter graphs in Appendix 1). This key is located on each crew member's control column and allows, when activated, for radio communication on the selected frequency.

After the aeroplane's transfer to Niamey, there were 7 VHF keying activations of durations between 2 and 7 seconds between 01 h 37 min 38 and 01 h 41 min 30. They did not correspond to any messages received by Niamey and were most likely calls from the crew trying to establish contact with the controller.

After the call from Niamey ACC at 01 h 41 min 38, eight further keying activations were recorded, of which the last was at 01 h 45 min 05. They likely correspond to answers or attempts by the crew to make contact with the Niamey ACC (see table below).

All of these exchanges occurred during the aeroplane's deceleration phase and the disengagement of the auto-throttle occurred during the last VHF keying activation.

Times	Activation of VHF keying by crew	Message from Niamey ACC	Message from RAM
01 h 41 min 38		Algérie five zero one seven Niamey?	
01 h 41 min 41	Message transmitted but not recorded by ATC (6 seconds duration)		
01 h 41 min 49		Algérie five zero one seven Niamey?	
01 h 41 min 54	Message transmitted but not recorded by ATC (2 seconds duration)		
01 h 42 min 03	Message transmitted but not recorded by ATC (2 seconds duration)		
01 h 43 min 13	(*) Algérie five zero one		
01 h 43 min 22			Err Niamey err for information Air Algérie is calling you
01 h 43 min 53		Algérie five zero one seven Niamey?	
01 h 43 min 57	Message transmitted but not recorded by ATC (1 second duration)		
01 h 44 min 02		Algérie five zero one seven Niamey?	
01 h 44 min 06	Message transmitted but not recorded by ATC (2 seconds duration)		
01 h 44 min 09		Maroc five four three kilo I read I need a relay	
01 h 44 min 13			Go ahead with the relay for Air Algérie
01 h 44 min 18		Yes so he is to call me back on one thirty one point three	

01 h 44 min 21			he is to call you back on one thirty one point three Alger... Air Algérie go ahead for your message
01 h 44 min 29	Yes Algérie five zero one seven we are maintaining flight level three one zero we are (*) (interruption) (*) to avoid		
01 h 44 min 39			Err Niamey, Air Maroc five four three Kilo?
01 h 44 min 42		Yes thank you very much, Algérie five zero one seven squawk three two three five three two three five report passing GAO, report passing GAO and say estimate MOKAT	
01 h 44 min 56			(Did you) receive Air Algérie?
01 h 45 min 04	Message transmitted but not recorded by ATC (4 seconds duration)		
01 h 45 min 12			Air Algérie from Air Maroc five forty three did you receive the message from Niamey?

1.11.3 CVR data readout

An A100 type CVR records on 4 audio tracks:

- a track including radio communications and the pilot on the left's microphone signal;
- a track including radio communications and the pilot on the right's microphone signal;
- a track including radio communications, the third man (rear seat)'s microphone signal and the flight crew messages to the cabin (*public address*);
- a CAM track including the cockpit area microphone signal.

Listening to the four CVR tracks showed that the contents of most of the first three tracks was difficult to understand or unintelligible and that the CAM track contained a priori no useful signal.

The first process of listening, however, enabled some messages between the crew and the control centres to be transcribed, without being able to confirm initially if these concerned the accident flight or not. Comparing these messages later with the recordings and the transcripts of the ATC communications provided by the Ouagadougou and Niamey control centres, it appeared that several of them did in fact belong to the event flight; this element made it possible to determine that the CVR was operating and that it was recording data during the event flight.

Analysis of the process of this recorder's operation, combined with the various tests to reproduce the observed recording anomaly, made it possible to identify a failure of the erasing mechanism, causing the overlaying of data relating to a large number of flights.

Note: recording data on a magnetic tape is done in two stages:

- *erasing the oldest data by running the tape through the erase head;*
- *then recording new data to replace the erased data by running the tape through the record head.*

Further, in order to identify the warnings which may have been broadcast during the flight, the CVR CAM track was analysed. Listening to this track did not reveal any useful data, only sounds related to electricity generation on board. Work to improve the quality of the signal was undertaken to check the recorded audio content of this track and to try and find some useful data.

No useful signal for the investigation could be extracted from this track. The investigation was not able to determine the origin of this failure.

1.11.3.1 Description of an A100-type CVR operation

The signals from the four audio tracks received at the CVR input are each sent to a recording card which manages the pre-amplification of the signals before recording.

A single card generates a common polarisation signal which is issued to each of the amplification cards. This signal mixed with the audio contents acts as a carrier (modulation process) for the useful signal to be recorded. This technique is intended to improve the efficiency of recording data on magnetic tape by ensuring proper dynamics in the recorded audio content.

For each of the channels the mix of the polarisation signal and the useful signal is recorded using the record head on the magnetic tape to make a track. The four tracks are recorded at the same time.

The polarisation signal also supplies the erase head which, by magnetisation of the tape upstream of the record head removes the old data before recording the new.

1.11.3.2 Determining failure modes

In order to determine the CVR failure mode that led to the malfunction of the erase function, various overlay tests were conducted on equipment identical to that of the event. Audio recordings from the same type of CVR were used as a recording source to ensure that the signals recorded had similar characteristics to that of the event CVR.

The tests conducted in a situation with the absence of any polarisation signal made it possible to reproduce identically the audio anomalies observed on the accident flight recording.

The absence of any polarisation signal was the only failure mode tested that made it possible to reproduce exactly the anomalies noted.

1.11.3.3 Estimation of CVR erase function failure occurrence date

As the third track of the CVR (the third crew member's microphone and *Public Address*) were less saturated in signals than the others, it was possible to count roughly the number of welcome messages traditionally performed by the flight crew before each flight. Fourteen messages of this type were counted. The CVR malfunction had been present for at least 13 flights before the accident flight.

1.11.3.4 Consequences on the pre-flight test

The operator's procedures ensure that the crew conduct a CVR test before each flight during cockpit preparation. The test, conducted on duty, consists of keeping the control panel TEST button pressed down and checking that the indicator needle, called galvanometer, reaches and remains within the green arc, with the exception of short interruptions caused by transitions from one track to another.

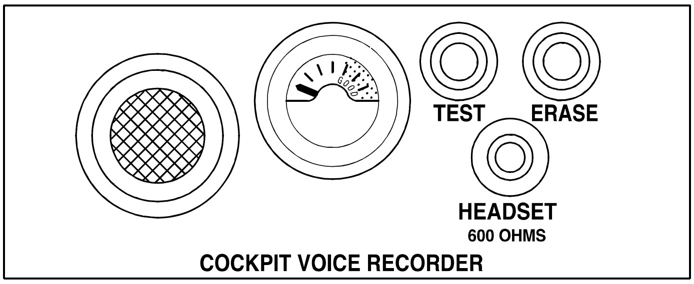


Figure 37 - CVR control panel

In the CVR itself, pressing the *TEST* button triggers generation of a test signal of a frequency of about 600 Hz which is sent successively to each of the 4 tracks of the writing head.

The play head (physically located after the erase and write heads) then reads the contents of the 4 tracks simultaneously. This audio mix is send to an amplification and filter card which enables the test signal to be detected. If the frequency corresponding to the test signal is detected, it makes the needle move within the green section.

Laboratory tests have shown that the audio content recorded on the magnetic tape of the event, sent to the amplification and filter card of the A100 CVR, systematically causes the incorrect movement of the galvanometer needle in the green section. Consequently, it was not possible for the crew to identify the erase function failure of this CVR with the aid of the pre-flight test.

It was also not possible for the crew to identify the absence of signals on the CAM track if this resulted from the failure of a component of the CAM line upstream of the CVR (microphone, electrical connections, control panel, etc.).

1.11.3.5 Maintenance procedures

A CVR check is performed during every type C maintenance check. According to the manufacturer's documentation, this type of check is scheduled every 3,600 flying hours or every 15 months at the latest. This procedure makes it possible to check to correct operation of the whole sound recording system and takes 5 minutes.

The maintenance engineer:

- connects his headset to the CVR control panel and conducts the pre-flight test; he must hear the test signal at 600 Hz and monitor the movement of the galvanometer needle;
- then, he covers the CAM with his hand and speaks into the captain's microphone; he must then listen to himself in the headset; he then repeats the previous check with the copilot's microphone.

Listening to the pre-flight test with the headset makes it possible to detect the presence of over-recording (vocal hubbub) resulting from the erase function failure. However, the correct functioning of the CAM line from the microphone to the record head on the magnetic tape is not tested, unlike the captain and copilot's microphones.

This maintenance operation was also unable to detect a failure of the CAM line if this was located upstream of the CVR.

The last time this periodic check was carried out on EC-LTV was on 26 November 2013, thought at that time the aircraft was fitted with a different CVR. The CVR on the accident flight was installed on the aircraft and tested on 16 January 2014. The test performed contained only the first of the two steps described above. This operation could have detected the erase function failure. No failure was reported on the maintenance documents.

1.11.3.6 Signal quality improvement tests by external centres

With the agreement of the Commission of Inquiry, the BEA contacted several organisations with expertise in analysing sound signal, specifically the INA (Institut National de l’Audiovisuel) and the ENST (Ecole Nationale Supérieure des Télécommunications), both French organisations, in order to try to improve the quality of the CVR recordings. The objective was to highlight the aural warnings and to separate the various voices recorded on the CVR.

The last 2 min 45 of the copilot's CVR track, the most intelligible track, were given to both institutes. The ATC recording of the same period as the CVR was given to the ENST.

The INA has specific expertise in restoring tape recordings. Noise reduction and filtering tools used for this type of work were used on the CVR recordings. The intelligibility of some of the ATC communications was improved, but no warning or other communication was brought to light.

The audio, acoustics and wave group of the ENST department for signal and image processing is a benchmark organisation for voice separation using computer algorithms. Various methods were used to extract the ATC communications and to separate the speakers' voices. No information other than the ATC conversations could be detected. There are two reasons for this:

- the high number of voices present on the CVR;
- the non-linear overlay of signals during successive recordings.

The state of the art tools and methods available did not bring to light any warnings or communications other than those the ATC ones already identified.

Consequently, no useful signal for the investigation could be recovered from the CVR recordings.

1.11.4 Regulations Relating to Magnetic Tape CVRs

Annex 6 to the ICAO convention on international civil aviation, relating to the technical operation of aircraft, provides that the use of magnetic tape CVR shall be discontinued as of 1 January 2016 for international commercial air transport. However, this text has no direct legal force on Member States. Thus, until they amend their own regulations it does not have the force of law for operators.

Operators are required to comply with the regulation defined by the civil aviation authorities on whom they depend. In Europe, a draft regulation is now being adopted to specifically prohibit the carriage of magnetic tape CVRs from 1 January 2019.

1.12 Wreckage and Impact Information

1.12.1 Description of Crash Site

The accident occurrence site is located in Mali, in the Gourma-Rharous Circle and the region of Timbuktu. The impact area is about 80 km southeast of the town of Gossi, which is 160 km southwest of the town of Gao. The geographic coordinates[21] of the wreckage are: 15°08’ N – 1°04 W.

Given local security constraints, examination of the wreckage could only take place in the area secured by French armed forces, and lasted three days.

[21] In the WSGS84 referential

Figure 38 - Location of crash site

The area is flat, located at an average altitude of 270 m and the only visible obstacle consists of sparse vegetation of a height not exceeding 5 m. The natural terrain consists of bedrock covered by a 50 cm layer consisting of a mixture of sand and clay, in varying proportions.

1.12.2 Distribution of Wreckage

On aeroplane impact with the ground, a crater approximately 35 m wide, 11 m long and 1 m deep was formed[22].

[22] The wingspan of the aircraft is 32.8 m.

Figure 39 - Top view of the crater

The wreckage was spread over a triangular area with a length of 420 m, the summit[23] of which was the point of impact, which spread out to a width of 340 m. The general distribution of the debris was along a mean axis oriented at 090°.

Trees, about 5 m high and located about ten metres before the impact point, were not cut off. A few elements of the tail section, as well as the rear door and the tail skid, were discovered near these trees.

[23] The centre of the crater is the reference point for the distances given in this paragraph

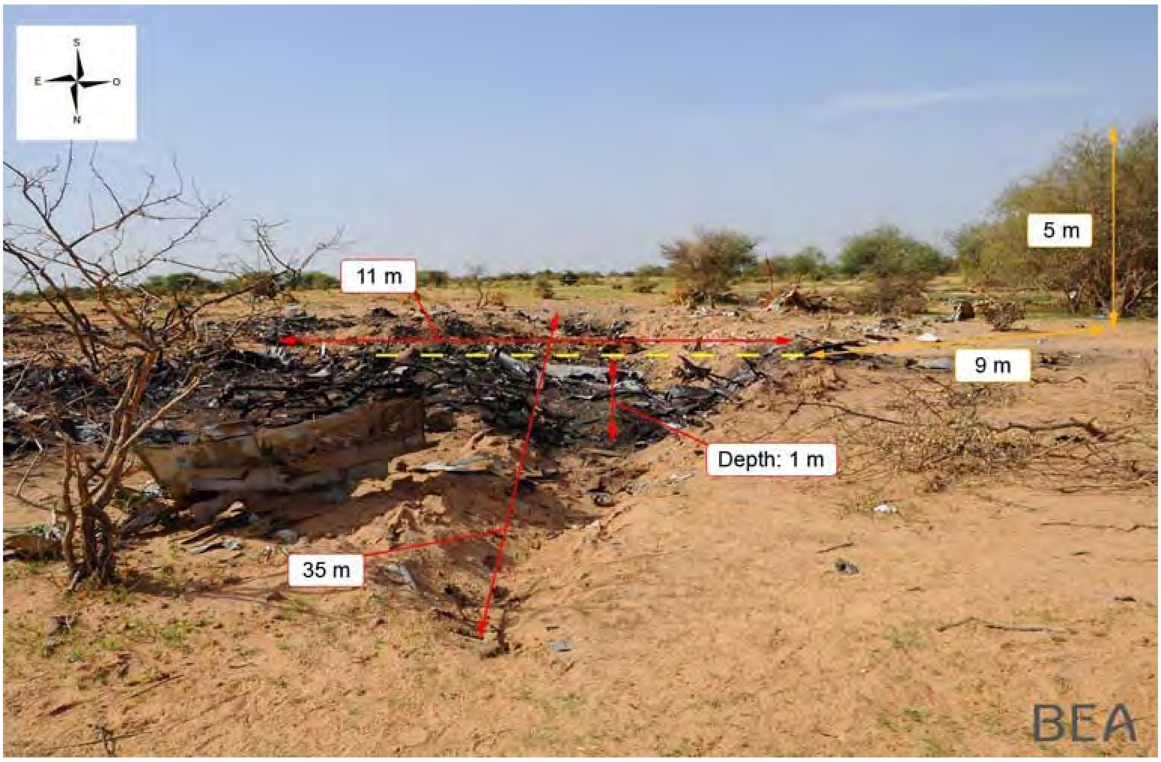


Figure 40 - Side view of the crater

From the impact zone and moving eastward, three debris distribution areas were defined:

- The first area mainly had a concentration of large pieces of wreckage (around one metre or more) and of average density. The debris was mainly parts from the engines, the wings, the fin, the nose gear and the upper parts (shafts) from the main landing gear;
- In the second area, the size (of a few dozen cm) and density of debris were lower than previously observed, most of the elements from the instrument panel and the windshield being found in this area;
- Finally, in the third area, the debris was medium volume (decametric to metric) and high density. It consisted of engine pieces and lower parts (axles) of the main landing gear.

Figure 41 - Aerial view of the debris field

Area1:

The debris found in the impact crater was mainly pieces from the wings, from the auxiliary power unit, as well as from the nacelles and engine accessories.
These engines pieces were spread over approximately 50 m.
The upper parts of the nose gear were found 50 m away and its lower part, 125 m from the impact crater.
The fin was about 50 m away and the trimmable horizontal stabilizer (THS) jackscrew was about 65 m away.

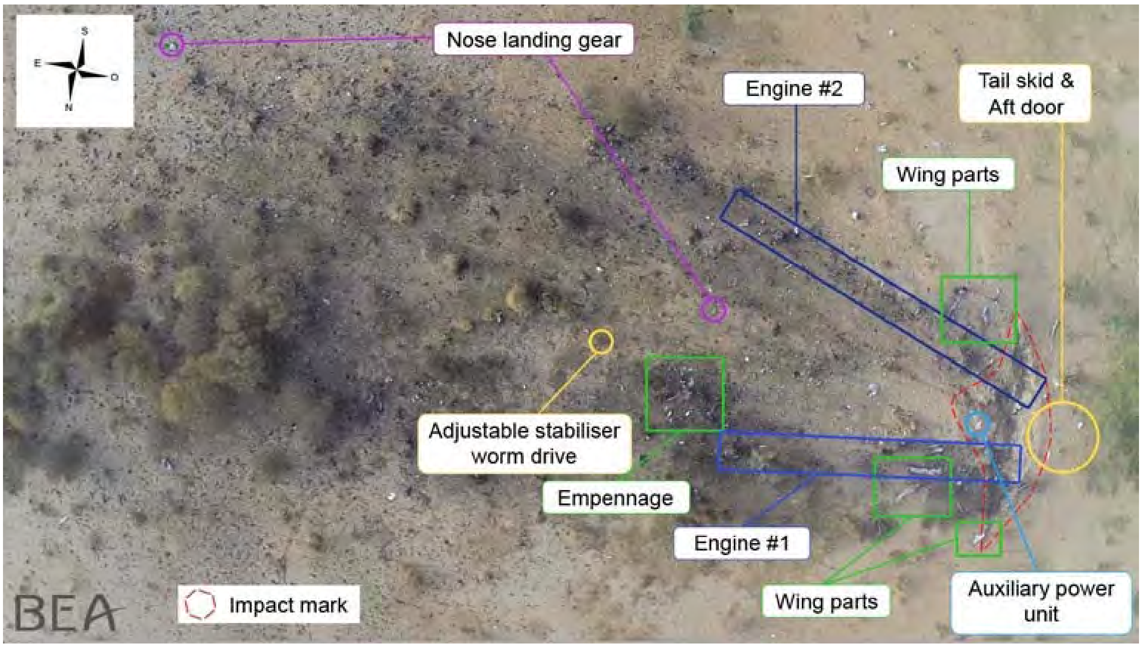


Figure 42 - Distribution of debris in the first area

Areas 2 and 3:

The upper parts of the main landing gear were found 120 m from the impact crater for the left gear and 205 m away for the right gear.

From 130 m away, the smallest debris was found.

This area, between 170 m and 190 m from the impact crater contained parts of the instrument panel (altimeter, speed indicators, circuit breaker panel) and a piece of windshield.

Parts from engine n°1 were found 160 m and 230 m away. Parts from engine n°2 were found 185 m, 260 and 300 m away.

Two pieces of the wing were found 140 m and 240 m away. The final parts belonged to the lower parts of the main landing gear; the left main landing gear was 295 m and the right 375 m away.

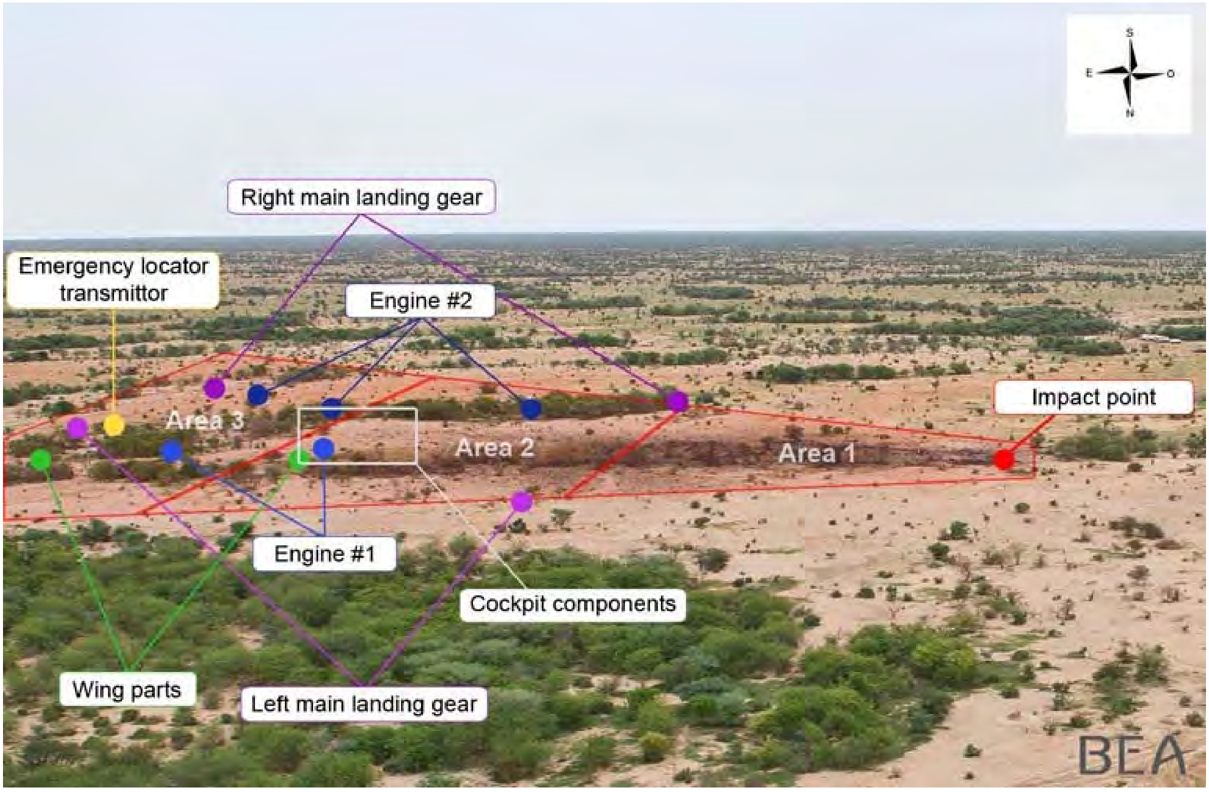


Figure 43 - Distribution of wreckage in areas 2 and 3

The French armed forces preserved the flight recorders as soon as they arrived on site.

1.12.3 Controls and Control Surfaces

The aeroplane has two trailing edge flaps on each wing. Each of the flaps is actuated by two hydraulic actuators. Two of these eight actuators were found.

Figure 44 - Right inner flap

Figure 45 - Right outer flap

Their examination showed that they were in the retracted position. This information was consistent with the data read out from the FDR.

Figure 46 - THS control mechanism

The jackscrew, which enables the THS to be moved, was found. The position of the nut on the jackscrew that enables the THS to move corresponded to a pitch-up deflection angle of 6°, which coincided with the last recorded values on the FDR.

1.12.4 Engines

Both engines were destroyed. All of the equipment attached to the periphery of the fan housing was torn out and scattered over the site.

All of the fan blades were broken. The rotating components of the engines were badly damaged.

The identified engine elements presented no visible traces of fire.

1.12.5 Landing Gear

The aeroplane is equipped with retractable tricycle landing gear made up of a nose gear and two main landing gears. Once extended, the landing gear is held in position by a strut. When it is retracted, the landing gear is held in place by a hydraulic actuator.

The right landing gear actuator was found.

Figure 47 - Right main landing gear

Examination showed that it was likely in the retracted position.

1.12.6 Emergency Locator Beacon

The aeroplane was equipped with an emergency locator beacon that is designed to be triggered automatically. This emergency locator beacon was found destroyed at the accident site. No signal from it was detected.

1.12.7 Summary

The shape of the impact crater and its position in relation to the preceding trees showed that the aeroplane collided with the ground at high speed, with a low bank angle and a steep nose-down pitch attitude. The aeroplane disintegrated upon impact. The debris was spread over a distance of about 420 m with a mean magnetic direction of 90°.

The damage to the engines showed that both engines delivering power. This is consistent with the last recorded data on the FDR.

Examination of the wreckage showed that the aeroplane was in clean configuration and pitched nose-up, with the landing gear retracted.

This information was consistent with the phase of flight that the aeroplane was in at the time of the event, as well as with the data from the FDR.

No additional examinations were undertaken.

1.13 Medical and Pathological Information

Taking into account the violence of the impact, it was not possible to undertake toxicological analysis on the crew members.

1.14 Fire

Examination of the site showed burned groups of trees and bushes, from the impact crater on, between headings 065 and 120, over a distance of about 140 metres. Observation of the damage to the vegetation made it possible to conclude that the fire was subsequent to the aeroplane's collision with the ground and did not spread after the impact.

1.15 Survival Aspects

The violence of the impact led to the immediate decease of all the occupants of the aircraft.

1.16 Tests and Research

1.16.1 Questions Relating to Flight Crew Flight Time Limitations

1.16.1.1 Applicable regulations

For the needs of this investigation, checks were carried out on duty period, flight duty time and rest time.
The regulation in force at the time of the accident was European Regulation (EC) n° 859/2008 (sub-part Q of EU-OPS Annex III), that is to say articles OPS 1.1090 to OPS 1.1135.
Provisions for this regulation are reproduced in part A of the airline's operations manual, to which are added national circulars, provisions planned by the European regulation.

The ministerial circular issued on 17 December 2010 by the Spanish civil aviation authority provides additional requirements in terms of minimum rest time and the minimum number of monthly rest days at the home base.

1.16.1.2 Definitions:

- Duty period

Duty period is the time that passes between the time a crew member must begin a service at the request of an operator until the time he is free of all service.
The regulation determines limits over periods of 28 consecutive days in one case and 7 consecutive days in the other case.

- Flight duty period

Any period during which a person is working on board an aeroplane as a crew member. This time is counted from the moment the crew member has to be present, at the request of an operator, for a flight or a series of flights, and stops at the end of the last flight during which the crew member is on duty.

- Rest time

Any uninterrupted and defined period during which a crew member is free from any service as well as from standby at the airport.

The regulatory limitations for each item are included in Appendix 6.

1.16.1.3 Application of these provisions to the crew of flight AH 5017

For the duration of the charter contract, Air Algérie airline was responsible for scheduling the flight programme. Swiftair S-A was in charge of the crews planning in relation to the programmed flights.

The contractually defined home base was Madrid.

In the context of the investigation all of the crew's aviation activity was examined in relation to these provisions.

This showed that the limitations on flight duty period and minimum rest time between flight duty periods were respected for both crew members for the duration of the contract.

It was noted that in the period from 10 to 16 July inclusive the maximum cumulative duty period over 7 calendar days was exceeded, which occurred on 15 July with a total of 66 h (authorised maximum of 60h) and reached 77h on 16 July.

This flight period was preceded and then followed by 5 rest days.

It may be considered that this rest period could neutralize the potential fatigue effect of this exceedance. However, the lack of detailed information on the flight crew members' activities and rest did not make it possible to determine if this exceedance had an impact on the physiological condition of the crew on 23 July during the Algiers – Ouagadougou round trip.

1.16.1.4. Minimum rest days at the home base:

There were no rest days at the home base (Madrid) between 23/06 and 24/07.
The Spanish ministerial circular requires 8 days a month of rest at the home base, which it is possible to carry over to the following month.

Furthermore the investigation was not able to establish with any certainty the activity of the flight crew members during their rest time in Algiers. Nevertheless, some crews present in Algiers in July 2014, interviewed in the context of the investigation, stated that the rest conditions in Algiers were satisfactory.

1.16.1.5 Fatigue

The early morning time period between 02 h 00 and 05 h 00 is commonly regarded as a period during which the physiological capabilities are at their lowest. The accident occurred at 02 h 47 Algiers time, to which the crew was acclimatized.

However, due to the absence of CVR data, the investigation could not to determine whether actual fatigue was present or not.

1.16.2 Erroneous EPR Measurement

1.16.2.1 EPR recalculation

Variations during the flight to the recorded engine parameters show inconsistency in the evolution in the EPR between the left and right engines and that of the other engine parameters from about 01 h 39 min 35. As a result, the EPRs were recalculated from other recorded engine parameters in order to estimate the EPR values corresponding to the engine rpm.

The following graph shows the result of these calculations.

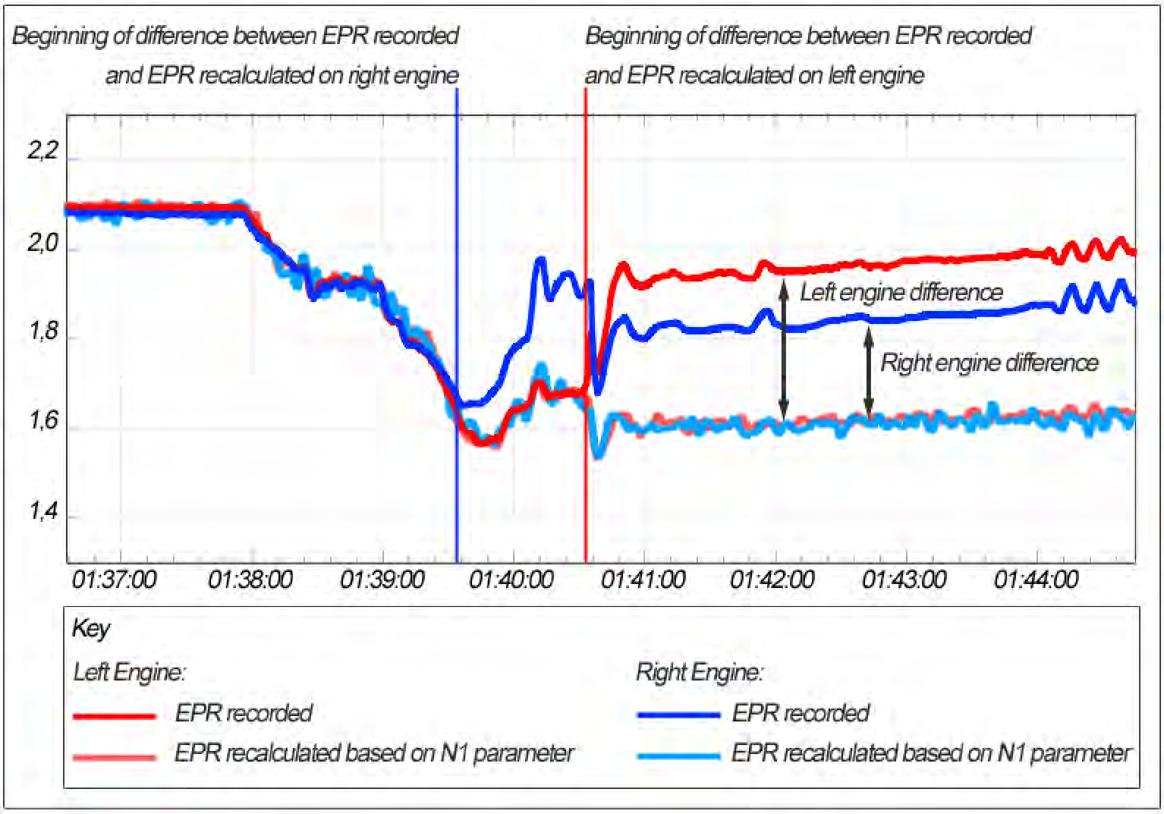


Figure 48 - Comparison between recorded EPR and recalculated EPR

These calculations show that the value of the recorded EPR became erroneous and overestimated on the right engine at about 01 h 39 min 35, then on the left engine at 01 h 40 min 30.

As a result of this overestimation the measured EPR values on each engine approached the EPR limit values, forcing the autothrottle to maintain true thrust lower than that planned during this phase of flight (see 1.6.5.1). The gap between recorded value and the real value was about 0.34 on the left engine and 0.20 on the right engine.

On the previous flights, the EPR values in cruise varied between 1.7 and about 2.0. For the event flight, the erroneous EPR was close to the typical values for cruise.

The recalculated EPR values for the left and right engines were very close. There was thus no difference between the thrust from each engine, contrary to what may be thought based on the gap between the EPR's recorded on the FDR.

This situation continued until at least the appearance of high amplitude oscillations in EPR 1 and 2 (See chapter 1.16.3.1). Beyond this period and until the increase in the engine rpm during the last twenty seconds of the flight, it was not possible to recalculate the EPR, the engine parameters being consistent with a surge on both engines (see 1.16.3.2).
In the last twenty seconds of the flight, the engine RPM increased and the recalculated EPR values were again consistent with the recorded values.

1.16.2.2 Possible causes of erroneous EPR measurement

The erroneous EPR values recorded for this event may have resulted from:

- an equipment failure in the measuring and transmission system for the EPR including possible failure of Pt7 sensors;
- an obstruction of the PT2 total pressure sensors.

The first case would have involved, during the same flight, a failure in the right engine EPR system, then about 55 seconds later, a similar failure on the left engine EPR system, then the disappearance of these two failures during the last twenty seconds of the flight when the engine rpm was increasing.

However the left and right systems have no components in common and do not receive the same electrical supply. This scenario is thus very unlikely.

The presence of a storm cell close to the aeroplane's flight path, as well as the absence of activation of the engine anti-ice systems (see 1.16.4) at the time the phenomenon occurred, makes more likely an obstruction of the P_{t2} pressure sensors on the right engine, then on the left engine, resulting from icing. The reappearance of EPR values consistent at the end of the flight indicates that the icing of the pressure sensors disappeared, probably under the effect of the increase in temperature during the drop.

1.16.2.3 Consequences on thrust

The manufacturer calculated, using the aerodynamic model of the aeroplane, the EPR required to maintain flight level 310 under the event conditions as well as the EPR that the engines were able to produce in relation to the anti-icing selections. The following graph shows the required EPR, the available EPR, and the EPR calculated from the corrected N1, which thus corresponds to the EPR actually produced.

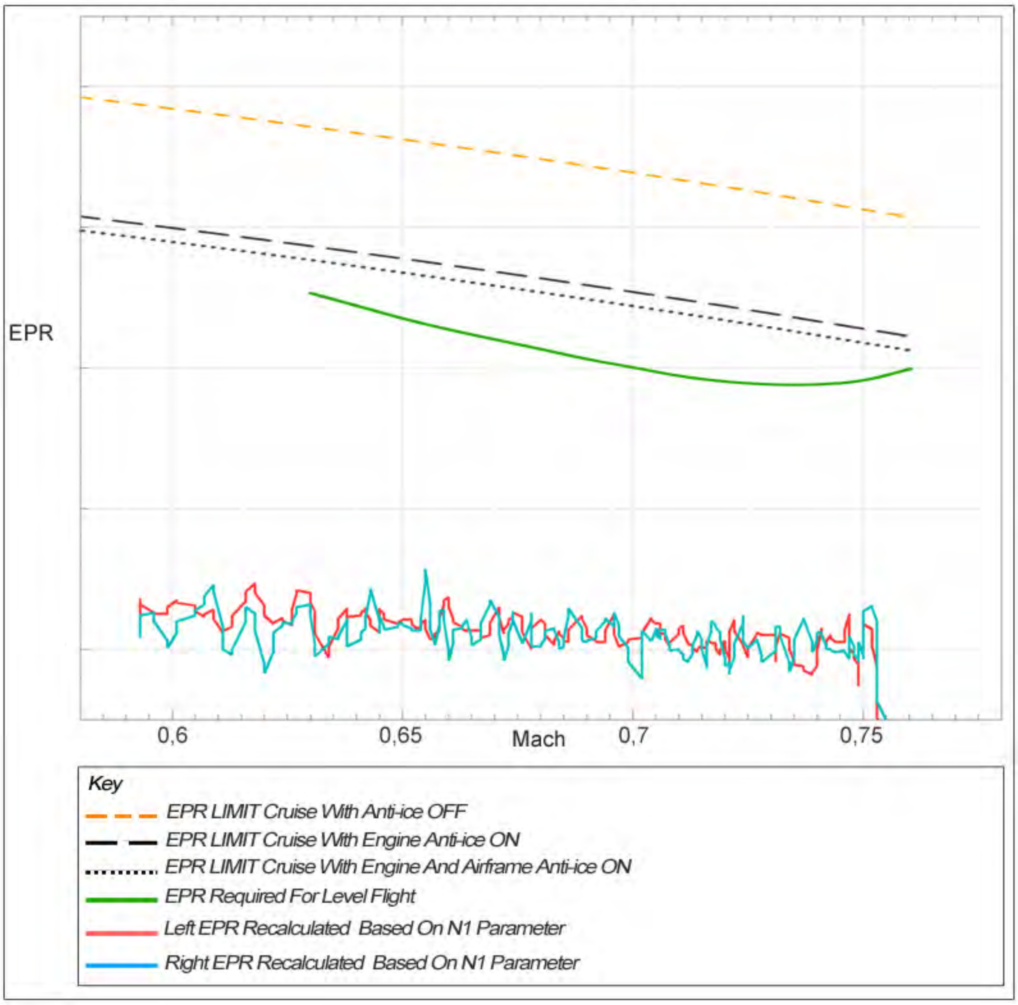


Figure 49 - Comparison of the EPR required, the EPR available and the EPR produced by the engines

When the recorded EPR values became erroneous, the EPR effectively produced by engines 1 and 2 remained around 1.6, whilst the EPR required to maintain flight level 310 under the event conditions was about 1.8. Under these conditions the aeroplane could not maintain stable, level flight at flight level 310 and the aircraft speed start to drop. However flight in cruise with autopilot engaged was possible at this flight level since the EPR LIMIT in CR (Cruise) setting was higher than the EPR required, including when the anti-icing systems were activated.

In this case, however, the EPR LIMIT approached the EPR required and the thrust margin was low.

1.16.3 Evolution in Engine Parameters during Event

1.16.3.1 Selection of CR setting

Between 01 h 38 min 26 and 01 h 38 min 58, evolution of the left and right EPR and the auto-throttle modes was consistent with selection of the CR thrust setting on the TRP. In fact, the EPR values remained close to the EPR limit value of the CR setting, and when they decreased at around 01 h 38 min 30, the auto-throttle changed to MACH mode.

The crew thus selected the CR setting at 01 h 38 min 26 at the latest.
Figure 50 provided in 1.16.3.4 illustrates this point.

1.16.3.2 Decrease in engine rpm/thrust

Between 01 h 40 min 35 and 01 h 40 min 39, all of the parameters on both engines decreased and then increased again until 01 h 40 min 49. The auto-throttle is then in MACH mode, and tries to maintain the Mach number selected by the crew. The values of this instruction is not recorded. As the aeroplane's Mach was dropping during this time, a decrease in the engine rpm could result from a decrease in the Mach instruction or from a manual input by the crew on the throttle levers, overriding the auto-throttle.

1.16.3.3 EPR oscillations

Between 01 h 44 min 52 and 01 h 45 min 17, two high amplitude EPR oscillations were recorded. The first oscillation occurred while the autothrottle was engaged, then the autothrottle disengaged and the second oscillation occurred.

During these two oscillations, all of the engine parameters varied in a consistent manner with the EPR. It was thus not a question of simple EPR parameter oscillations but in fact variations in engine EPR.

In relation to the first oscillation, the EPR values reached were 2.52 for the left engine and 2.54 for the right engine. These values were significantly higher than the EPR LIMIT that was then 1.98 and that correspond to the maximum EPR that the autothrottle could command in this phase of flight. Consequently, it is likely that the first EPR oscillation was also commanded by the crew by overriding the autothrottle action. In addition, the recorded EPR values exceeded those that the JT8D-219 engine is capable of producing, which is a further confirmation of the erroneous EPR measurement.

The second oscillation occurred while the autothrottle was disengaged, and thus resulted from crew action.

1.16.3.4 Engine surge

From about 01 h 45 min 17, the evolution of the recorded parameters for both engines was consistent with a surge[24]:

- sudden drop in the N1, N2, fuel flow and EPR down to values close to engine idle;
- increase in EGT up to values higher than those at takeoff.

When the phenomenon occurred, the recorded aeroplane angle of attack was 14°. Data from the flight tests undertaken by Boeing showed that the behaviour of MD83 engines can become unstable when the angle of attack exceeds a certain value between 7.5 and 11.5 degrees, according to the aeroplane's speed. This is due to air flow disturbance upstream of the wings, which then arrives at the engine inlets.
The excessive angle of attack was likely the cause of the surge on both engines.

[24] Disturbance of the airflow inside a jet engine, generally caused by a failure in its air supply, leading to a sudden loss of thrust.

1.16.3.5 End of surge and increase in engine rpm

During the last 20 seconds of the flight all of the recorded engine parameters showed an increase in the rpm in both engines up to values close to maximum rpm. The surge situation thus stopped.

The decrease in the angle of attack from 23° to 8°, as well as the aeroplane's altitude being below 10,000 ft, likely led to a natural end to the surge situation on both engines.

1.16.3.6 Summary of evolution in engine parameters

The following graph summarises the evolution in the engine parameters during the event.

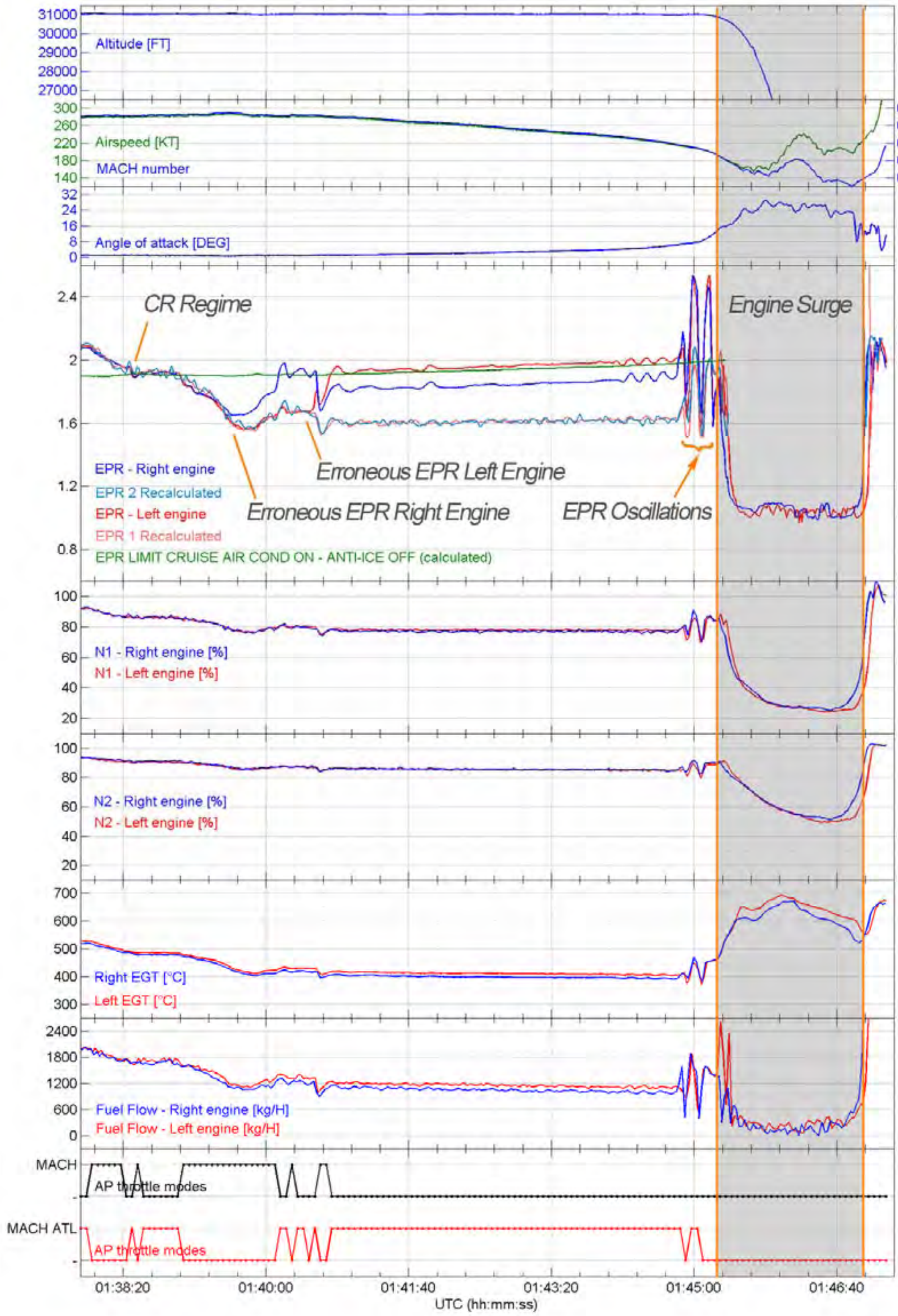


Figure 50 – Evolution of engine parameters during the event

1.16.4 Flying behind the power curve

Calculation of the thrust required made by the manufacturer also made it possible to determine the speed corresponding to flying behind the power curve. When the aircraft is flying behind the power curve its speed is unstable: starting with a situation where engine thrust equals the drag a reduction in the engine speed, under the influence of an external disturbance for example, results in an increase in the thrust required for stable level flight. Consequently if the thrust on both engines does not increase to reach the new thrust required the aeroplane continues to decelerate and the gap between the thrust applied and the thrust that would be required to return to the initial conditions increases.

The following graph shows that the flying behind the power curve occurs when Mach is about 0.72. The aeroplane reached this speed at 01 h 41 min 52, that is to say 2 min 17 after the appearance of the first engine EPR measurement error. Although the engines were capable of providing enough power to accelerate the aircraft, this was not actually commanded by the autothrottle due to erroneous EPR values.

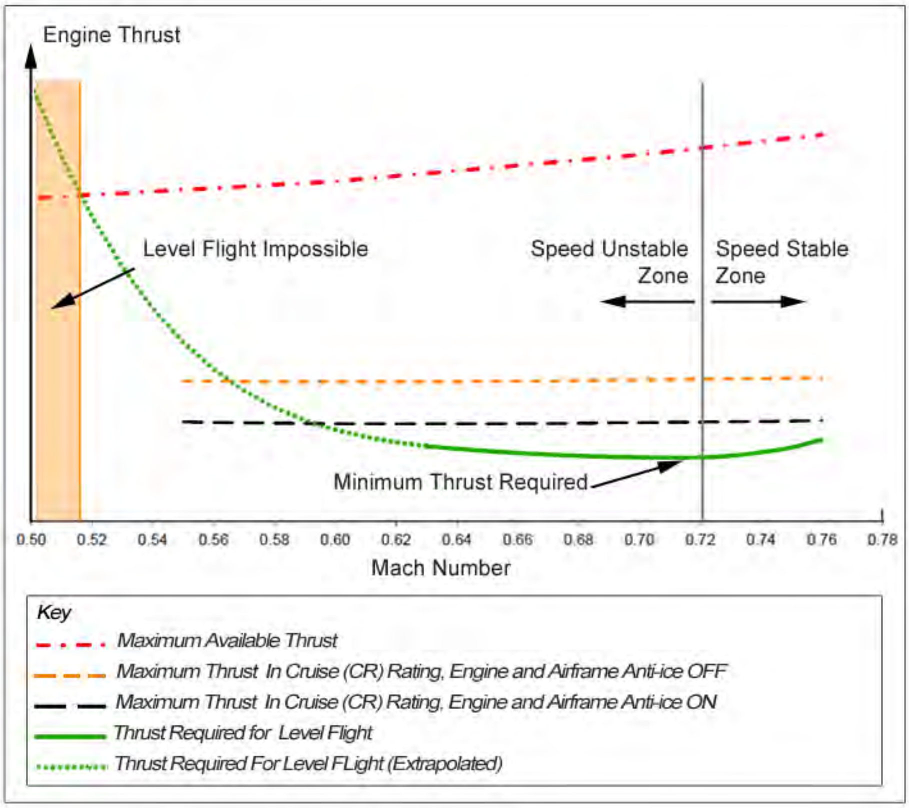


Figure 51 - Thrust required and thrust available

Below about Mach 0.52, the maximum thrust that the engines could deliver was lower than the thrust required to maintain level flight at flight level 310. The only possibility was to descend.

This speed was reached about 5 seconds after the triggering of the stall warning.

1.16.5 Determination of Activation of Anti-icing Devices

1.16.5.1 Method used

The engine and airframe anti-icing systems use hot air bled from the engine compressors. Consequently, activating them causes a reduction in the thrust available, which specifically leads to a drop in the EPR LIMIT values.

Activation of the anti-icing systems is not recorded on the FDR. To determine if these systems were activated by the crew during the flight, the recorded EPR values were compared to the limit values that the autothrottle can command, the latter being significantly different when one or more anti-icing systems is activated.

The correlation between the recorded engine parameters, such as the EGT in relation to N1, was also studied in order to detect any possible change during activation of the anti-icing systems. This method was not able to positively identify parameter shifts that would have been consistent with the crew turning on engine or airfoil anti-ice systems.

The estimation, described in the following paragraph, of the activation of these systems during the accident flight is thus based on the first method only.

1.16.5.2 EPR/EPR LIMIT comparison

When the autothrottle is in EPR LIM mode, during climb for example or in MACH ATL mode in cruise, the aim of the autothrottle is to maintain the EPR at the EPR limit value. It is then possible to compare the recorded EPR values to the recalculated EPR limit values based on the FCOM. The FCOM provides maximum EPR values for the climb and cruise phases in relation to the altitude, temperature and the various selections of the anti-icing systems. It is then possible by comparing the recorded EPR values to the EPR LIMIT supplied by the FCOM to obtain information on the activation of the anti-icing systems.

When the autothrottle is in MACH mode the target is the Mach selected by the crew and the EPR is lower than EPR LIMIT. The comparison between the EPR and the EPR LIMIT does not therefore make it possible to determine the activation of the anti-icing systems by the crew.

The following graphs represent the evolution in the EPR and EPR LIMIT values for the climb and cruise phases.

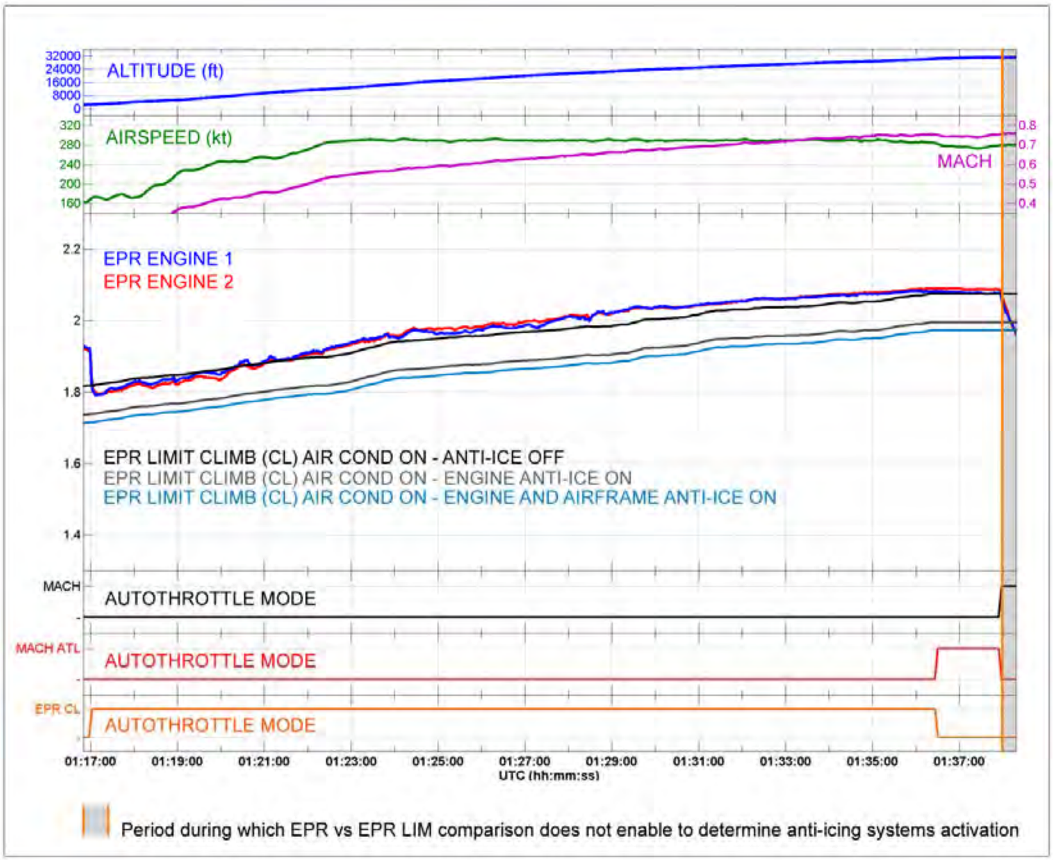


Figure 52 - EPR/EPR LIMIT comparison in climb

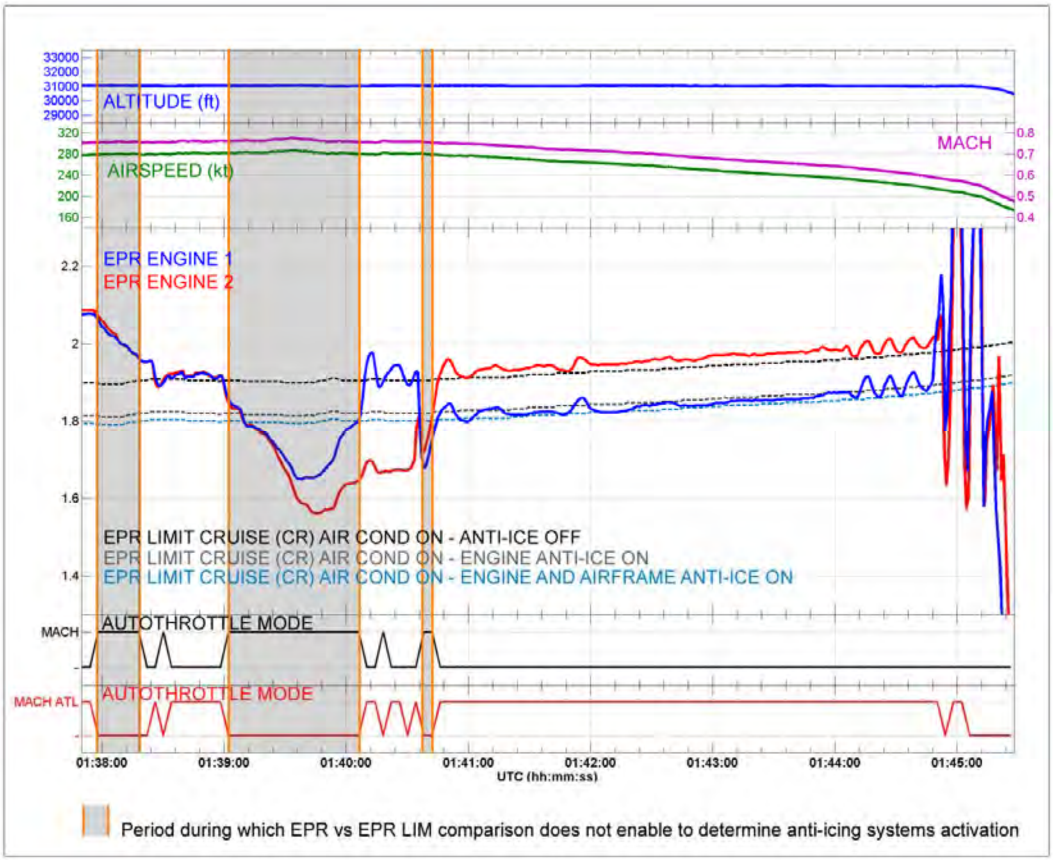


Figure 53 - EPR / EPR LIMIT comparison in cruise

During the climb the EPR values on both engines remained close to the EPR LIMIT values without anti-icing protection activated and significantly higher than the EPR LIMIT values with anti-icing. This indicates that the engine and airframe anti-icing systems were not activated during the climb.

During cruise the error in the EPR measurement caused differences between the left engine's EPR and the right engine's EPR (see paragraph 1.16.2.1). By design, the EPR LIMIT is necessarily the same for both engines. In addition, the autothrottle having only one servo control, it regulates the two engines in an identical manner. Consequently, in case of a gap between the EPR values of the left and right engines, the autothrottle adjusts the thrust on both engines to prevent the higher EPR from exceeding EPR LIMIT. In the case in point, the EPR value of the other engine is subject to regulation by the autothrottle. The previous graph shows that when the autothrottle is in MACH ATL mode there is always at least one engine whose EPR is consistent with EPR LIMIT without anti-icing system activated.

These results indicate that the anti-icing systems were not activated during the climb or during the phases in the cruise when the autothrottle was in Mach ATL mode.

1.16.6 Stall

1.16.6.1 General points on stall

The lift of a wing depends on its lift coefficient (Cz) and on the square of the air flow speed. The lift coefficient increases with the angle of attack (called alpha) up to a maximum value, after which it decreases while the angle of attack continues to increase. This point where the lift coefficient is at its maximum marks, from an aerodynamic point of view, the stall. The angle of attack at which the Cz is at its maximum is thus the stall angle of attack (alphamax).

The aerodynamic characteristics of a wing, thus the shape of the CZ = f(alpha) curve, are different between the lower levels (low Mach, subsonic air flow) and high altitudes (higher Mach, air flow close to trans-sonic).
This leads to a lower stall angle of attack at a higher Mach level.

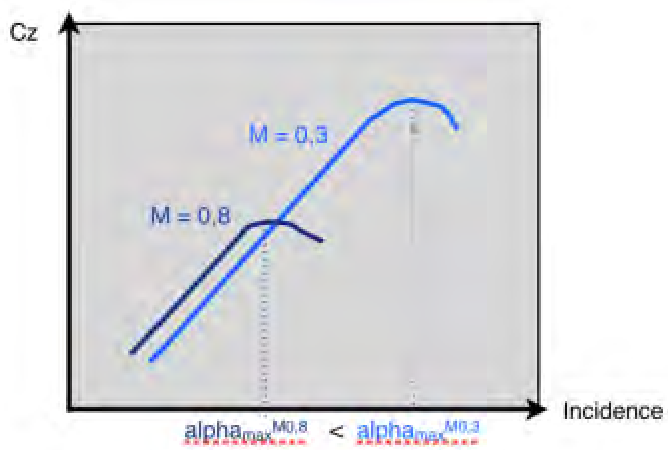


Figure 54 - Graph of lift at low and high Mach

In a more pronounced way at a high Mach the compressibility of air results in particular in the appearance of vibrations (buffet) at high angle of attack, whose amplitude can then increase until it becomes a deterrent (*deterrent buffet*).

1.16.6.2 Specific features of MD80 type aeroplanes in cruise

On the MD80 type aeroplanes, the angle of attack thresholds used by the SWCs to activate the stickshaker and the stall warning were defined based on the aerodynamic characteristics of the aeroplane at a low altitude and low Mach number (around Mach 0.2). The SWC use these AOA values regardless of the aeroplane's Mach (see chapter 1.6.5.5 for a description of these systems).

At high Mach, as in the case of cruise, the stall occurs at a lower angle of attack than at low altitude. Consequently the stickshaker and the stall warning trigger with a lower margin in relation to the real stall of the aeroplane.

Based on the flight data from the stall tests at high altitude undertaken for the certification of the MD80 type, the buffet phenomenon appears at the centre of gravity at the same time as the stickshaker or a few knots before the latter. However, these data do not include recordings of the load factor in the cockpit.

Other flight test data supplied by the manufacturer, specific to the appearance of buffet, show that on the MD80, buffet at the level of the captain's seat appears either at the same time, or within a few seconds following the appearance of buffet at the centre of gravity. Buffet probably became noticeable by the pilots at the moment that it became clearly discernible at centre of gravity, or a few seconds later.

In addition buffet at the level of the captain's seat can in some cases be of a lower amplitude to that at the centre of gravity.

1.16.6.3 Triggering of stall warning devices during event

Buffet

On the FDR recordings, there is a change in the behaviour of the vertical load at 1 h 45 06, at a speed of 203 kt. This change in behaviour is characterised by the appearance of a high frequency component whose recorded amplitude increase up to about 0.1 g peak to peak and temporarily 0.2 g peak to peak at 1 h 45 min 15. This component may correspond to the buffet.

The data from the flight tests supplied by the manufacturer include recordings of the load factor at the centre of gravity and at the captain's seat, measured with test instruments whose sampling frequency is greater than that of the FDR. The frequency of the buffet recorded at the captain's seat was close to 8 Hz and that measured at the centre of gravity, more difficult to measure based on the available data, was higher.

Consequently, the sampling at 8 Hz on the FDR can only provide a partial view of this phenomenon[25] and the data from the test flights supplied do not include recordings that would make it possible to establish a correlation between the buffet seen by the test instruments and by the FDR. Such a correlation would have made it possible to demonstrate that the appearance of this high frequency component at 1 h 45 min 06 corresponds with certainty to buffet. However, vibrations of this type can be caused neither by turbulence nor by the flight controls, whose position is recorded. Later in the report we will thus consider that buffet appeared at the centre of gravity at that moment, and that it likely became perceptible to the crew at the same time or a few seconds later.

The Aeroplane Flight Manual (AFM) contains a chart[26] that gives the speed and the Mach for the potential onset of buffet at a given altitude, in relation to the aeroplane's load factor, and its weight and balance. This chart corresponds to the onset of a 0.2 g peak to peak buffet as measured by the accelerometers located at the aeroplane's centre of gravity. This information is intended to provide flight crews with the maximum flight level an MD-80 can operate at, while providing a sufficient margin against buffet.

Based on the weight and balance recalculated by the manufacturer, as well as the recorded load factor, this chart shows that the onset of buffet could have occurred during the event at a computed airspeed of 218 kt, which was reached at 1 h 44 min 41. This result does not correspond to what the FDR data show: the load factor was then stable around 1 g and was not subject to any significant variations. The flight manual does not make it possible to confirm the appearance of the buffet that is very likely indicated by the FDR data.

Differences were also identified between this chart and the data from the Spirit Airlines event (see chapter 1.16.10 for a description). The investigation was not able to determine the cause of these differences. However, the chart is consistent with the appearance of buffet during the stall test flights at high altitude performed for certification of the aeroplane, including those undertaken at flight points close to those of the event.

According to the manufacturer, this chart is not intended to predict the appearance of buffet in given flight conditions but rather to determine the maximum flight level that would guarantee a margin in relation to the appearance of buffet. In that sense, AFM buffet onset data are not inconsistent with FDR recordings.

Stickshaker and stall warning

Exceeding the stickshaker and stall warning activation thresholds was established on the basis of the recorded angle of attack and the documentation supplied by the manufacturer. The value of these thresholds depends on the AOA and its rate of variation.

Precision on the timing of these triggers was limited by the following factors:

- the timing is based only on the angle of attack measured by the left sensor, used by the SWC 1, since only this angle of attack is recorded. However, the SW 2 could also have triggered these devices based on the right side angle of attack.
- The calculation of the rate of variation of the angle of attack and its integration into the value of the stickshaker activation and stall warning threshold could also generate errors in the estimation.

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[25] Based on the signal processing theory, the sampling frequency required to represent a signal is higher than double the maximum frequency of the signal in question. Thus 8 Hz signal requires sampling above 16 Hz.
[26] Buffet Onset Boundary Chart

On the basis of this information, triggering of the stickshaker and the stall warning were timed at 1 h 45 min 10 and 1 h 45 min 13 respectively.

1.16.6.4 Aeroplane stall

According to the information supplied by the manufacturer, on MD83 at Mach 0.5, the stall appears progressively as the angle of attack increases. The area in which the aeroplane stall appears at Mach 0.5 is between 9° and 11.5° angle of attack. Beyond 11.5°, the aeroplane is in a developed stall. The recorded data indicate that this angle of attack was reached at 01 h 45 min 12.

During the test flights at high altitude undertaken for MD80 certification, the aeroplane was considered stalled at the moment the stall warning triggered.
This alarm being timed at 1 h 45 min 13, this moment will be chosen to establish the time of the aeroplane’s stall during the accident.

Before that, at 01 h 45 min 00, while the autopilot was engaged in altitude hold mode, the load factor went below 1, which indicates that the lift was insufficient to completely balance the aeroplane’s mass. The autopilot commanded a continuous nose up evolution of the trimmable horizontal stabiliser. The aeroplane’s deceleration also increased. These phenomena indicate that the autopilot did not manage to compensate for the aeroplane’s decrease in speed and maintain level flight.

The table and the graph below illustrate all of the preceding information.

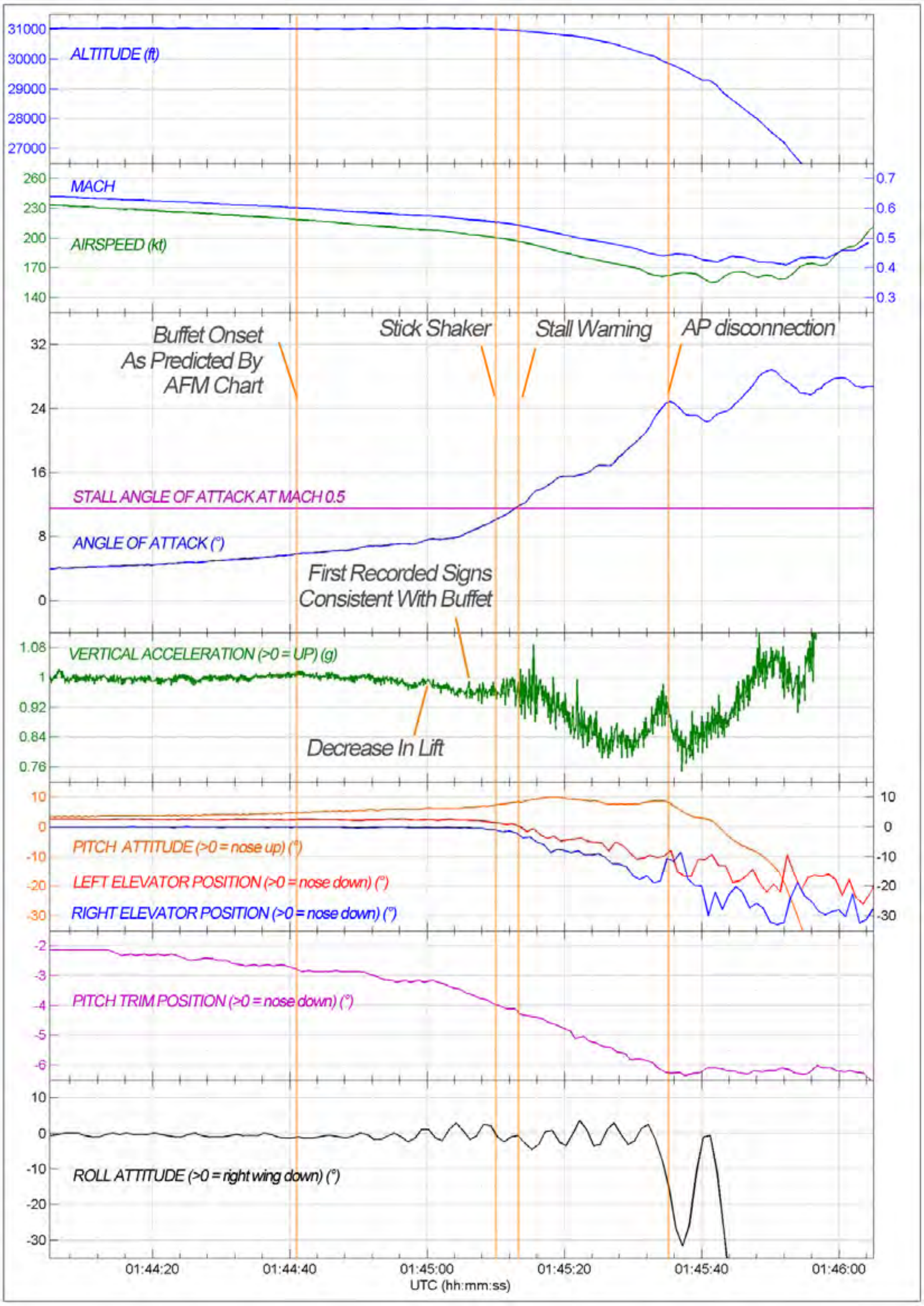

Figure 55 - Flight parameters relating to stall

UTC time	Phenomenon	Speed (kt)	Angle of attack (°)
01 h 45 min 00	Decrease in lift	208	7.5
01 h 45 min 6	Probable Buffet	203	9
01 h 45 min 10	Stickshaker	200	10
01 h 45 min 13	Stall warning	197	12
01 h 45 min 35	AP disconnection	162	25

1.16.6.5 Certification requirements

The certification requirements applicable during the MD80 type certification (FAR 25, amendments 25-1 to 25-40, effective as of 2 May 1977) set a speed margin of 7% between the stall and the stall warning[27]. This warning can be supplied either by the aerodynamic characteristics of the aeroplane itself (such as buffet) or by a system that provides clearly identifiable indications in the foreseen flight conditions (such as a stall warning or a stickshaker). However, these requirements specify that this 7% margin could be reduced if the stall warning possessed adequate characteristics in terms of clarity, duration and distinguishability, or similar properties.

In this event, if we consider that the stall occurred at a speed of 197 kt, the margin of 7% gives a minimum computed airspeed of 211 kt for the appearance of the first warning sign of a stall. This speed was reached at 1 h 44 min 54, which was 19 seconds before the stall. The available data and the calculations performed indicate that buffet and the stickshaker triggered at lower speeds : the buffet occurred at a speed of 203kt, 7 seconds before the stall, and the stickshaker triggered at a speed of 200kt , 3 seconds before the stall.

These margins were compared with those obtained during the high altitude stall tests undertaken for MD80 type certification. The speed margins for buffet and stickshaker during the event are comparable to the margins during these tests. The flight certification test report provided by the manufacturer, considered that these characteristics respected the certification requirements, without however mentioning the fact that the warning devices triggered at high altitude with a speed margin below 7%. No certification document which would explain why a speed margin lower than 7% would have been accepted for the certification of the MD80 was brought to the knowledge of investigators.

These specific features are not mentioned in the operational documentation.

The certification requirements, applicable to aeroplanes designed today, have evolved and specifically require that the speed margin between the stall and the activation of the warning be at least 5 % or 5 kt, whichever is the greater. The possibility of a reduced margin has thus disappeared.

1.16.6.6 Stickshaker and stall warning triggering on the simulator

Following the training session undertaken for the needs of the investigation on the MD80 simulator in Madrid, tests were performed in that simulator in order to reproduce the sequence of events, as close as possible to those of the accident. This simulator represents a MD88 which has the same aerodynamic characteristics as the MD83.

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[27] Paragraph FAR 25.207 modified by amendment 25-7 :
(a) Stall warning with sufficient margin to prevent inadvertent stalling with the flaps and landing gear in any normal position must be clear and distinctive to the pilot in straight and turning flight.
(b) The warning may be furnished either through the inherent aerodynamic qualities of the airplane or by a device that will give clearly distinguishable indications under expected conditions of flight. However, a visual stall warning device that requires the attention of the crew within the cockpit is not acceptable by itself.
(c) The stall warning must begin at a speed exceeding the stalling speed by seven percent or at any lesser margin if the stall warning has enough clarify, duration, distinctiveness, or similar properties.

To do this, the simulator was initialised in such a way as to reproduce the altitude, external temperature, aeroplane mass, slats and flaps configuration conditions corresponding to those of the accident. Then, the autopilot was engaged in maintain altitude mode, the autothrottle was disengaged and the throttle levers placed in idle position, in order to obtain deceleration in level flight close to that of the accident.

During these tests the stickshaker triggered at 180 kt instead of the calculated 200 kt during the accident and the stall warning triggered at speeds close to 170 kt instead of the calculated 197 kt during the accident.

The investigation was not able to determine the cause of the differences in speed.

It should also be noted that during the check on the simulator performed by the authorities, the calibration of these two devices is only objectively [28]tested in approach and landing configuration, at altitudes close to 14,000 ft. The behaviour of these devices in cruise is only tested subjectively.

New EASA and FAA regulations will require objective tests in cruise configuration at altitude near the maximum operating altitude.

1.16.6.7 Manual takeover of control by crew

The autopilot was disengaged 23 seconds after the aircraft entered the stall situation. During this period the angle of attack increased by 13° beyond the stall angle of attack and the position of the trim pitched up by 2°.

Thus when the crew took over manual control of the aeroplane the angle of attack was 25° and the aircraft was trimmed pitch up.

After disengagement of the autopilot the elevators were mainly deflected pitch-up, and when they were deflected pitch-down, the deflection remained less than half the maximum travel.

The EPAS system was thus never activated during the event because it would have caused complete nose down deflection of the elevators. The manufacturer made simulations using the aeroplane aerodynamic model in order to estimate the effort to apply to the control column to activate the EPAS. The maximum angle of attack at which these simulations were realisable was 10°, the model being invalid beyond this. The results show the effort on the control column required under these conditions was between 222 and 266 Newtons. As a comparison, the maximum efforts authorised by the FAA to demonstrate the controllability and manoeuvrability of transport aeroplanes is 334 Newtons for a short duration pitch input with both hands, on a non-stalled aircraft.

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[28] The term « objective testing » means a quantitative assessment based on comparison with data, whereas « subjective testing » means a qualitative assessment based on established standards as interpreted by a suitably qualified person.

Another simulation performed by the manufacturer showed that, at a similar angle of attack to that reached approximately at the triggering of the stall warning devices, the aircraft reacted to a nose down input on the control column by pitching down. During the event, the pitch control surfaces remained in the pitch-up position at the time the stall warning devices triggered, and the angle of attack continued to rise to reach values above 25°. There is no flight test data or aerodynamic model available to determine and analyse the behaviour of the aircraft for such angles of attack. Nevertheless, at around 1 h 46 min 50, approximatively 27 seconds before impact, there was a decrease in the nose up position of the elevators that coincided with a decrease in the aeroplane angle of attack. At that moment, computation based on the FDR data shows that the stall warning and the stick shaker were momentarily not activated.

1.16.7 Disengagement of Automated Systems

Chapter 1.6.5.4 shows the conditions for manual or automatic disengagement of the autopilot and the autothrottle.

The parameters recorded on the FDR did not make it possible to determine if the disengagement of the automatic system resulted from a voluntary manual input by the crew on one of the disengagement devices or on the flight controls, or automatic disengagement due to a malfunction detected by the DFGC or to an internal failure on the DFGC. Specifically, the usual means of disengaging autopilot and autothrottle by the crew which include pushing the appropriate buttons located on the control columns for the autopilot and on the throttle levers for the autothrottle, are not recorded.

Whatever the type of disengagement, the autopilot remained engaged despite a speed that was incompatible with stabilised level flight, the triggering of the stickshaker then the stall warning and the aeroplane's fall. The orders generated by the autopilot then caused an increase in AOA and a degradation of the stall situation.

In the certification regulations applicable to MD80[29] type aeroplanes, there is no requirement related to disengagement of the autopilot in case of an abnormally low speed or triggering of a stall warning device.

In the current version of the requirements, one of them requires that when the guidance system is engaged, there must be some means of preventing the speed from approaching the limits of the flight envelope below an acceptable margin. When the aeroplane's speed crosses this threshold, some means must be provided to prevent the guidance system from guiding or controlling the aeroplane towards an unsafe speed.

1.16.8 Operational Ceiling

To determine the operational ceiling of the aircraft on the day of the event, the aeroplane weight was recalculated based on recorded fuel flow and the ramp weight filled in by the crew on the weight and balance sheet. According to the FCOM tables the results were as follows for cruise at Mach 0.76 under the event conditions:

- propulsion ceiling without anti-icing system activated: 34,000 ft;
- propulsion ceiling with engine anti-icing activated: 32,000 ft;
- propulsion ceiling with engine and airframe anti-icing activated: 31 000 ft;
- ceiling at 1.3g : 31,800 ft.

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[29] FAR 25.1329

The ceiling used is the flight level immediately below the lowest value, thus in this case FL 310.

This therefore means that, at FL310, stabilised level flight was possible and that the crew could manoeuvre at normal cruise speed with a load factor of 1.3g before the appearance of buffet.

1.16.9 Visual and Aural Warnings

1.16.9.1 Management of priorities for aural warnings

During the event the triggering conditions of a certain number of aural, visual and tactile (stickshaker) warnings were met. In the absence of any usable data from the CVR, it was not possible to check the triggering of aural warnings and of the stickshaker. The following results are thus based on recorded data from the FDR, computation and on the description of systems provided by the manufacturer.

The following table shows the time periods the activation conditions of the various warnings were met.

UTC Time	Warnings/visual or aural warning devices	Recorded or calculated
1 h 40 min 10	FMA display: MACH ATL (intermittently)	Recorded
Between 1 h 40 min 46 and 1 h 44 min 50	FMA display: MACH ATL (continuous)	Recorded
Between 1 h 41 min 22 and 1 h 45 min 00	4 aural warnings on horizontal stabilizer movement (“stab tone”)	Calculated
Between 1 h 45 min 00 and 1 h 45 min 35	5 or 6 stab tone warnings, 2 or 3 of which could be followed by the synthesized voice saying “stabilizer motion”	Calculated
Between 1 h 45 min 02 and 1 h 45 min 06	Disengagement of the autothrottle: red “THROTTLE” light on the FMA	Recorded
	SPD LOW display on the FMA(continuous)	Calculated
1 h 45 min 06	Buffet appears on FDR data	Recorded
1 h 45 min 10	Stickshaker (continuous)	Calculated
1 h 45 min 13	Stall warning (continuous): red STALL light, aural horn warning and synthesized voice	Calculated

	saying “Stall”	
1 h 45 min 22	Altitude warning (continuous) : flashing amber altimeter light and C chord aural warning and synthesized voice saying “Altitude”	Calculated
1 h 45 min 35	Autopilot disengagement: red “AP warning “ light	Recorded

1.16.10 Study of Events Involving Speed Decreases and Approach to Stall on MD80

The investigation team studied several events on MD-80 type aeroplanes involving speed decreases or approach to stall for which it had:

- ASRs[30] relating to approach to stall situations published by NASA[31];
- feedback from two major airlines operating MD-80 type aeroplanes;
- in service events known to the manufacturers Boeing and Pratt & Whitney, in response to a request based on criteria established by the investigation team;
- extracts from data bases (BEA – DGAC – EASA);
- Swiftair feedback reports.

1.16.10.1 Summary of ASRs from NASA

The NASA document analysed ASRs in which MD80 crews stated that they had been made to fly close to stall, whatever the circumstances might have been.
The information contained in 14 of the 22 events extracted from the NASA document made it possible to identify some significant points in terms of environment, situational awareness and reaction by crews.

- Concerning environment, it showed that:

  - the majority of events were identified between flight levels 270 and 370;
  - 5 occurrences mentioned icing or a strong probability of being in icing conditions, of which 3 occurrences in VMC.

- Concerning the information that made it possible for crews to become aware of the degraded situation of the flight:

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[30] The Aviation Safety Reports (ASR) are pilot reports on safety-related events encountered in flight
[31] NASA Document: « Search Request No. 6712 - MD80 Series Aircraft Stall Incidents” published 6 December 2005.

A variation in the indicated airspeed was mentioned in 14 eventsl. However, for some of those events, flight crews reacted just before stall or at the time of stall occurrence.

- for seven events, reaction occurred after a speed decrease was observed
- for four events, reaction occurred after buffet was sensed
- for one event, reaction occurred after a stickshaker actuation
- for one event, reaction occurred after stall warning
- for one event, aural alarm associated with trim runaway was mentioned

- Concerning crew reactions the following points should be noted:

- in 3 cases, the crew activated the engine anti-icing systems.
- a variation in the EPR displays was mentioned in 2 cases
- one event was reported to be potentially related to PT2 issues, but the weather experienced prior to or during the event was not specified.

1.16.10.2 Feedback from major airlines operating MD80-type aeroplanes

This feedback is based on voluntary reports and the information described below is based on the experience and perception of the facts as seen by the reporters.

The investigation team used feedback reports related to the accident of flight AH5017 from two major airlines operating large fleets of MD-80 type aircraft over a long period. In this context, 6 cases were reported related to a drop in power on both engines attributable, according to the two airlines, to icing from ice crystals. This shows that:

- in all of the events, the airplanes were operating at an average altitude of 30,000 ft based on the crew reports, in visible moisture, and sometimes in the vicinity of convective weather activity
- the aeroplanes were flying with autopilot and autothrottle engaged, in altitude and Mach hold modes
- The crews reported the airplanes slowed down to near stall speeds
- The crews put the aeroplanes into a descent, sometimes requesting lower altitudes from air traffic control and sometimes descending while declaring an emergency
- In each case, the problem was rectified after the crews activated engine anti-icing.
- The two operators also reported that they have had a large number of single engine events where the EPR indication would get erratic and would increase without any corresponding throttle movement. In those situations, the corrective action was to activate the engine anti-ice.

General comment by operators

The two operators stated that their MD80 crews have a good understanding of the relationship between EPR and N1. If the crews suspect that there is an issue with the EPR indication, they know that they set engine power by N1 rather than EPR. One of the operators is developing a chart that has EPR and corresponding N1 values for cruise altitudes.

1.16.10.3 *Other known in-service events*

The BEA participated in the safety investigation into the accident on 16 August 2005 to the DC-9-82 (MD-82) operated by West Caribbean Airways.

> On 16 August 2005, flight WCW 708 was at flight level FL310, likely with the anti-icing system for the airframe and the engines operating. The crew climbed towards flight level FL330 and the anti-ice systems were turned OFF during the climb.
> After the aircraft reached FL330, as the engine thrust available was reduced due to the activation of all the anti-ice systems, the available thrust was not adequate for level flight, when considering the aircraft's mass and altitude. As noted in the final report associated with this accident, "*The crew continued to keep the aircraft at a flight level at which, according to the performance tables and graphs, and also given the use of the anti-ice systems and their effects on engine performance, it could not be maintained in flight in an appropriate manner*".
> The speed decreased, then at the time the crew left FL330 to descend to lower altitudes, the stickshaker and stall warning triggered, and the aeroplane descended in a stall situation down to the ground.

The aerodynamic conditions and performance put the aeroplane into a critical state that led to the stall.

> "*The cause of the accident was the failure to take timely action to correct the aircraft's entry into a stall, and from the start of the emergency until the collision with the ground, the prioritisation and execution of procedures were misguided. In sequential terms, an operation was initiated outside the limits and parameters laid down in the manufacturer's performance manual, in conjunction with inappropriate flight planning which failed to take into account the climatic aspects, in addition to erroneous and belated interpretation of the loss of power by the aircraft on the part of the flight crew. Consequently, the evidence indicates that human factors should be classified as the cause of this accident*."

The BEA asked the NTSB to conduct research into events similar to the accident to flight AH5017 with the manufacturers Boeing and Pratt & Whitney. The research was carried out in their data base of in service events using key words that related to the accident. Fifteen events were identified. The majority of them coincided with those already listed in the NASA document. The NTSB drew attention to the incident on 4 June 2002 to the MD-82 operated by Spirit Airlines:

- The aeroplane at flight level FL330, autothrottle engaged, was subject to a drop in engine rpm. The crew noted a low speed and the stickshaker and the stall warning triggered. They disengaged the autopilot, started a descent and activated the anti-icing systems. The flight continued normally.

- The pressure sensors had been blocked, likely by ice crystals, leading to an erroneous EPR indication and a drop in the power provided by the engines, without the anti-icing system having been activated.

1.16.10.4 Extractions from databases (BEA – DGAC – EASA)

The BEA researched similar events in its Eccairs data base as well as in the DGAC and EASA Eccairs[32]databases.

The BEA made two requests, based mainly on a search using key words in French and English, one bearing on manufacturers/aircraft models and the other on manufacturers/ engine types.

Searches in the three data bases showed only one event with similarities that is not reported above:

- Incident on 15 September 2002 to the MD-82 operated by Air Lib, a summary of which is included below:

  A DC-9-82 suffered a decrease in speed during a flight from Tenerife - Paris Orly, in cruise, at the upper limit of the cloud layer. The crew interpreted this decrease in speed as airframe icing. They began a descent with reduced engine thrust and using wing de-icing. Since the vertical speed indicator and the cabin altitude were increasing, (engine thrust became inadequate to ensure wing de-icing and the aircraft pressurisation system function) the crew then made an emergency descent with triggering of the release of passengers' masks. Icing of the PT2 sensor was suspected.

1.16.10.5 Information received the operator Swiftair SA

In the context of the safety investigation, the operator provided a crew report concerning a similar event which can be summarised as follows:

On 8 June 2014 the Swiftair MD-83 registered EC-JUG, which was making a public transport passenger flight at FL330, suffered a drop in speed while it was flying during the day in VMC above the cloud layer with the autothrottle engaged. The crew detected the problem, put the aircraft into a descent and activated the engine anti-icing systems without reaching a stall situation, then continued the flight.

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32 ECCAIRS: European Coordination Centre for Accident and Incident Reporting Systems

1.16.10.6 Significant points from the study of events:

- Circumstances of the events
    - for 2 events for which the investigation had access to the flight parameters the decrease in speed was slow and progressive
    - the speed decrease phenomenon generally occurred at flight levels between FL270 and FL330
    - For most events, the crews had not activated the anti-icing systems
    - The two major airline reports show that some crews did not activate anti-icing systems in visible moisture conditions
    - Although the documentation stipulates that the anti-icing system must be activated in TAT conditions below 6° C and visible humidity, some events occurred in clear skies

- Crew reaction
    - The crews reacted by quickly putting the aeroplane into a descent, sometimes declaring an emergency.
    - By disengaging the autopilot and autothrottle and manually increasing engine power
    - In general by activating the anti-icing systems

- Warnings

Crews detected the decrease in speed and approach to stall situation, based on one or more of the following warning signs:

- by reading flight instruments,
- by observing and listening to trim runaway callouts,
- by the appearance of buffet
- by the appearance of stickshaker,
- by the stall warning.

In none of the cases studied did the crew mention applying the FCOM Approach to Stall or Stall Recovery procedure, however, for all incidents, , crew(s) did take actions consistent with items specified by the procedure.

1.17 Information on Organisations and Management

1.17.1. Operator

Swiftair is a private Spanish airline, founded in 1986. It is based in Madrid and employs around 500 people. It employs many part-time pilots (about half of the workforce for the MD83). Most of them are former pilots from the Spanair airline.
The airline's activities are mainly "wet lease[33]" and cargo contracts (on B737s, Embraer and ATRs). The airline does not sell passenger tickets.

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[33]Leasing of an aeroplane with crew, the flight is then performed according to Swiftair operational procedures and under its AOC

The airline had an Air Operator Certificate (AOC) renewed by the Spanish authority on 25 April 2014 in accordance with Annex III of European Regulation 3922/91.

The Certificate of Air Transport specified in particular that the aeroplane registered EC-LTV could be operated worldwide.
In February 2014 Swiftair obtained the IOSA label established by IATA in February 2014.

1.17.1.1. Fleet

On 1 September 2014, Swiftair S.A. had a fleet of 43 aeroplanes and flew passengers and cargo to Europe, Central Africa and the Middle East. Since 2005, it has also operated flights for the benefit of the United Nations.

The fleet consisted of six B737-300s, one B737-400, three MD 83s, six ATR 42-300s, seventeen ATR-72s, and ten Embraer 120s.

The airline stopped operating MD83s in October 2014.

1.17.1.2 The Swiftair coordination centre

The Swiftair coordination centre updates and monitors the aeronautical documentation, flight preparation, management of real-time flights, and provides standby services to manage contingencies related to air operations.
In particular it establishes the operational flight plans and sends them via the SITA network to the crews including those operating from abroad under "wet lease" contracts. To enable this work, the charter airlines are responsible for providing flight plans to the Swiftair coordination centre in good time.
For the flights operated by Swiftair on behalf of Air Algérie in 2014, the planned route from Ouagadougou to Algiers systematically went through Niamey (NY) since the MD-80s operated by Swiftair were not ETOPS approved. In this case, a landing aerodrome must be accessible within one hour of flight, that's to say 320 NM.
Going through EPEPO leads non ETOPS approved flights to exceed the maximum authorized distance. In the present case, the accident occurred before the maximum distance was exceeded.

The coordination centre also provides real-time tracking of aircraft thus equipped. The aeroplane registered EC-LTV, though equipped with 2 GPS integrated into the FMS, was not equipped with a system that allowed real-time tracking.

1.17.1.3 Flight data monitoring

The airline carries out flight analysis using an FDM program (Flight Data Monitoring), the features of which are contained in the operations manual. They are compliant with EU OPS 1.037.

The purpose of the program is to monitor safety by detecting and analysing any deviation occurring during a flight in relation to the criteria of respecting the flight path and flight parameters, as defined by the airline, and relevant to flight safety. These deviations are called events and are grouped into categories. Any event detected by the FDM is systematically analysed in particular on the basis of the data recorded on board (QAR data) and interviews with the crew.
The analyses are used to monitor and quantify the deviations, provide anonymous instructive feedback for the crews, detect trends and if necessary increase training on specific points.
This list mainly includes events that may occur on approach, take-off or landing. It does not include events such as the decrease in speed in cruise, icing, incorrect EPR values or stall recovery.

1.17.1.4 Operational procedures

1.17.1.4.1 Swiftair FCOM procedures

The Swiftair FCOM procedures bearing some relation to the crash of flight AH 5017 are summarized below. They are duplicates of the procedures found in the Boeing FCOM. The complete FCOM records relevant to the investigation are included in appendices 11, 12 and 13, except for the “EAI ground and flight” FCOM text which is included in 1.17.1.4.1.4.

1.17.1.4.1.1 The “EPR erratic or fixed” procedure

This procedure applies in the case of an erratic or fixed EPR value. It states that this situation may occur in the case of icing or an EPR indication failure. It specifically requires activation of the engine anti-icing system. In case of failure, it requires that the thrust levers be moved and the EPR, EGT, N1, N2 and Fuel Flow indications be observed. If as a result of these observations, the value of the EPR is found to be erratic, or fixed, then the N1 indications are to be used to adjust power.
The name of the procedure, however, may not encourage one to refer to it in case of behaviour similar to that observed during this accident, where the EPR values were neither erratic nor fixed but erroneous.

1.17.1.4.1.2 The “Approach to stall or stall recovery” procedure

This procedure applies in the case of an approach to stall or stall recovery. It must be applied at the first indication of stall: buffet or stickshaker. The first actions are to disconnect the autopilot, and the autothrottle, to apply either take-off / go-around thrust or climb thrust and simultaneously to decrease the angle of attack until buffet and the stickshaker stop.
A warning given at the beginning of the procedure indicates that during take-off, the stall warning may be triggered during the rotation due to an incorrect configuration of the slats. In this case extension of the slats is requested.

It should be noted that before 2012, the manufacturer’s stall recovery or stall avoidance procedure provided for the extension of the slats below FL 250 while simultaneously applying a nose-down input to decrease the loss of altitude, regardless of the phase of flight.

After a review of events related to stall situations (on all types of aeroplanes), it was decided to modify the procedures in terms of stall recovery or avoidance. In particular it was considered more appropriate to accept a loss of altitude (if the terrain allowed it) and give priority to reducing the angle of attack instead of trying to maintain altitude during the approach to stall as was previously recommended.

This led the manufacturers to modify their procedures accordingly:

In the case of the MD80, Boeing removed from the Flight Manual the reference to the extension of the slats below FL 250, except in cases of stall warning on rotation at take-off (the priority being given to maintaining altitude) to cover a configuration error of the aeroplane at take-off.

This also helped standardize the procedures for all of the Boeing fleet.

The Swiftair operations manual was modified accordingly and thus fully incorporated the new elements from the Boeing FCOM.

Training in approach to stall and stall recovery for Swiftair crews was conducted in the cruise phase, in clean configuration. The pilots themselves cause the approach to stall and the stall by disconnecting the autopilot, reducing power and manual input on the pitch trim.

1.17.1.4.1.3 The "airfoil ice protection operation" procedure

This procedure is to protect the airframe against icing. In the preamble it is stated that the anti-icing system should be on whenever icing conditions exist or are expected. It also states that icing conditions can exist when the total temperature (TAT) is less than 6°C and moisture is visible in the air. It also requests that crews be vigilant about the formation of ice on the windshield wipers or the edges of the windshield. It notes that the higher the temperature, the higher the liquid water content in the air mass and that below -20°C, icing is less severe. It nevertheless states that severe icing had been reported at temperatures down to -60°C.
The procedure is applicable based on the crews' assessment of the conditions of occurrence or observation of icing.
The procedure consists in activating the engine and airframe anti-icing systems.

1.17.1.4.1.4 The "engine anti-ice on ground and in flight" procedure

This procedure concerns the protection of the engines against icing, on the ground and in flight. The foreword states that the anti-ice system should be activated as soon as icing conditions exist or are expected. The anti-ice system should be activated in flight when the total temperature is below -6°C and that visible humidity is present or if one observes icing on the windshield wipers or the windshield edges.
The procedure consists of activating the anti-icing system of one engine and waiting for its parameters to stabilize before activating the anti-icing system on the other engine.
A note in the procedure states that icing of the engines' Pt2 pressure sensors can cause the autothrottle to reduce thrust when engaged in EPR LIM mode. In this case the EPR value displayed corresponds to the EPR limit value. The note states that in this case flight performance may be degraded (rate of climb). There is no other mention in the FCOM of the icing phenomenon affecting the Pt2 pressure sensor.

Note: the only procedure that deals explicitly with a speed problem is the "unreliable airspeed" procedure. This applies in the case of a speed indication anomaly. It was not applicable therefore in the case of this accident since the speed indication showed no anomalies.

ENGINE ANTI-ICE ON GROUND AND IN FLIGHT

CAUTION: Periodic engine runup (with engine anti-ice system on), to as high a thrust setting as practical (70% N1 for a minimum of 15 seconds is desired, or alternately 60% N1 for a minimum of 40 seconds), should be performed to minimize possibility of ice buildup during extended ground idle operation in icing conditions. It is suggested that such runups need not be made more frequently than at 10-minute intervals. Subsequent airplane takeoff under these icing conditions should be preceded by a static runup to as high a thrust level as practical with observation of EPR and EGT to assure normal engine operation. Engine runups on the ground are equally applicable to taxi-in as well as to ground holding and taxi-out.

NOTES: Engine anti-ice should be on whenever icing conditions exist or are expected. Airfoil anti-ice should also be used if conditions warrant.

Engine anti-ice should be used during ground operation if outside air temperature is less than 6°C (42°F) and visible moisture is present or dewpoint and outside air temperature (RAT or SAT) are within 3°C (5°F) of each other.

Engine anti-ice should be used during flight when ram air temperature is less than 6°C (42°F) and visible moisture is present or if ice buildup occurs on windshield wipers or edges of windshields.

The higher the temperature, the higher the cloud liquid water content and the more severe will be the icing conditions. At temperatures below –20°C (–4°F), icing conditions encountered should be less severe. However, heavy icing has on occasion been reported at temperatures as low as –60°C (–76°F).

(CONTINUED)

ENGINE ANTI-ICE ON GROUND AND IN FLIGHT (Continued)

ENG IGN Switch/Selector . . . . GRD START & CONTIN / CONTIN / SYS A OR SYS B

NOTE: When encountering engine inlet icing conditions and before engine anti-ice system is turned on, verify ENG IGN switch/selector is in GRD START & CONTIN / CONTIN / SYS A or SYS B.

ENG Anti-Ice Switches (One at a Time) . . . . ON

Move ENG anti-ice switches to ON (one at a time). Wait until engine is stabilized before turning on opposite engine anti-ice.

L and R ENG ANTI-ICE ON Lights . . . . CHECK ILLUMINATED

L and R ENG VALVE Lights/Annunciations . . . CHECK EXTINGUISHED

NOTES: During ground operation, if an L or R ENG VALVE light remains illuminated, call maintenance.

In flight, if an L or R ENG VALVE light/annunciation is illuminated, one or more engine anti-ice valves have malfunctioned. Depart icing area as soon as possible. Maintain engine operation at desired thrust level. Minimize throttle movement until clear of icing area. Make log entry.

While operating in EPR LIM mode with autothrottles engaged, icing of engine pressure ratio probes may cause throttles to retard. EPR indication will be the same as limit shown in TRI/TRP. If engines are icing at different rates, autothrottles may disconnect. If throttles retard, degradation of climb performance may occur. If allowed to continue in indicated airspeed or Mach mode, a descent will be initiated. If in vertical speed mode, airspeed will decrease.

If required in flight,

AIR FOIL Anti-Ice Switch . . . . ON

(CONTINUED)

Figure 56 – Engine anti ice on ground and in flight procedure
Boeing Proprietary Information. *Copyright © Boeing. Reprinted with permission of the Boeing Company*.

1.17.1.4.2 Provision in the Swiftair operations manual concerning the avoidance of thunderstorms

The airline operations manual states that crews are recommended to avoid storm areas. It gives no specific distance value to be maintained by the crew in relation to these areas.

1.17.1.5 Observation of a simulator training and checking session

For the purposes of the investigation, observation of a 4-hour simulator session including training and checking was carried out by the BEA in June 2015. The objective was to check whether the combination of training and checking sessions for a full crew (i.e. two pilots) covered the entire programme and under what conditions it took place.

The airline made a crew available in addition to the airline's simulator examiner who performed most of the simulator training and checking for MD83 crews. However since the airline stopped its MD-80 activity in October 2014, although the crew was experienced it had no recent practise on this type of aeroplane.

For the purpose of observation, it was decided to perform the training and checking session for the second half of 2014 (scheduled for November 2014 for the crew of flight AH5017), which included in particular training on unusual attitudes, approach to stall and stall recovery.

It emerged that:

- Even though the regulations do not require a minimum duration for simulator sessions, the combination of a training session and an OPC check in a single simulator session of four hours for two pilots is intense.
- The approach to stall exercise is performed in manual flight below FL 250. The pilot reduces thrust, manually compensates the aeroplane to nose-up (up to about 180 kt). When the stall warning is triggered, the crew extends the slats and decreases the attitude to exit the stall situation. The slat extension corresponds to the former stall recovery procedure (ref. 1.17.1.4.1.2).

1.17.1.6 Stationing of Swiftair SA crews for charter purposes

Three crews were stationed in Algiers for as long as the flights were chartered by Air Algérie. A relief crew was available in Madrid if needed. The captain and co-pilot were generally paired for the contract period to help manage schedules.

Since the beginning of the chartering arrangement, the captain and the co-pilot had carried out almost all of their flights together (43 flights out of 45 for the captain, and all 43 flights for the co-pilot).

The working rhythm generally fixed for contract was 7 working days on, including flights either in the morning or afternoon, followed by 5 days off.

1.17.1.7 Flight crew employment framework

Since they joined Swiftair, both members of the flight crew had only flown during the summer season under fixed-term contracts. According to the information gathered during the investigation, they did not work as pilots for any operator other than Swiftair. For the summer season of 2014, they were under contract from 20 June to 20 September 2014.

1.17.1.8 Operator's conversion course (OCC)

1.17.1.8.1 Regulatory Aspects[34]

Before they start to work with an operator, pilots must take and pass a complete operator's conversion course (OCC), the features of which are detailed in OPS Chapter 1.945[35]

This course includes:

- ground training including: aircraft systems, study of the operator's normal, abnormal and emergency procedures, quality in training, safety and dangerous goods;
- training on emergency and safety equipment;
- training in crew resource management (CRM);
- training on the aeroplane or a flight simulator
- an operator proficiency check (OPC);
- line flying under supervision (in flight with passengers under the supervision of an instructor pilot);
- a line check.

At the end of this training and the associated checks, the pilot is authorised to carry out his/her duties with the operator.

Chapter OPS 1.945 (a) (2) (ii) specifies that a crew member has to take a new OCC in case of a change in aeroplane type or operator.

1.17.1.8.2 Training courses undertaken by crews

The captain joined Swiftair for the summer season of 2012 and took the Swiftair OCC from May to July 2012.

The co-pilot joined Swiftair for the summer season of 2013 and took the Swiftair OCC from May to June 2013.

The captain and the co-pilot not having flown for another operator between each summer season, Swiftair considered there had been no change of operator under OPS 1.945 (a) (2) (ii) and that the original OCC was still valid.

[34]The new European "Air-Ops" regulation published in 2012 applied at the latest in October 2014 for the Member States. In Spain, on the date of the accident, the EU-OPS regulation was the regulatory reference for public transport operations.

[35]Chapter of the OPS Subpart of the EU-OPS regulation

1.17.1.9 Recurrent training and checking

1.17.1.9.1 Regulatory aspects

Within an airline, each flight crew member has to follow both the programme associated with the annual extension of his type rating, as defined in appendix 9 of EU regulation 1178/2011 PART FCL, and the operator's recurrent training and checks as defined in OPS chapter 1.965.

Type rating:

From a regulatory perspective (appendix 9 Part FCL), the programmes for initial type rating training include crews' abilities to recognise the approach to stall, to take steps to counter an imminent stall and to recover from a full stall[36]. However, for the initial type rating skills test, this item is not mandatory, and is performed at the examiner's discretion. This principle also applies for the type rating extension proficiency check.

Recurrent training and checks :

For airlines, the specific requirements for recurrent training and checks were, as of the date of the accident, defined by EASA in the EU-OPS 859/2008 regulation.

The recurrent training and checks include:

- A refresher course on theoretical knowledge including the aircraft systems and study of the operator's normal, abnormal and emergency procedures
- Training on a flight simulator integrating CRM issues
- Operator proficiency checks (OPC) on a flight simulator (2 per year)
- A line check on the aeroplane during a commercial flight (1 per year)

Appendix 1 to OPS 1.965 (2) states:

- (i): the training programme must be established such that all the major failures of the aeroplane's systems and associated procedures are covered over a period of 3 years.
- (ii): simulator training may be combined with an operator proficiency check.

Approach to stall or full stall situations are not part of the aeroplane systems failures. As a result, performing them was not made mandatory by the EU-OPS regulation. Nevertheless, EASA issued a recommendation (Safety Information Bulletin n° 2013-02 – Stall and stick pusher training) asking operators to integrate this training into the recurrent and check training programmes. A new EASA regulation (UPRT[37]), specifically deals with mandatory training for recognizing stall and its recovery in various configurations, including in cruise near maximum operating altitude, and should be implemented during 2016.

[36] Part FCL Appendix 9 - §6 :
Section 3.8: Early recognition and steps to take to counter an imminent stall (up to triggering of the stall warning) in takeoff configuration (flaps in takeoff position) in cruise configuration and in landing configuration (flaps in landing position, landing gear extended).
-Section 3.8.1: Recovery from a full stall or after triggering of the stall warning in climb, cruise and approach configuration.

[37] UPset Recovery Training

The EU-OPS regulation does not define the hourly volumes of the training courses, which depend on the type of operation and the type of aeroplane.

1.17.1.9.2. Recurrent training and checking carried out by the crews

At the end of each seasonal contract, the operator has two options:

- either to keep crews in the recurrent training and checking cycle as if they were still active in the airline. In this case the crews remain integrated into the airline's training program in the same way as the permanent crews and are called during the year to take the scheduled training courses and checks.

- or to interrupt the recurrent training and checking cycle. In this case, it is customary for the pilot to take a new operator's conversion course when he/she resumes activity in the airline. The volume of training in this course may nevertheless be reduced in the case of experienced pilots at the airline.

Swiftair had chosen the first option for its crews under seasonal contract.

Nevertheless, until 2012, the training courses and checks for the second half of the year were not carried out and the crews did not carry out a new course when they resumed their activities the following summer. They therefore missed that part of the training and checking corresponding to the second half-year of the cycle (see appendix 5).
This was corrected by Swiftair in coordination with the Spanish oversight authority, from the recurrent training and checking cycle of 2013.

For this reason, the Swiftair operations manual (Part D - Training Manual) scheduled a recurrent training and checking cycle over a period of 2 years starting in the first half of 2013 and ending in the second half of 2014, using the MD83 simulator located in Madrid at CAE.[38]

Swiftair chose to group the training sessions with the OPCs: a portion of the training took place during the first OPC and the other during the second OPC.
In this way, 2 simulator sessions lasting 4 hours were scheduled each year, involving training and checking.

The simulator session of the first half of each year was also used to renew the type rating.

The entire training records for the crew were examined during the investigation. There was no issue with their respective evaluations on their knowledge of the aircraft systems, flight management, CRM[39], skills and decision-making. During their training and recurrent checks, their professional level was judged by their instructors and examiners to be above standard.

The training and checks carried out during the recurrent training and checking at Swiftair are summarized in the table in appendix 5.

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[38]As of 2015 the cycle is now three years long.
[39] CRM at Swiftair is in accordance with appendix 1 to OPS 1.965 a) 4) ii)

Training in the approach to stall and stall recovery:

Training in unusual attitudes, the approach stall and stall recovery was scheduled for the last half of the 2013-2014 recurrent training and checking cycle, i.e. during the simulation session in November 2014 (after the accident).

This means the captain and co-pilot had not been given training or checks on these items since they joined the airline.

Because it was impossible to access the archives of their former employer (Spanair no longer exists), it was not possible to know how far back their last training on these points took place.

1.17.1.10 Flight preparation in Ouagadougou

In Ouagadougou, the flight dossier was prepared by the Ground handling agency. The dispatcher in charge of the dossier collected all the elements required for the departure of the flight, including those required to loading passengers and fuel as well as calculating the weight and centre of gravity. The crew then filled in and validated the load and trim sheet, taking into account the no show of one passenger at the last moment.

The dispatcher then removed the weather dossier from the ASECNA meteorological office. This folder contained the meteorological information in effect at 22 h 30 (see 1.7.3)

He filed the flight plan based on the elements provided by Swiftair, which included:

- A departure at 00H45 to Niamey (NY) on air route UG854, at FL 290
- Then a route to point ROFER at FL 310
- Then FL330 to Algiers for a scheduled arrival at 03H47

1.17.1.11 Charter terms

A charter contract of the ACMI type (Aircraft/Crew/Maintenance/Insurance or "*wet lease*") was established between Air Algérie and Swiftair S.A. through the Avico company.

In the present case, the contract was established for the period from 20 June to 23 September 2014. It provided for the positioning by Swiftair SA in Algiers for the duration of the contract of:

- the aeroplane registered EC-LTV. This aeroplane could be replaced if necessary;
- three crews, both flight and cabin. A fourth standby crew was available in Madrid.

It stated that the crews' home base remained Madrid.

This type of "wet-lease" charter is regulated by the EU-OPS regulations, which specify that the chartered airline remains the operator of the aeroplane for flights of the chartering airline. In the present case, the flight was operated by Swiftair under its own Air Operator Certificate, under an Air Algérie commercial flight number, respecting the provisions described in the Swiftair operations manual.

1.17.2 Oversight of the Operator by the Authority

1.17.2.1 Principles

The Spanish oversight authority (Agencia Estatal de Seguridad Aérea) is responsible for ongoing oversight of Swiftair. This oversight ensures that the conditions for issuing the Air Operator Certificate described in the EU-OPS regulation are maintained.
ICAO Doc 8335 "Manual of Procedures for Operations Inspection, Certification and Continued Surveillance" serves as a reference for the methods to be used for oversight operations.

Oversight is carried out by means of scheduled inspections and spot checks in flight or on the ground. In-flight checks or on simulators are undertaken by pilot inspectors.

1.17.2.2 Approval of the training programme

The office responsible for oversight of Swiftair, as well as the flight operations inspectors studied and then validated the training programme. The regulation in force was the EU-OPS.

The parts of the manual concerning the FCL are examined by the FCL division of the Spanish oversight authority.

Inspections during simulator sessions are carried out at least every six months. However, they are performed on ATR simulators. No inspection was carried out during the training and checking sessions on MD 80 simulators.

According to the Spanish oversight authority, carrying out a 4-hour simulation session, combining training and checking, is possible under the following conditions:

- The examiner is experienced and knows the simulator well;
- A briefing lasting a minimum of one hour takes place before the session with a good review of the training items;
- All "before departure" briefings and performance calculations are made before entering the simulator.
- Out of the 4 hours, 1 hour 30 minutes must be devoted to training, and 2 hours 30 minutes to checking.

The observation by the investigation team of the simulator session combining recurrent training and the check for two pilots in four hours (1.17.1.5) confirmed that the pedagogical objectives cannot be addressed if these conditions are not respected.

1.17.2.3 Overview of SAFA inspections

In 1996, the Member states of the European Union, the European Civil Aviation Conference (ECAC) and various other states participating on a voluntary basis, launched a programme to assess the safety of foreign aeroplanes. In every participating state, aeroplanes are inspected during stopovers in the state in question using a common procedure. The results of these inspections are reported using a common format; when an inspection identifies an irregularity, it is transmitted to the operator and to its oversight authority. If irregularities have an immediate impact on safety, the inspector may request corrective action before the aeroplane takes off. All of the inspection reports and any corrective actions are centralized in a database set up by the EASA.

A standardized list of 54 inspection items is used during these inspections; it includes the pilot licenses, the procedures and manuals that must be present in the cockpit, compliance with these procedures by the crew, safety equipment, aeroplane cargo and its technical condition. Since a SAFA inspection should not delay the aeroplane, the checks must be made during the time of the stopover; for this reason, it is possible that not all of the items in the inspection will be completely checked.

SAFA inspections are performed extemporaneously and do not replace oversight of airlines by the national regulatory authority.

Between February 2011 and September 2014, Swiftair aeroplanes were subject to 97 inspections. Thirty-seven of them concerned aeroplanes of the MD80 type, six of which resulted in corrective actions. They mainly concerned mountings to be improved on certain passenger seats, and the need to improve compliance with certain principles of loading in the hold. No inspection resulted in an aeroplane being grounded.

The last inspection of EC-LTV was carried out on 22 July 2014 at Marseille-Provence airport, during a stopover on an Algiers-Marseilles-Algiers flight; the inspection resulted in information being given to the captain. The remarks made concerned the means of monitoring the access door to the cockpit, on brake wear that needed checking and the format of the CTA which was not compliant with the latest ICAO provisions.

A review of the 97 inspections by the investigation team did not reveal any elements that may have contributed to the accident.

1.17.3 Air Traffic Control Organisations

The agency for the safety of air navigation in Africa and Madagascar (ASECNA) primarily manages the airspace of the 18 Member States of ASECNA, divided into 6 flight information regions (FIRs). In particular it ensures air traffic control via en-route control centres.

1.17.3.1 Ouagadougou ACC

This centre manages all of the air traffic flying within its TMA and its UTA with a procedural control method. An air traffic display system, including a secondary radar, was being installed and tested.

During this event, the Ouagadougou radar detected perfectly AH5017 throughout its flight and specifically supplied information on altitude, heading and speed.

The Ouagadougou ACC communicated with the Niamey ACC during various phone calls which occurred from 04h47. Those exchanges were related to elements of the flight plan route and to the lack of radio contact with flight AH5017 at GAO and MOKAT. The track recorded by the Ouagadougou radar was not mentioned.

1.17.3.2 Niamey ACC

1.17.3.2.1 ATC and information provision

The en-route control centre manages all of the air traffic operating within the airspace, whether controlled or not, within the boundaries of the Niamey FIR/UIR, excluding the TMA and CTR of Niamey and the TMA, UTA and CTR of Ouagadougou.
The space managed by the Niamey ACC is divided into two sectors called CCR1-3 (in the north) and CCR2 (in the south).

Air traffic is managed via the EUROCAT-X system which uses data from a radar on Niamey airport with range of about 250 NM and merges them with flight plan. Controllers also use « strips[40] » that they annotate and position in front of them as the flights advance.

The radar is used as an aid to monitor the progress of flights. The ATC service provided remains non-radar, that's to say that flights are spaced according to level and overflight times at waypoints or significant landmarks.

1.17.3.2.2 Operational instructions at the Niamey ACC relating to the SAR

Besides ATC service, the Niamey ACC provides an alerting service for the benefit of all aircraft within the airspace under its area of responsibility. The alerting service consists in assisting a crew in flying an aeroplane in difficulty, alerting the search and rescue authorities and assisting such organizations as and when required.

The provisions of the Niamey ACC operations manual include the following rules regarding the activation of emergency phases for an aeroplane "in flight in the en-route phase":

- Uncertainty phase (INCERFA) if two consecutive mandatory messages[41] have not been received,
- Alert phase (ALERFA), 45 minutes after the activation of the uncertainty phase,
- Distress Phase (DETRESFA), 45 minutes after the activation of the alert phase.

The duration of the uncertainty and alert phases is used to attempt to contact the aeroplane either directly on the route frequencies or by asking radio stations with which the aeroplane may have had radio contact or aerodromes at which it may have landed.

The Niamey ACC operations manual specifies that the body responsible for activating the emergency phases, when the position of the aeroplane is not well known, is that of the airspace:

- in which the aeroplane was located when the last air-ground contact was established
- or which the aeroplane entered if the last air-ground contact was established at the boundary of two airspaces.

Flight AH5017 contacted the Niamey ACC. It was detected on the radar screens of the Niamey ACC. After it disappeared from the radar plot, the en-route control centre initiated the ALERFA and then the DETRESFA emergency phases. The Niamey RCC took charge of the coordination of search and rescue operations.

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[40] Strip of paper on which is printed the main information on the flight plan and which the controller annotates according to the content of successive communications on the frequency

[41] They include:

- The *position reports and QRU messages that aircraft are required to transmit*
- The *FIR boundary crossing message,*
- *The control transfer messages."*

1.17.4 Organisations responsible for Search and Rescue (SAR)

The SAR service refers to all of the location and rescue operations for people in distress on land and at sea.
With regard to aviation, SAR plans are listed in the ICAO Regional Air Navigation Plans (RANP). They emanate from Annex 12 to the Convention on International Civil Aviation and are the basis for the deployment of national and regional SAR plans, manuals, agreements and associated documents.

- ICAO Annex 12: Search and Rescue

Annex 12 requests that Contracting States coordinate their search and rescue services with those of neighbouring States.

It states in particular that:

Contracting States shall, individually or in cooperation with other States, take all measures necessary to arrange for the establishment and prompt provision of search and rescue services to ensure that assistance is rendered to all persons in distress.
Contracting States should ensure the closest practicable coordination between the relevant aeronautical and maritime authorities to provide for the most effective and efficient search and rescue services.
Any authority or any element of the search and rescue organization having reason to believe that an aircraft is in an emergency shall give immediately all available information to the rescue coordination centre concerned.
When information concerning an aircraft in an emergency situation is received from other sources than air traffic organisations, the rescue coordination centre shall determine to which emergency phase the situation corresponds and shall apply the procedures applicable to that phase.
In the event that an emergency phase is declared in respect of an aircraft whose position is unknown and which may be in one of two or more search and rescue regions, the rescue coordination centre that is notified of the existence of an emergency phase for which, as far as it is aware, no other centre has taken appropriate action, shall assume responsibility for initiating suitable action (i.e. the actions corresponding to the emergency phases) and shall confer with neighbouring rescue coordination centres with the objective of designating one rescue coordination centre to assume responsibility forthwith for the operations.
Unless otherwise decided by common agreement of the rescue coordination centres concerned, the rescue coordination centre that shall coordinate search and rescue action shall be the centre responsible for:

- *the region in which the aircraft last reported its position, or;*
- *the region to which the aircraft was proceeding, when its last reported position was on the line separating two search and rescue regions, or;*
- *the region to which the aircraft was destined if it was not equipped with suitable two-way radio communication or was not under obligation to maintain radio communication, or;*
- *the region in which the distress site is located as identified by the Cospas-Sarsat system.*

- ICAO Annex 11: Air Traffic Services

Annex 11 governs the application of air traffic service procedures. Chapter 5 is concerned with the alerting service and particularly describes its operation and the alerting of the relevant organisations (notably en-route control centre and rescue operation centres).
The alert service entrusted to air traffic control organizations is based on the definition of alert phases:

- the INCERFA uncertainty phase: this phase is established when no communication has been received from the crew within a period of 30 minutes after the time a communication should have been received;
- The ALERFA alert phase: this phase is established following the uncertainty phase, when subsequent attempts to contact the crew or inquiries to other relevant sources have failed to reveal any information about the aircraft;
- The DETRESFA distress phase: this phase is established following the alert phase when further more widespread inquiries have failed to provide any information, or when the fuel on board is considered to be exhausted. This phase may also be established when information is received which indicates that the operating efficiency of the aircraft has been impaired to the extent that a forced landing is likely.

These phases are designed to alert the search and rescue services, which should implement suitable measures, and to notify the air traffic control organisations monitoring the flight.

1.17.4.1 SAR agencies

The search and rescue operations relating to flight AH5017 concerned Algeria and three member countries of ASECNA: Niger, Mali and Burkina Faso. The search and rescue services (en-route control centre[42] and RSC[43]) of these four countries are organized in accordance with the Standards and Recommended Practices of ICAO Annex 12.
Search and rescue operations are activated at the initiative of the SAR services (ICAO Annex 12) or after an alert has been transmitted by the air traffic services (ICAO Annex 11) or by a third party (ICAO Annex 12).

1.17.4.1.1 The Niamey RCC

The Niamey RCC is a civil and military organization that is subordinate to the Ministry of National Defence of Niger for all issues concerning the employment of personnel and equipment in the preparation and execution of SAR operations.
It is based on Annex 12 of the ICAO, the "Plan for conduct of SAR search and rescue operations" of 9 March 1972 (of the Ministry of National Defence of Niger), the IAMSAR manual[44] and two SAR cooperation agreements, one with Mali (5 April 2007) and the other with Algeria (20 November 2011). The Ouagadougou RSC is attached to the Niamey RCC. A national SAR exercise was carried out in 2011.
On the date of the accident the RCC was only staffed with an SAR coordinator who also filled another post at the air base on which the en-route control centre is located.

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[42]Rescue Coordination Centre, responsible for ensuring the efficient organization of search and rescue services and coordinating operations within a search and rescue area
[43]Rescue Secondary Centre, subordinate to an en-route control centre and created in order to assist the latter in accordance with the specific provisions of the authorities in charge.
[44]International Aeronautical and Maritime Search and Rescue, manual serving as a guide for the organization and provision of search and rescue services.

Niger has permanent aviation assets (Cessna 208, DA42, MI 17 and MI 35) and additional resources.

1.17.4.1.2 Algiers ACC

The Algiers ACC is the body responsible for the conduct and coordination of SAR operations in the Algiers FIR.

It was in telephone contact with the Niamey ACC from 05 h 30 onwards. It initiated a search mission by an Algerian C130 based in Tamanrasset. The Algiers ACC was advised on 25 July 2014 by the French military forces in Mali about the location of the wreck.

1.17.4.1.3 Bamako RSC

The Bamako RSC is an organization that is depends on the Ministry of Defence and Veterans of Mali through the Air Force Chief of Staff. The Bamako RSC is a secondary coordination and rescue centre of the Niamey RCC.

It is based on Annex 12 of ICAO, the IAMSAR manual and two SAR cooperation agreements, one with Niger (5 April 2007) and the other with Algeria (11 September 2011). It has no cooperation agreement with Burkina Faso.
Mali has permanent aviation assets (Cessna 185, AS 350B in particular) and additional resources.
The Bamako RSC manual for SAR operations indicates the role and activities of the RSC when involved in SAR operations requested by an en-route control centre responsible for SAR operations.

1.17.4.1.4 Ouagadougou RSC

The Ouagadougou RSC is an organization that depends on the Ministry of Defence of Burkina Faso through the Air Force Chief of Staff.
The Ouagadougou RSC is a secondary coordination and rescue centre of the Niamey ACC.
The Ouagadougou RSC is organized and operates in accordance with the provisions of Annex 12 of the ICAO and the IAMSAR manual.

The Ouagadougou RSC was not formally activated. An SAR representative was part of the Ouagadougou crisis management team. The Niamey RCC did not contact Ouagadougou.

1.17.4.2 Chronology of SAR and ATC events

The chronology of the paragraph below summarizes the key moments of the search and rescue (SAR) operations that resulted in the implementation of the search capabilities for flight AH5017.

The detailed sequence of these operations is included in appendix 6.

- At 01h27, the Ouagadougou ACC called the Niamey ACC (post CCR2) to announce flight AH5017 and its take-off at 01H17.
- At 01h31, the radar plot of AH5017 appeared on the screen of the controller at the Niamey ACC. The aeroplane was climbing (FL233) approximately on route 350, 12 NM west of the ARBUT-EPEPO route and approximately 20 NM from ARBUT. It was 190 NM from NY.
- At 01h33, the radar plot of AH5017 disappeared as it was approaching the Niamey control sector. The aeroplane was outside the range of the Niamey radar because it was moving away from Niamey after taking a route further to the west.

- At 01h34, the Ouagadougou ACC contacted the Niamey ACC to inform it that flight AH5017 was "making an avoidance manoeuvre because of weather."
- A 01 h 37, the Ouagadougou ACC asked AH5017 to contact the Niamey ACC on 131.3.
- At 01 h h 42, the radar plot of AH5017 reappeared. It was about 35 NM northwest of the EPEPO-GAO route. For the following five minutes, the plot reappeared under different symbols, indicating that the aeroplane was at the limit of the Niamey radar's range.
- At 01h44min20, the Niamey ACC "accepted the flight plan track"[45] of flight AH5017.
- At 01h44min28, AH5017 called the Niamey ACC stating that it was stable at flight level 310 and in an avoidance phase. The Niamey ACC asked it to squawk transponder code 3235, to give its estimated arrival time for MOKAT and to call back passing GAO. The crew did not read back this last message. The requested transponder code did not appear on the radar tracks. As a result, at no time was the track flight plan correlated with the radar plot for the aeroplane.
- At 01h47min28 the AH5017 radar plot disappeared definitively from the Niamey controller's screen. The aeroplane was approximately 30 NM west along the EPEPO-GAO route. It was situated 95 NM from GAO and 215 NM from NY.
- At 01h52min45, the "track flight plan" of AH5017 passed GAO. The controller on duty who had contact with the flight orally informed the controllers in the adjacent position that AH5017 had not called back from GAO as requested and that it no longer had it in contact.
- Between 01h55 and 02h07, the Niamey controllers attempted to contact flight AH5017 on the VHF and HF frequencies. They also tried to establish contact by asking flights RAM543K, AH5005 and TAP289, which were flying in the sector, to relay.
- At 02 h 30 the flight plan track passed MOKAT point, the limit and transfer point between the Niamey and Algiers FIRs. In the following minutes, the Algiers ACC indicated concern to the Niamey RCC that it had not yet been contacted by flight AH5017.
- At 03h30, the Niamey ACC activated the alert phase (ALERFA) on the suggestion of the Algiers ACC. It sent the ALERFA message to the Algiers en-route control centre which transmitted it to the Algiers en-route control centre. The content of this message for flight AH 5017 stated: "loss of contact at GAO and MOKAT".
- At 04h38, the Niamey ACC sent the DETRESFA message.
- At 04h48, at the request of the Algiers en-route control centre concerning "the last radar contact" of AH5017, the Niamey ACC stated "around 01h55 and through GAO".
- At 05h28, the Algiers en-route control centre signalled to the SAR coordinator of the Niamey RCC, who had also just been called by the Niamey RCC, "the last contact" with AH5017 took place "through GAO at 01h55" for a "estimated MOKAT at 02h33."
- At 06h20, based on these various items of information, the SAR coordinator of the Niamey RCC estimated the probable area of the accident was located between GAO and MOKAT.

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[45] A flight plan track is a theoretical plot developed by the Eurocat system. It represents the estimated position of the aeroplane based on the elements of the flight plan. It merges with the real plot of the aeroplane when the pilot displays the transponder code assigned by the controller. Acceptance of the flight plan track by the controller means the latter has taken into account the future arrival of the flight in its airspace.

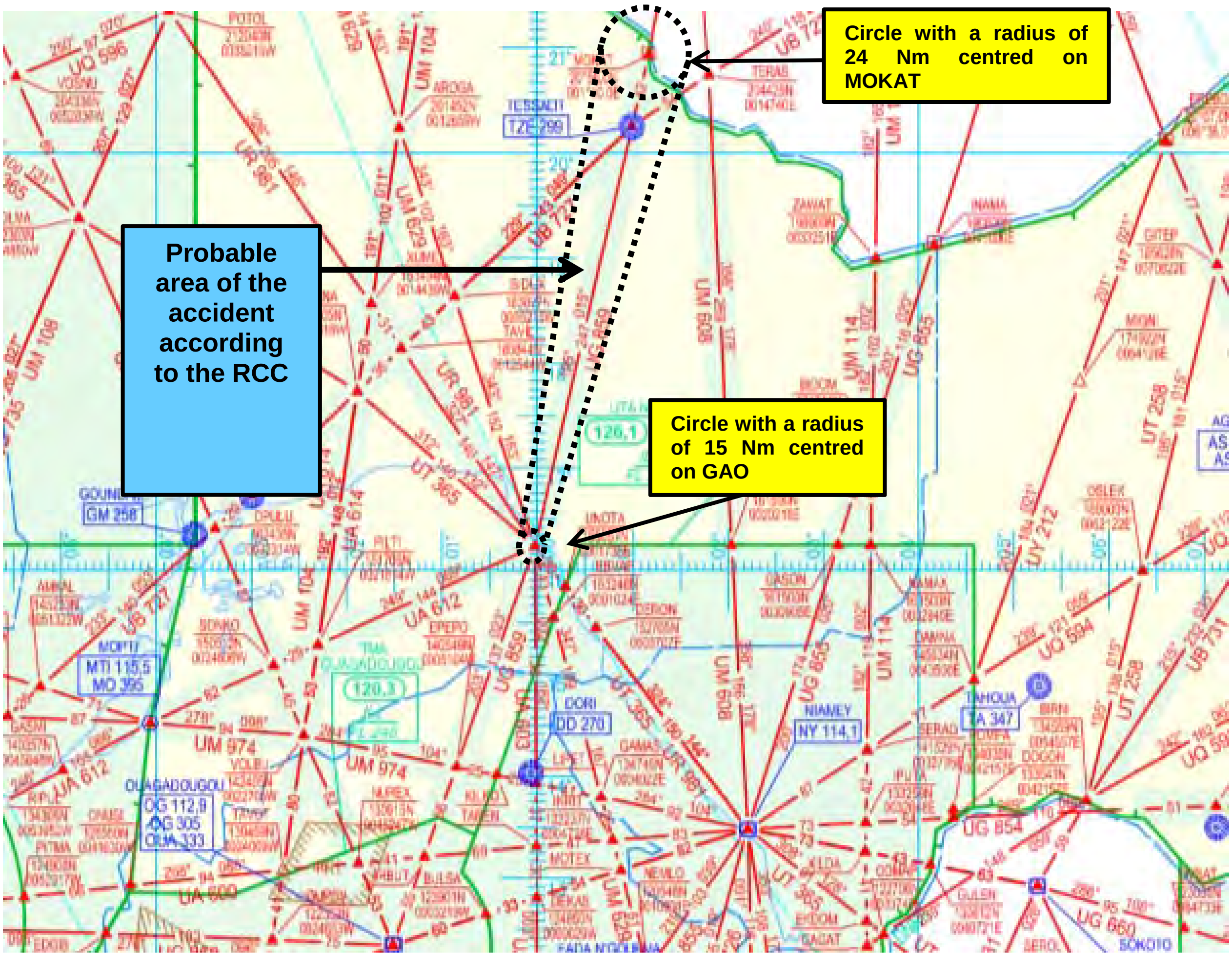

Figure 57 - Area estimated by the Niamey ACC

- At 06h32, it requested assistance from the Operations Support of the French Air Force, stationed at air base 101, which responded favourably.
- At 08h16, it was informed that an aeroplane of the French Air Force was carrying out a search while two Nigerian Cessna 208s were being kept on alert.
- At 08h17, a Crisis Management Team (CMT) was activated by Burkina Faso.
- At 10h07, the coordinator for SAR missions at the Niamey ACC informed the Operations Support of the French Air Force and specified that the last radar contact with the aeroplane was at ARBUT and that radio contact was made through GAO at 01h55. Search operations therefore concentrated on the area estimated by the Niamey RCC.
- At 13h08, the Burkina Faso CMT determined that the area of the accident was located around Boulekessi (Mali) based on radar information[46] from the Ouagadougou ACC and on testimony stating that an aeroplane had fallen in this area.
- At 15h00, a helicopter from the Burkina Faso Air Force took off from Ouagadougou and identified the crash zone at 18h23. The absence of survivors was noted.

[46] The Ouagadougou en-route control centre radar had continuous details of the flight path (altitude, speed, heading) for flight AH5017 from take-off from Ouagadougou until the disappearance of the radar plot in the accident area

Table summarising the various emergency phases and associated timings

PHASE	THEORITICAL TIME	REAL TIME
INCERFA	Passing MOKAT at 2 h 30	Not triggered
ALERFA	Passing MOKAT + 45 min, so at 3 h 15	3 h 30
DETRESFA	ALERFA + 45 min, so at 4 h 15	4 h 38

1.17.4.3 Summary of interviews

- The Niamey ACC controllers

The Niamey controllers stated it was frequent not to have radar contact on an aeroplane beyond 200 NM from NY, especially if the aeroplane was below FL300. Aeroplanes taking off from Ouagadougou that follow the ARBUT-EPEPO-GAO route are usually detected. As flight AH5017 had deviated to the west of the route and was therefore moving away from the Niamey radar, the controller on duty was not unduly worried, estimating that the aeroplane was out of radar detection and radio range and would appear again later, around MOKAT. It would then enter the Algiers radio / radar coverage, which would inform the Niamey ACC of same.

No explanation was provided why the INCERFA phase was not initiated at 02h30, the estimated time for AH5017 to pass waypoint MOKAT, which was the second checkpoint (see 1.17.4.2).
The reason for the choice of 45 minutes delay, scheduled in the operations manual, between the INCERFA-ALERFA and ALERFA-DETRESFA phases was not explained.
The controllers said they sent the ALERFA and DETRESFA messages a little late because they experienced difficulties in using the EUROCAT-X and AFTN system.

- The coordinator of SAR missions in Niamey

The only person in charge of carrying out and coordinating SAR operations, he determined a first search area based on the elements collected from the Niamey ARO and the Algiers en-route control centre. The latter indicated that the last contact with the aeroplane had taken place off GAO at 01 h 55 and that the flight should overfly MOKAT at 02 h 33 . The SAR coordinator thus determined a search area defined by 15 NM circle centred on GAO meeting up with a circle of 24 NM centred on MOKAT. The SAR coordinator stated that the information received was imprecise and had led him to determine an erroneous search area.

He did not ask to attend a radar playback of the flight path at the Niamey ACC, nor did he contact the neighbouring RSCs of Bamako and Ouagadougou.

1.18 Additional Information

1.18.1 Testimony

1.18.1.1 Dispatcher from the administrative authority responsible for assistance at the stopover

The dispatcher from the administrative authority responsible for assistance at the stopover was in charge of the preparation of this flight. He stated that the aeroplane arrived at the ramp about 15 minutes late due to the parking area being full at that time. This did not have any impact on flight preparation which occurred completely normally. The only difference with the other flights serving Ouagadougou was that the Swiftair crew wanted to do the loading plan and the weight and balance sheet themselves. The stopover lasted about 50 minutes.

The crew were calm and conscientious. The captain asked about the number of bags to be loaded. The copilot decided how to distribute the baggage in the hold, preferring to load the aft hold. She then made the weight and balance calculations based on the data provided by the dispatcher. The dispatcher then took the flight plan to the aeronautical information office.

1.18.1.2 Air Algérie commercial agent at Ouagadougou

The Air Algérie commercial agent's testimony indicated that the crew were under no pressure and that the flight was prepared quite normally.

He greeted the crew on its arrival at the Ouagadougou airport operations office and accompanied them back to the aircraft until the doors were closed before departure. He stated that the captain sat in the left seat.

He also stated that the turnaround time was standard. The crew examined the flight dossier attentively. During refuelling the captain checked the quantity of fuel loaded, then checked the locking of the holds himself. The copilot filled out the weight and balance sheet carefully and gave it to the captain. The latter examined and then validated it with a signature.

1.18.1.3 The air traffic controller on duty at Ouagadougou tower

The controller explained that, during the telephone call from the Niamey controller informing him of the arrival of flight AH 5016[47], the aeroplane's flight plan was not available to him. He added that this was very common for arrivals from Algiers and was not surprised by it. The aeroplane arrived via EPEPO. During this telephone coordination the controller wrote a strip including the flight details and then prepared manually, in advance, a strip for the coming departure indicating a departure via EPEPO.

When the flight plan filed by the crew was processed, the controller received a "machine strip" mentioning a departure via Niamey.

He chose to give the crew departure clearance via EPEPO because the crew had arrived via that point, which is also an exit point towards Algiers.

Conscious that this route was different from that requested by the crew in its flight plan, he stated that the crew could express any disagreement at any moment.

He added that controllers did not have radar visualisation of the meteorological conditions in the region on their screens. This principle is not in contradiction with ICAO Annexes 3 and 11, or with the national regulations of Burkina Faso

1.18.1.4 The pilots stationed in Algiers in July 2014.

Swiftair pilots in place in Algiers in July 2014 stated that all the crews in place at Algiers for the duration of the contract were seasonal, former Spanair pilots, and knew each other well. Since their arrival in Algiers, they had been living in the same hotel located close to Algiers airport. The accommodation was judged to be very acceptable by all.

Relations with Air Algérie were excellent. There was good team spirit between them and a high level of mutual consideration. The flight planning was done by Air Algérie in accordance with the provisions of EU-OPS sub-part Q relating to flight, service and rest times. For the pilots in place in Algiers, flight planning posed no problems at all.

[47] Inbound from Algiers the flight number was AH5016.

All of them knew the meteorological conditions in this part of Africa at this time of the year. They were always very stormy, especially at night. These conditions often made it necessary to perform avoidance manoeuvres. At the hotel the pilots debriefed their flights together and exchanged feedback.

They were all aware that the weather radar was a tool that needed to be managed well. The radar was usually set on 80NM then 40 or 20 NM if necessary to improve the precision of an avoidance manoeuvre. It was not always easy to fly into an area with no precipitation displayed on the weather radar. In such cases crews flew through areas with lower concentrations displayed in green but never through areas displayed in yellow or red. They also stated that the presence of clouds was easy to see, even at night, since the aeroplane's lights reflected from them.

They all knew that the anti-icing system had to be activated as soon as the TAT was below 6°C and that there were visible signs of humidity. According to them, the first indication of icing was on the rough parts of the windshield wipers.

All of the Swiftair pilots interviewed were aware of the FCOM approach to stall and stall recovery procedure and they were surprised the accident flight crew allowed the airplane to stall. For all of them, the captain was very experienced and was a reference on this type of aircraft. Those flight crew members who had flown with the accident flight crew also stated they were very rigorous and professional.

They stated that the stopover at Ouagadougou posed no particular problem, the personnel were competent and refuelling took place without any waiting. There were no ATC slots. This stopover was judged to be pleasant.

1.18.1.5 Crew of flight AH 5005

Flight AH 5005 bound for Algiers was on the Ouagadougou - EPEPO route at FL 370 with an estimated time at EPEPO at 1 h 56, that is to stay 18 minutes after flight AH 5017.

The crew, contacted for the requirements of the investigation, stated that:

- CB type clouds were present in all sectors west and north-west of Niamey and from EPEPO point up to the north of Gao;
- at FL 370 the TAT temperature was - 22 °C, the SAT - 48 °C. At FL 310 the SAT was - 36 °C.

The crew of flight AH 5005 stated that they often requested a change of heading to avoid the storm cell over a period of 46 minutes from the south of Ouagadougou up to the north-west of Gao.

They heard a call from flight AH 5017 (female voice) on the Niamey frequency (131.3 Mhz). The crew said "abeam *FL 310, request heading 350 to avoid"*. The Niamey control centre did not read back. The control centre called the crew of flight AH 5005 to relay messages to flight AH5017. The relay was tried on several occasions without success on all of the possible frequencies (4 VHF frequencies and one HF frequencies).

1.18.2 Type Certification and Continuing Airworthiness

1.18.2.1 Notions of type certificate and airworthiness certificate

Certification principles state that it is necessary to first certify a generic product (type of aircraft). When the product meets these requirements, a "type certificate" is issued by the authority to the industrial product designer.
This certificate attests that the generic product meets the applicable requirements. An individual airworthiness certificate is then issued to each product (individual aeroplane) after demonstrating its conformity with the certified type.
The holder of a type certificate has, among other obligations, that of ensuring follow-up on the e airworthiness of its fleet, that's to say to gather and analyse reports on in-service difficulties that are sent to the holder, and to study and implement, where necessary, any corrective actions relating to the design of the aeroplane, or to the documentation on its use and maintenance.

1.18.2.2 Regulatory aspects

The MD-83 meets the requirements of the regulations in force at the time of the original application for the type certificate, that's to say Amendment 40 of Part 25[48](May 1977).

The JT8D-219 engines are certified in accordance with the requirements of Amendment 6 of Part 33[49](October 1974). They specify how such engines must be designed, installed and tested in order to ensure their operation under all specified operating conditions.
In relation to systems to protect against icing, the regulation specifies:
• the types of tests to be performed when a manufacturer wants the plane or the engine may be operated in icing conditions (FAR25.1419);
• the technical conditions to be checked in order to certify an engine and its air inlet (FAR 25.1093 and FAR 33.68);
• the icing certification standards that are defined as a function of altitude and temperature, in terms of concentrations of water and volumetric mean droplet diameters in Appendix C of FAR Part 25.

Appendix C defines two envelopes:

- "Maximum continuous" cloud corresponding to an average of 17.4 NM, with low water concentrations, and up to 22,000 ft and - 30 ° C;
- "Intermittent maximum" cloud corresponding to an average of 2.6 SL, with high water concentrations, and values up to 30,000 ft and - 40 ° C.

1.18.2.3 Continuing airworthiness

Evaluation of the occurrences studied during type certification can be based on the classification of failure conditions, made during type certification on four levels: minor, major, critical and catastrophic. The certification regulations associated with each of these levels an acceptable probability.
Continuing airworthiness is undertaken by both the manufacturer and the certification authority according to a division of tasks and principles set out in FAR Part 21.

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[48]Part 25 of Title14 of the Federal Aeronautical Regulations
[49]Part 33of Title14 of the Federal Aeronautical Regulations

Obligations of the manufacturer, holder of a type certificate

Section 3 of FAR Part 21 says that the holder of a type certificate shall report to the FAA any failure, malfunction, defect or other problem about which it is informed and that resulted or may result in conditions that may compromise safety. These reports must reach the FAA within 24 hours after the identification of the unsafe condition.

Role of the FAA

In accordance with FAR Part 21, when the FAA believes that an unsafe condition existed or exists and may recur on another plane, it may issue an airworthiness directive. In this case, the manufacturer must propose corrective actions that the airworthiness directive makes mandatory.

1.18.2.4 Pt2 pressure sensor certification process

Pt2 pressure sensors were tested in the context of the certification of the engine in icing conditions through wind tunnel tests and flight tests. These tests were conducted with supercooled water.
These tests, carried out as part of the aircraft certification process, did not reveal any anomalies in the Pt2 sensor anti-icing system.

1.18.3 Previous Accidents and Recommendations

1.18.3.1 Relating to loss of control (triggering of stall warning)

Accident on 16 August 2005 to the DC-9-82 (MD-82) operated by West Caribbean Airways (see 1.16.10.4).

Following the safety investigation, the Venezuelan authorities issued the following specific recommendations:

- 058/2005-AA1: Require effective training of flight crew in the use of the performance tables, focusing on knowledge of the limits applicable when operating an aircraft in flight, in order to ensure that the altitude margins laid down in the operations manuals are not exceeded, thereby averting high-altitude stalls. We also recommend that dispatchers and all staff involved in the preparation of flight plans be instructed in the aspects associated with their specific working roles and the implications or effects on the performance of aircraft in the various flight phases.

- 058/2005-AA2: Require the inclusion in flight crew training of recovery from high-altitude stalls. This is justified on the grounds that in simulator training, low-altitude stalls are induced, from which the aircraft can recover more quickly, because it can increase power in order to maintain altitude in a more accelerated manner, whereas at high altitudes, the behaviour of aircraft is different, calling for more precise manoeuvres in terms of time of execution.

- 58/2005-AA5: In those countries in which there are air operators certified to operate MD-80 series aircraft, increase and optimise the requirements in the flight crew training programmes in the presence of buffeting at high altitudes, and also those with regard to the various configuration modes for the autothrottle system (ATS), the anti-ice system, and the monitoring of altitude and speed and their relation to aircraft power status.

- 58/2005-ODF1: Study the possibility of designing a new algorithm or of reviewing (with a view to improving) the existing algorithms in these aircraft or systems to provide alarms or warnings in sufficient time for flight crew, firstly to recognise in good time aural and/or visual indications of any abnormal or hazardous situation, and secondly also to react in time to such alarms or warnings and then carry out a rapid and appropriate analysis and decision-making process. In this particular case, the present Civil Aviation Accident Investigation Board suggests that an additional alarm, both aural and visual (e.g. lights and a voice saying "Warning: Performance", "Warning: Performance Conflict", etc.), in what is determined to be sufficient time, could alert the crew and put it in a state of situational awareness in a more appropriate manner, and initiate more timely corrective action in order to avert this type of accident. We therefore recommend analysis of the inclusion of an additional audio-visual warning appropriate to the situation detailed here and to the causal factors of this accident.

1.18.3.2 Relating to the risk of icing of Pt2 pressure sensors by ice crystals

Following the Safety Investigation into the incident on 4 June 2002 to the MD-82 operated by Spirit Airlines, the NTSB issued the following recommendations:

- A-04-034: NTSB recommends that the FAA issue a flight standards information bulletin to principal operations inspectors to alert all affected air carrier flight crews about the icing situation encountered by Spirit Airlines flight 970 and to emphasize the need to maintain vigilance for the signs of high altitude icing conditions, the effect these conditions can have on airplane and engine performance, and the need for the appropriate use of the engine anti-ice system.

- This recommendation led to the publication by FAA of «Information for Operators » on 30 June 2004 (appendix 9).
  This document provides advice and information to pilots and operators concerning high altitude icing conditions.

- A-04-035: NTSB recommends that the FAA Actively pursue research with airplane and engine manufacturers and other industry personnel to develop an ice detector that would alert pilots of inlet pressure sensor icing and require that it be installed on new production turbojet airplanes, as well as retrofitted to existing turbojet airplanes.

1.18.3.3 Follow-up on recommendations and corrective actions taken

On 06 August 2002, in response to the Spirit Airlines event, Boeing issued a Flight Operations Bulletin (FOB) referenced MD-80-02-02A describing the MD-80 autopilot and autothrottle modes. This FOB specifically described speed management by the automated systems and the possibility of airspeed decay under certain circumstances. It also informed crews that “the airplane could decelerate into a stall warning before the autopilot trips off” (see appendix 10).

On 30 June 2004 the FAA, in response to the fist recommendation A-04-034 had published an Information Bulletin concerning high altitude icing conditions. NTSB had considered that this publication answered the objective of the recommendation.

On 23 November 2009, the FAA's reply to NTSB stated that the installation of a detector did not seem to be relevant given the significance of the technological modifications required. NTSB kept the second recommendation A-04-035 open.

On 11 February 2015, after numerous exchanges with the FAA, NTSB considered that the evolution in certification rules concerning icing conditions constituted an acceptable alternative to the safety recommendation.

As regards the Venezuelan recommendations:

- the FAA and Boeing did not answer those addressed to them and applicable to MD80 aircraft (design of visual and aural warnings, training of and information to flight crews),
- EASA did not define any actions identified as being taken in response to these recommendations

1.18.3.4 SAR coordination plans in maritime or desert areas

Accident to flight AF 447 on 1 June 2009 to the Airbus A330-203 registered F-GZCP operated by Air France.

The accident occurred at 2 h 14 min 28 in the FIR ATLANTICO. A contact should have been made at about 2 h 20 passing TASIL point. The first ALERFA/INCERFA message was broadcast by the Madrid ACC at 8 h 22. Thus about 6 hours had passed between the expected communication from the crew and the transmission of the first message launching the uncertainty phase. It was only at 11 h 04 and 12 h 14 respectively that Brazilian and Senegalese aircraft took off bound for two different search areas.

Once the critical phases had been triggered and the rescue coordination centres had been alerted to a possible accident, the latter wasted a lot of time gathering information and taking into account the need to trigger searches.

The investigation showed that, contrary to ICAO recommended standards and practices, there was no SAR coordination plan between the two countries, which meant it was not possible to quickly find out what aerial means were available in each country (such as the Bréguet Atlantic 2 in Dakar) nor to quickly decide on a single RCC in charge of the coordination of the SAR mission.

This absence of a plan caused a considerable delay in the launching of the SAR mission.

At the end of the investigation, the BEA issued the following recommendation:

- ICAO ensure the implementation of SAR coordination plans or regional protocols covering all of the maritime or remote areas for which international coordination would be required in the application of SAR procedures, including in the South Atlantic area. [Recommendation FRAN-2012-032).

2. ANALYSIS

The absence of usable CVR data limited the possibilities for analysis of the crew's behaviour during the flight.

Specifically, it was not possible to study CRM aspects, such as the flight crew's performance to the expectations associated with the pilot flying and the pilot monitoring duties, or to evaluate the possible contribution of the employment context and experience of the crew members.

2.1 Scenario

Flight preparation and takeoff

On 24 July 2014, the crew of the MD83 operated by Swiftair prepared flight AH5017 from Ouagadougou to Algiers.

At the ramp, the crew requested FL330 then changed their minds and requested FL310 due to the weight of the aircraft. FL310 corresponded to the operational ceiling of the day with all the anti-icing systems activated.

During taxiing, air traffic control assigned to the crew an identical route to that taken during the inbound flight passing by waypoint EPEPO and different from the route scheduled in the flight plan, which passed by Niamey. The crew accepted this clearance.

The crew had arrived in Algiers via waypoint EPEPO a little over one hour previously. They therefore knew the general weather situation in the region and in particular in the ITCZ through which they were to pass again. It was also described in the items in the weather dossier received during the stopover in Ouagadougou. In addition, the crew had experience of flights crossing the ITCZ in the region. This also was the subject of regular exchanges among the crews of the airline based in Algiers. The crew was therefore aware of the difficulties involved in crossing the ITCZ, especially in terms of the risk of turbulence and icing.

The aeroplane took off at 01 h 15 and the initial climb took place without any particular incident.

Climb and avoidance of storm area

Thirteen minutes after take-off, as they climbed and passed FL215, the crew performed the first course alteration to the left to avoid a storm area located on their route and reported this to the Ouagadougou ACC to which they had just been transferred.
The engine anti-icing system had not been activated by the crew at that time. The total temperature was then greater than the one below which the anti-icing systems should be activated according to the FCOM. Even if the FCOM provides that they should be activated when icing conditions are expected, it is possible that the crew may have postponed the actual operation. In the absence of any usable CVR recording, the investigation was not able to determine if subsequent non-activation of anti-icing was due to an oversight or to a decision by the crew considering that the environmental situation did not require it.

There were no subsequent signs of activation of the anti-icing systems during the flight.

Thereafter, the changes in the aeroplane's heading made it pass along the western edge of the convective system in an area where ice crystals were likely present. The presence of supercooled water was however less likely, and as a result it is unlikely that the airframe was affected by icing.

The probable absence of signs of icing on the airframe, in particular on the windshield wipers, the possible lack of clear signs of ice crystals, which may be difficult to visually detect, especially at night, and which are usually not detectable on the weather radar, and the absence of significant turbulence probably did not encourage the crew to activate the engine anti-icing systems.

The airline does not indicate in its operations manual any minimum lateral distance for circumventing storm systems. Throughout the avoidance manoeuvre, the flight path shows that the aeroplane flew near the edge of the cloud system. It is probable that the management of the avoidance path was then a priority for the crew.

Levelling off, appearance of the EPR measurement error and deceleration on autopilot

At 1 h 37 min 28, the aeroplane levelled off at FL 310 at Mach 0.740. The autopilot then held the altitude and heading of the aeroplane, while its speed was controlled by the autothrottle. At the same time, the aeroplane was transferred to the Niamey ACC.

In this phase of flight, priority tasks of the crew would be to manage the flightpath to avoid weather hazards and to establish contact with ATC control centre while performing monitoring of primary flight parameters.

Within two minutes of levelling off, the speed of the aeroplane increased and the crew selected the cruise thrust regime on the TRP. The EPR values of the right engine became incorrect, probably due to the obstruction of the Pt2 pressure sensor of this engine by ice crystals. The autothrottle then adjusted the thrust to prevent the erroneous values from exceeding the EPR LIMIT in cruise setting. The thrust delivered by the engines was then lower than the thrust required for level flight, and the speed of the aeroplane continued to decrease.

For about one minute, the gap between the EPR values of the left and right engines gradually increased and then stabilized between 0.2 and 0.3 and the autothrottle switched to MACH ATL mode three times.

Fifty-five seconds after that of the right engine, the left engine's EPR also became erroneous and started to increase. Five seconds later, and for four seconds, this increase was interrupted by a decrease in both engines' RPM. This decrease could have resulted from the crew reducing the Mach target, or from a manual decrease in engine RPM by over-riding the autothrottle. That may therefore correspond to the crew becoming aware of an anomaly.

However, the information indicating the occurrence of an anomaly at that time was the gap between the left and right EPR values, and the intermittent appearance of the MACH ATL mode on the FMA, the speed of the aeroplane still being close to a nominal value in cruise. At that moment, these non-prominent elements,, whose interpretation is not straightforward, may not have led the crew to suspect a problem of insufficient thrust due to blockage of the Pt2 pressure sensors on both engines.

The engine RPM then increased again until the erroneous left EPR values reached EPR LIMIT. The thrust delivered by the engines remained lower than the thrust required in this phase of flight and the aeroplane continued to decelerate. About one minute later, that's to say two minutes after the appearance of the measurement error on the first engine, the aeroplane passed behind the power curve in thrust-drag ratio. The gap between the thrust required in level flight and the thrust actually delivered by the engines accentuated and the decrease in speed became more marked.

For about four minutes, the autothrottle was in MACH ATL mode, but the gap between the left and right EPR had decreased and their values were close to those expected in cruise. The N1 values were slightly lower than the typical cruise values (77% instead of 80 to 85%). The inconsistency between the EPR values and N1 values was therefore hardly noticeable to the crew, more so since the documentation they had did not have a table of correspondence between EPR and N1 and they had not been trained to monitor the correct correspondence between these two parameters. In addition, the crew were still avoiding the convective weather and in addition were busy trying to establish contact with the Niamey ACC. In fact, during this time, the crew tried to contact ATC eight times. Of these eight occasions, only two messages were received by the Niamey control centre[50].

During this period the aeroplane speed decreased from 278 kt to 213 kt. The Fast/Slow indicator on the PFD probably reached the lower stop and the attitude of the aeroplane increased by 4°, accompanied by aural warnings indicating movements of the THS. Although these elements were more perceptible and are not encountered during cruise flight at normal speed, they do not seem to have resulted in any reaction by the crew.

The representation of speed on the Mach-airspeed indicator means that up to 250kt, which corresponds to the first two minutes of deceleration, the loss of aeroplane speed caused very small movement of the needle. Even if the Mach number is indicated by three digits on the instrument, the general image of the dial corresponded to that expected by the crew in this phase of the flight.

It is likely that the crew workload involved in managing the circumvention of the convective weather and various attempts at establishing contact with the Niamey area control centre contributed to the lack of timely response to the decrease in speed, despite the visual and auditory information aimed at warning the crew.

The review of previous events showed that other MD80 crews had suffered significant losses of speed at altitude without detecting them.

The autopilot in altitude hold mode remained engaged and compensated for the decrease in altitude due to the speed decay by increasing the nose-up position of the trimmable horizontal stabilizer.

At 01 h 44 min 29, the crew reported to Niamey that they were at FL 310 on an avoidance manoeuvre. No other message from the crew was received by the Niamey area control centre.

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[50] Between the crew's transfer to the Niamey ACC and the end of the flight, in total 15 attempts at radio contact by the crew were recorded. Only two messages were received by the Niamey centre (see 1.11.2.5).

Approach to stall and stall

When the speed reached 210 kt, the position of the needle on the Mach-airspeed indicator was close to vertical. At that moment a quick reading of the instrument could have made it possible to detect inadequate speed. A prompt reaction consisting of putting the aeroplane in descent and increasing thrust to regain speed would be expected from a crew in this case.

Two variations in engine RPM caused by crew inputs on the throttle levers were observed. It is therefore possible that the crew at this moment suspected an EPR problem. In fact, these actions are consistent with the items in the "EPR erratic or fixed" procedure which recommends moving the throttle levers and observing the indications of the engine parameters. However this action alone does not correspond to the reaction expected of a crew in an approach to stall.

The autothrottle was disengaged between the first and second variations in the RPM. The speed was then 203 kt, the conditions of the "SPD LOW" display were met and it might have been displayed on the two FMAs. In this situation, this indication is expected to trigger a quick check of the flight parameters, the attitude and speed in particular.

The investigation could not explain the lack of reaction to the « SPD LOW » display. However, when this indication appeared, the crew was handling the radio messages with Niamey ATC control centre and making inputs on the throttles. The AP was still engaged.

The buffet phenomenon likely also appeared at the same time. Without usable CVR recordings, and taking into account available data, it was not possible to determine if the crew noticed and identified it, or whether they assimilated it as turbulence associated with avoiding the convective system.

When the speed reached 200 kt, the stickshaker triggered, followed three seconds later by the triggering of the stall warning.

From this time onwards, the captain’s side loudspeaker only broadcast the “STALL” warning, while that on the co-pilot’s side alternated the “STALL” warning with the other warnings that were active (altitude and THS movement, where applicable).

The triggering of the STALL warning would have called for the following corrective actions as provided for in the airline’s procedures in relation to stall:

- disconnection of the autopilot and autothrottle
- application of maximum thrust
- decrease in the angle of attack until the buffet stops.

The crew did not disconnect the autopilot and did not execute the stall recovery procedure.

Presumably they did not identify this critical situation.

In order to maintain altitude, the autopilot then commanded a continuous nose-up movement of the trimmable horizontal stabilizer and the elevators. This resulted in an increase in the angle of attack of up to 24°, or 13° above the stall angle of attack in the event conditions, as well as the broadcast of several “STABILIZER MOTION” warnings.

Both engines suffered a surge probably due to the aeroplane’s high angle of attack. Both engines rpm then decreased to values close to idle. This surge may have been noticed by the crew.

There was no sign of a reaction by the crew, other than the throttles movements, until the disconnection of the autopilot[51] which occurred 25 seconds after the triggering of the stickshaker. The speed was then 162 kt, the altitude had decreased by about 1,150 ft. The aeroplane was banking to the left and its pitch was decreasing. The crew applied input mainly to roll to the right to bring the wings level. At the same time, they applied mainly nose-up inputs, contrary to the inputs required to recover the stall and continued to do so until the ground.

In the current case, the environmental conditions, over the desert at night, deprived the crew of visual references to help them recover from this situation.

2.2 Procedures for Activation of Anti-icing Systems

The procedures described in the manufacturer's FCOM, adopted by the airline, constitute the main basis for the operational procedures that its crews must follow before and during the flight. They were initially developed by the manufacturer based on the results of the aeroplane's certification, in particular on the flight tests. They can subsequently be modified, based on regulatory, operational and technical developments, as well as on improvements and lessons learned from the analysis of events in service.

The FCOM procedures for protecting the engines and airframe against icing ("Airfoil Ice Protection Operation" and "Engine Anti-Ice on Ground and in Flight") indicate that icing conditions can exist when the total temperature (TAT) is less than 6°C and visible moisture is present or if ice build-up occurs on the windshield wipers or edges of the windshield.

The latter description, as well as performance considerations, may well encourage some flight crews to consider that the criterion of ice accretion on the windshield wipers or edges of the windshield can be used instead of the visible moisture criterion. They can thus be led to assess the risk of icing reactively.

Reports from two major airlines with wide MD80 experience show that some crews did not activate anti-icing systems in visible moisture conditions, in the absence of visible signs of icing. Other reports indicate that Pt2 icing may occur outside of visible moisture.

The wording “when visible moisture is present” can be ambiguous and subject to different interpretations, such as of the presence of the aircraft in clouds or not, the visual detection of clouds in the vicinity or the detection of echoes on the weather radar.

In the case of icing by ice crystals, experience shows that ice crystals do not adhere to external parts of the aeroplane, that they are difficult to detect with current on-board weather radars and not necessarily visible to the naked eye especially at night or at low concentrations. Feedback from some crews that experienced this type of in-flight icing is in line with this. The criterion of ice accretion on the windshield wipers is thus inadequate for an ice crystals environment. The visible moisture criterion, if it is interpreted as meaning “flight inside clouds” can also be inadequate for this situation.

In addition, the possibility of icing of the Pt2 pressure sensors is only described in the FCOM in the case of the EPR LIM engaged mode and only describes the consequences of Pt_2 icing in such cases in the climb phase.

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[51] The investigation was unable to determine if the disengagement of the AP was manual or automatic

These procedures also state that the warmer the air mass, the higher its water content and the more severe the icing conditions. They state that below -20°C, icing should be less severe. In the present case, the temperatures were below - 30°C, under which the water in the atmosphere is essentially present in the form of ice crystals, without the water content necessarily being very high. The procedure does inform flight crews that heavy icing has on occasion been reported at temperatures as low as - 60°C, but does not inform of the risk of Pt_2 icing due to ice crystals, which may not be clearly visible at low concentrations but may nevertheless alter Pt2 measurement when anti icing systems are not activated.

These are indications that the FCOM procedures for the protection of the engines and airframe against icing were developed from classic icing phenomena (the formation ice resulting from the impact of supercooled water droplets), the only type of icing taken into consideration in the context of the certification of the aeroplane. These procedures are not adapted to icing by ice crystals to which Pt2 pressure sensors are sensitive.

As a result, under the current FCOM procedures, crews, although aware of the classic risks of icing, may not be aware of the warning signs (or lack thereof) associated with icing by ice crystals, and may ignore the possibility of the potential obstruction of the Pt2 pressure sensors and the associated consequences in cruise.

2.3 Approach to Stall and Recovery

During the initial phase of falling speed, the autopilot has no protection to prevent the speed from dropping below a speed that would guarantee adequate margin in relation to a stall. Correcting this initial speed decrease thus depends on attentive monitoring of this parameter by the crew and taking into account the visual and aural indications provided: air speed indicators, Fast/Slow indicator on the PFD, MACH ATL display on the FMA and PHR aural warning.

The study of similar approach to stall events on MD80 type aeroplanes shows that these safety barriers can be crossed. In fact several of these crews were not aware of the degraded situation of the flight before the triggering of the stall warnings.

On MD80 type aeroplanes, if the speed continues to decrease, the buffet and stick-shaker alert the crew to the approach to stall and represent the last safety barriers before the stall, the stall warning being designed as an additional device to assist in stall recognition.

Data from flight tests at high altitude show that the buffet and stick-shaker appear with small margins in relation to the stall, lower than the 7% criteria called for in the certification requirements. No explanation has been found on the rationale for accepting this lower margin.

Recovering this situation thus depends on a prompt and appropriate reaction by the crew to their activation, in particular with the disengagement of the autopilot and the auto-throttle.

Without any disengagement by the autopilot, the latter tries to keep its target. If it is in altitude hold mode, as is the case in cruise, the autopilot gives nose-up orders that are contrary to those required to recover the stall. After the triggering of the stall warnings such orders, by maintaining the aeroplane's pitch and by increasing the angle of attack and the nose up position of the horizontal stabilizer, rapidly make the situation worse, as well as the difficulty of recovery for the crew. In fact, these nose-up orders mask or delay the occurrence of a nose down movement which for the crew would constitute the ultimate indication of entering the stall, and make it necessary for the crew to apply a stronger and sustained nose-down input to recover from the stall. The FOB published by Boeing indicates that the aeroplane can slow down until the stall warning before the autopilot disengages. It does not however state that the autopilot may continue to give nose-up orders after the stall warning and does not indicate the consequences of this behaviour in terms of detection of and recovery from the stall.

The crew was not trained to immediately take back manual control and perform a recovery procedure, including under the startle effect. On the contrary, the operator’s pilots were trained for this type of exercise by causing an approach to stall and a stall by disengagement of the autopilot, with reduction in thrust and manual input on the THS control. Furthermore, the specific qualities of the MD80 in relation to the late triggering of the stall warnings in cruise and the absence of automatic disengagement by the autopilot are not sufficiently brought to the operators' attention and are not integrated in the crew training programmes.

However, in cruise, the following factors might explain the absence of immediate manual autopilot disengagement as a reaction to the triggering of the stall warnings:

- in case of startle effect, the desire to understand the situation before undertaking the recovery procedure, considering that the high altitude of the aeroplane and the engagement of the autopilot would ensure some safety;
- hesitating to take back an unusual and little practised manual procedure in this phase of flight.

The engaged autopilot may have contributed to the crew's lack of reaction to the triggering of the stall warnings during the accident.

Training is crucial in relation to stalls because a flight crew, during their career, is rarely exposed to an approach to stall, even less so to a stall during an actual flight. The date of the crew's last training on approach to stall and recovery there from could not be determined. It was in any case prior to their arrival at Swiftair and was thus not recent.

2.4 SAR

The crew’s last radio communication with the Niamey ACC took place at 01 h 44 min 28. The accident occurred at 01 h 47. The wreckage was found at 18 h 23. This means that more than 16 hours passed between the disappearance of the aeroplane and its being located.

In the present case, the delays in its location had no consequence, since the violence of the impact left no chance of survival for the occupants of the aeroplane. However the investigation team sought to identify the dysfunctions that led to delays in the conduct of SAR operations

This accident is distinctive in that it took place in a complex environment, on the border of three countries and in a conflict zone. Moreover, flight AH5017 was under control from the Niamey ACC, which only had intermittent radar contact and had established only one real radio contact.

The controllers at the Niamey ACC knew from experience that aeroplanes flying west of the EPEPO - GAO – MOKAT route may be out of radio and radar range. They then expected the aeroplane's radar plot to reappear at MOKAT. This delayed awareness of the disappearance of flight AH5017 and therefore the triggering of the emergency phases by the Niamey ACC.

The first ALERFA message was only sent to the Algiers ACC, destination of flight AH5017. By failing to send this message to the neighbouring ACCs, including the Ouagadougou ACC, the Niamey ACC deprived itself from obtaining information quickly about the last position of the aeroplane. A lack of practice at the Niamey ACC by the various staff both in the use of the technical means and the implementation of the SAR emergency procedures may explain this omission.

The SAR coordinator of the Niamey RCC, the only member of staff available at the RCC during this period, defined a search area based on the same information he received that was transmitted successively by the various staff members of the air traffic control and SAR agencies indicating a loss of contact with the aeroplane after passing waypoint GAO at 01 h 55. Some ambiguity in the exchanges suggests that this loss of contact was a loss of radar contact, while it was in fact a loss of radio contact. This may have led the SAR participants to remain convinced of the relevance of the initial search area, defined between GAO and MOKAT.

This area proved to be inaccurate.

When taking into account the estimated position of the accident, the SAR coordinator did not take the initiative to corroborate and validate this information. The Niamey RCC could have benefited from a radar playback at the Niamey ACC. Similarly, contact with neighbouring SAR organizations would have allowed, through the Ouagadougou RSC, the latest radar plots from Ouagadougou to be available, on which the aeroplane’s decreasing speed and its disappearance can be observed. This could have allowed the SAR coordinator, if he had received this information, to specify the contours of the search area. In fact the localisation of the probable accident area, defined between GAO and MOKAT, thus further north of the actual accident zone, was only questioned when the Ouagadougou crisis management team was able to read out the Ouagadougou RCC radar data.

2.5 Feedback

Based on the various reported events, the investigation shows that several crews reactions to speed decrease, similar to the one observed in this accident, were triggered by detecting the speed decrease itself or following the activation of the approach to stall warnings (buffet, SSRS, stick shaker). Crews, though made aware of the risks of classic icing, can be unaware of the precursor signs (or their absence) associated with icing through ice crystals, and be unaware of the possibility of obstruction of the PT2 pressure sensors and their related consequences in cruise.

The accident to flight AH5017 shows that the dissemination of information published by the manufacturer, the civil aviation authorities and the investigating authorities did not result in sufficient assimilation by operators and crews of the specific features of the MD-80 in case of icing of the PT2 sensor by ice crystals and an approach to stall at high altitude. The fact that the operator had no criteria in its flight analysis at the time of the event for detecting the decrease in cruise speed at high altitude confirms this shortcoming.

The risk associated with PT2 sensor icing was known to the manufacturer and the oversight authority. Certain operators knew of this risk and were collecting icing-related cruise speed reduction events. One of them had taken the initiative to build a table of correspondence between the EPR and N1 values that is easily accessible in the cockpit.

Use of the feedback system is increasing among operators, aimed at various services, and at front-line operators in particular. This type of "vertical experience feedback" system is becoming increasingly effective but nevertheless remains compartmentalized at the operator level. Numerous other "horizontal experience feedback" initiatives are being set up between operators through symposia and associations, in order to share the feedback and contact the entire aviation community. At this stage, and taking into account the facts of this investigation, this type of system does not yet seem to be effective or accessible enough to all of the operators in order to warn their crews. The fact that the MD80 is an aeroplane operated by a diminishing number of operators has not facilitated the development of such horizontal feedback on the specific features of this aeroplane.

3. CONCLUSION

3.1 Findings

- The aeroplane took off from Ouagadougou bound for Algiers with 116 people on board with no known technical problems.
- The crew held the licences and ratings required to carry out the flight.
- The aeroplane had a valid airworthiness certificate.
- The aeroplane weight and balance was within operating limits.
- The meteorological situation was what could be expected at that time of the year in the intertropical convergence zone.
- A CVR malfunction that preceded the event flight prevented it from producing a useable recording of the noises and conversations in the cockpit. The crew could not detect this malfunction during the pre-flight test. The malfunction occurred after the last maintenance action where it could have been detected.
- During climb to FL310, the crew made some heading changes to avoid cloudy areas, which led it to fly on the edge of a convective cloud system.
- The route chosen led to them flying in an area where the presence of ice crystals was likely.
- The anti-icing systems had not been activated during aeroplane climb and the cruise phases during which the autothrottle was in MACH ATL mode.
- When levelling off, the autopilot went into altitude and heading hold mode while the speed was piloted by the autothrottle in MACH mode.
- The EPR values of the right engine then the left engine became erroneous probably following the obstruction of the Pt2 pressure sensors by ice crystals.
- These erroneous EPR values caused the autothrottle to limit the thrust produced by the engines to a level lower than the thrust required to maintain FL310.
- About two minutes after levelling off, the aeroplane speed started to decrease.
- The autopilot offset the speed decrease by increasing the aeroplane flight attitude to maintain altitude.
- After the transfer of flight AH5017 to the Niamey ACC, radio contact with the aeroplane was not immediately established. Flight RAM543K, flying in the same sector, acted as a relay between flight AH5017 and Niamey ACC.
- Between the transfer of the crew to the Niamey ACC and the end of the flight, 15 attempts at radio contact were recorded on the FDR. Only two messages were received by the Niamey ACC.
- The Niamey ACC heard the crew of flight AH5017 saying that they were at FL310 and undertaking an avoidance manoeuvre.
- The Niamey ACC received no other message from the crew after that.
- Two EPR fluctuations of strong amplitude caused by crew input on the throttle levers were observed. The autothrottle disengaged between these two variations, and the aeroplane started to descend. At the same time, the last activation of the VHF, 4 seconds long, was recorded on the FDR.
- When the aeroplane speed reached 203 kt, vibrations attributed to buffet appeared.

- Four seconds later, when the aeroplane's speed was 200 kt, the stickshaker activated, followed three seconds later by the stall warning. At that time, the aeroplane reached the 12° stall angle of attack.
- Both engines suffered a surge due to the aeroplane's high angle of attack.
- The autopilot disengaged about 22 seconds after the triggering of the stall warning. The aeroplane angle of attack had then reached approximately 25°. There was no apparent crew action between the stall warning activation and the autopilot disconnection.
- During the aeroplane's fall, its pitch attitude and bank changed significantly. The aeroplane continued to pitch down with a left bank angle down to the ground. During this flight phase, the control surfaces remained mainly deflected pitch up and in the direction of a bank to the right. When the elevators were commanded close to the neutral position, around 27 seconds before the impact, the stickshaker and stall warning system intermittently deactivated and the engines resumed normal operations.
- No problems were mentioned by the crew during their contacts with the Ouagadougou and Niamey air traffic controllers.
- No distress message was received by the control centres.
- The last recorded values were a 58° pitch-down attitude, a 10° bank to the left and a calibrated airspeed of 384 kt.
- The emergency DETRESFA phase was triggered at 04 h 38.
- The wreckage was recovered at 18h23.
- The crew had not received any training relating to approach to stall and recovery from it since joining Swiftair. The investigation could not determine how far back their last training on these points took place.
- During simulator training, the approach to stall is performed manually by the crew after disengagement of the autopilot.
- The stickshaker and stall warning initiation speeds on the airline's simulator are values lower than those calculated for the accident flight.
- The FCOM procedures relating to engine or airframe icing do not mention the characteristics of icing by ice crystals, and are thus not adapted to the specifics of this type of icing.
- The phenomenon of obstruction of the Pt2 pressure sensors due to icing is only described in the FCOM in the climb phase
- The stall warning devices triggered at high altitude with a speed margin below the 7% mentioned in the certification regulations. These specific features were not brought to the attention of operators.
- The autopilot remained engaged beyond the triggering of the stall warning devices and the stall. This specific feature, and its consequences on the detection of and recovery from a stall, is not explicitly detailed in the manufacturer's FOB, the only documentation supplied to operators on this point.

3.2 Causes

The aeroplane speed, piloted by the autothrottle, decreased due to the obstruction of the pressure sensors located on the engine nose cones, probably caused by ice crystals. The autopilot then gradually increased the angle of attack to maintain altitude until the aeroplane stalled. The stall was not recovered. The aeroplane retained a pitch-down attitude and left bank angle down to the ground, while the control surfaces remained mainly deflected pitch up and in the direction of a bank to the right. The aeroplane hit the ground at high speed.
The accident was the result of a combination of the following events:

- the non-activation of the engine anti-icing systems
- the obstruction of the Pt2 pressure sensors, probably by ice crystals, generating erroneous EPR values that caused the autothrottle to limit the thrust produced by the engines to a level below that required to maintain the aeroplane at FL310.

- the crew's late reaction to the decrease in speed and to the erroneous EPR values, possibly linked to the work load associated with avoiding the convective zone and communication difficulties with air traffic control.
- the crew's lack of reaction to the appearance of buffet, the stickshaker and the stall warning.
- the lack of appropriate inputs on the flight controls to recover from a stall situation.

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

- The FCOM procedure relating to the activation of the anti-icing systems that was not adapted to Pt2 pressure sensor obstruction by ice crystals
- Insufficient information for operators on the consequences of a blockage of the Pt2 pressure sensor by icing
- The stickshaker and the stall warning triggering logic that led these devices to be triggered belatedly in relation to the aeroplane stall in cruise;
- the autopilot logic that enables it to continue to give pitch-up commands beyond the stall angle, thereby aggravating the stall situation and increasing the crew's difficulties in recovery.

The absence of a usable CVR recording limited the possibility of analysing the crew's behaviour during the flight.

Specifically, it was not possible to study CRM aspects or to evaluate the possible contribution of the employment context and the experience of the crew members.

4. SAFETY RECOMMENDATIONS

4.1 Recommendations issued during previous investigations and relevant to the analysis of the accident to flight AH5017

4.1.1 Accident on 16 August 2005 to the DC-9-82 (MD-82) operated by West Caribbean Airways

The investigation recalls that the Venezuelan authorities, at the end of the safety investigation, had recommended that:

- 058/2005-AA2: the aviation authorities require the inclusion in flight crew training of recovery from high-altitude stalls. This is justified on the grounds that in simulator training, low-altitude stalls are induced, from which the aircraft can recover more quickly, because it can increase power in order to maintain altitude, whereas at high altitudes, the behaviour of aircraft is different, calling for more precise manoeuvres in terms of time of execution.

- 058/2005-AA5: In those countries in which there are air operators certified to operate MD-80 series aircraft, they increase and optimise the requirements in the flight crew programmes in the presence of buffeting at high altitudes, and also those with regard to the various configuration modes for the autothrottle system (ATS), the anti-ice system, and the monitoring of altitude and speed and their relation to aircraft power status.

- 058/2005-ODF1: Boeing study the possibility of designing a new algorithm or of reviewing (with a view to improving) the existing algorithms in these aircraft or systems which trigger alerts or warnings so that they provide sufficient time for flight crew, firstly to recognise in good time aural and/or visual indications of any abnormal or hazardous situation, and secondly also to react in time to such signals or warnings and then carry out a rapid and appropriate analysis and decision-making process. In this particular case, the present Civil Aviation Accident Investigation Board suggests that an additional warning, both aural and visual (e.g. lights and a voice saying "Warning: Performance", "Warning: Performance Conflict", etc.), in what is determined to be sufficient time, could alert the crew and put it in a state of situational awareness in a more appropriate manner, and initiate more timely corrective action in order to avert this type of accident. We therefore recommend analysis of the inclusion of an additional audio-visual warning appropriate to the situation detailed here and to the causal factors of this accident.

4.1.2 Serious incident on 4 June 2002 to the DC-9-82 (MD-82) operated by Spirit Airlines

The investigation recalls that the NTSB, at the end of the safety investigation, recommended that:

- A-04-034: the FAA issue a flight standards information bulletin to principal operations inspectors to alert all affected air carrier flight crews about the icing situation encountered by Spirit Airlines flight 970 and to emphasize the need to maintain vigilance for the signs of high altitude icing conditions, the effect these conditions can have on airplane and engine performance, and the need for the appropriate use of the engine anti-ice system.

- A-04-035: the FAA actively pursue research with airplane and engine manufacturers and other industry personnel to develop an ice detector that would alert pilots of air inlet pressure sensor icing.

4.1.3 Accident on 1 June 2009 to the Airbus A330-203 operated by Air France

The investigation recalls that the BEA, at the end of the safety investigation, recommended that:

FRAN-2012-032: ICAO ensure the implementation of SAR coordination plans or regional protocols covering all of the maritime or remote areas for which international coordination would be required in the application of SAR procedures, including in the South Atlantic area.

4.2 Interim Recommendations

The investigation confirmed that at the time of writing, documentation such as the AFM (Aircraft Flight Manual) does not contain specific procedures to enable crews, from the indicated engine parameters, to rapidly highlight a situation of EPR inconsistency resulting from an obstruction of the nose cone pressure sensor. Detection of this inconsistency would enable flight crews to react before the aeroplane came dangerously close to a stall situation.

Thus the Commission d'Enquête sur les Accidents et Incidents d'Aviation Civile du Mali and the BEA recommended that:

- the FAA, as primary certification authority, or if not, EASA, require a modification MD80 type flight manual to :

  - draw crews' attention to the risks linked to possible icing of the PT2 pressure sensor at cruise altitude including where there are no visible signs of icing, specifically when the engine anti-icing system is not activated. [Recommandation MLI-2015-002] [Recommandation MLI-2015-003] [Recommandation FRAN-2015-014] [Recommandation FRAN-2015-015]

  - provide them with the means to rapidly detect an erroneous EPR indication and to remedy it. [Recommandation MLI-2015-004] [Recommandation MLI-2015-005] [Recommandation FRAN-2015-016] [Recommandation FRAN-2015-017]

- that the FAA and EASA study the need for similar action for other aeroplanes equipped with engines using the same thrust management principles.
  [Recommandation MLI-2015-006] [Recommandation MLI-2015-007]
  [Recommandation FRAN-2015-018] [Recommandation FRAN-2015-019]

4.3 New Safety Recommendations

4.3.1 Anti-icing protection devices

In accordance with the current FCOM procedures, crews, though made aware of the risks of classic icing, can be unaware of the precursor signs (or their absence) associated with icing through ice crystals, and be unaware of the possibility of obstruction of the PT2 pressure sensors and their related consequences in cruise. Due to the impact of the engine anti-icing system on the performance of the MD80 in cruise, crews may be tempted only to activate the anti-icing system when they expect to encounter icing conditions. Icing of the PT2 sensor can occur, when the anti-icing devices are not activated, in the absence of any other sign of icing on the airframe or on the windshield wipers or the engines, even in situations of low concentration of ice crystals which may not be readily visible, and may not be detectable on the weather radar

Consequently the Commission d'Enquête sur les Accidents et Incidents d'Aviation Civile du Mali and the BEA recommend that:

- **the FAA ask the manufacturer to study the feasibility of installing of a permanent anti-icing system for the PT2 sensors, independent of any activation by the crew of existing anti-icing systems for the engines or the airframe. existants d'antigivrage des moteurs ou de la cellule.**
  [Recommandation MLI-2016-001] [Recommandation FRAN-2016-022]

- **pending the introduction of such a system, the FAA require that the manufacturer's FCOM procedures related to "Engine Anti-Ice on Ground and in Flight" mention the difficulties of ice crystals detection in particular at night and define clearly the associated criteria for the anti-icing systems activation. This may require the systematic activation of these systems in flight as soon as the total temperature is below 6°C, without taking into account the criteria of visible humidity or signs of ice accretion on the windshield wipers.**
  [Recommandation MLI-2016-002] [Recommandation FRAN-2016-023]

4.3.2 Stall in cruise on MD80 type aeroplanes and associated training

On the MD 80 buffet may appear late and may not be clearly noticeable. In addition, the stall warning systems such as the stick shaker and the stall warning in cruise are triggered in flight with a warning period that leaves little or no time for the crew to react before stall actually occurs. Further, the autopilot can remain engaged until a true stall and even beyond, which then aggravates the stall situation and increases the difficulty of recovery by the crew.
Test on a training simulator suggest that simulators may not be sufficiently representative as regards to the triggering of approach to stall warnings.

Consequently the Commission d'Enquête sur les Accidents et Incidents d'Aviation Civile du Mali and the BEA recommend that;

- **the FAA require that the manufacturer integrate into the documentation provided to operators the specific features of a stall in cruise on MD 80 type aeroplanes, linked to the late appearance of buffet, of the stick shaker and of the stall warning and with the non-automatic disengagement of the autopilot after the stall warning. [Recommandation MLI-2016-003] [Recommandation FRAN-2016-024]**

- **the FAA and EASA require that these specific features of MD 80 type aeroplanes be taught during type rating and recurrent crew training. [Recommandation MLI-2016-004] [Recommandation MLI-2016-005] [Recommandation FRAN-2016-025] [Recommandation FRAN-2016-026]**

- **the FAA ensure that the data made available by the manufacturer Boeing for the design of MD80 simulators be representative as regards the triggering of approach to stall warnings and the non-disengagement of the autopilot after the stall, at low altitude and at cruise level. [Recommandation MLI-2016-006] [Recommandation FRAN-2016-027]**

- **the FAA and EASA ensure the simulators used for training MD80 crews be representative of the triggering of approach to stall warnings, and the non-disengagement of the autopilot after the stall, at low altitude and at cruise level. [Recommandation MLI-2016-007] [Recommandation MLI-2016-008] [Recommandation FRAN-2016-028] [Recommandation FRAN-2016-029]**

- **the FAA require that the manufacturer Boeing studies the feasibility of a modification of the autopilot's engagement logic to allow automatic disengagement when the approach to stall is detected by the MD80 systems. [Recommandation MLI-2016-009] [Recommandation FRAN-2016-030]**

4.3.3 CVR

The pre-flight test performed by crews does not make it possible to detect the two major malfunctions of the CVR in this accident: the failure of the erase function and the failure to record cockpit sounds on the CAM. These two malfunctions deprived the safety investigation of essential information to understand the event and to make recommendations to improve flight safety.

A CVR maintenance check is performed at each type C check, every 3,600 flying hours or every 15 months at the latest. This procedure allows a malfunction of the erase function to be detected but does not check a failure to record cockpit noises on the CAM track.

In addition, ICAO Annex 6 relating to technical operation of aircraft states that magnetic tape CVRs shall no longer be used after 1 January 2016 for international commercial air transport activities.

Nevertheless, pending the enforcement of these provisions in national or European regulations, the Commission d'Enquête sur les Accidents et Incidents d'Aviation Civile du Mali and the BEA recommend that;

- **the FAA ensure that the maintenance check procedure for CVRs on MD80 type aeroplanes is modified by the manufacturer in order to ensure that all of the recording tracks are tested, including the CAM track. [Recommandation MLI-2016-010] [Recommandation FRAN-2016-031]**

- **the FAA and EASA ensure that this modification is implemented by the operators concerned. [Recommandation MLI-2016-011] [Recommandation MLI-2016-012] [Recommandation FRAN-2016-032] [Recommandation FRAN-2016-033]**

4.3.4 SAR

The investigation showed that there was no coordination between the Niamey RCC and the Ouagadougou and Bamako RSC, whose areas of responsibility bordered on the accident area.

Inadequate resources and a lack of practice at the Niamey RCC meant that rapid integration of available information was not possible.

Consequently the Commission d'Enquête sur les Accidents et Incidents d'Aviation Civile du Mali and the BEA recommend that;

- **the national authorities of Niger, Burkina-Faso and Mali put in place coordination plans and ensure that their effectiveness is validated by regular exercises. soit validée par des exercices réguliers.[Recommandation MLI-2016-013] [Recommandation MLI-2016-014][Recommandation MLI-2016-015] [Recommandation FRAN-2016-034][Recommandation FRAN-2016-035] [Recommandation FRAN-2016-036]**

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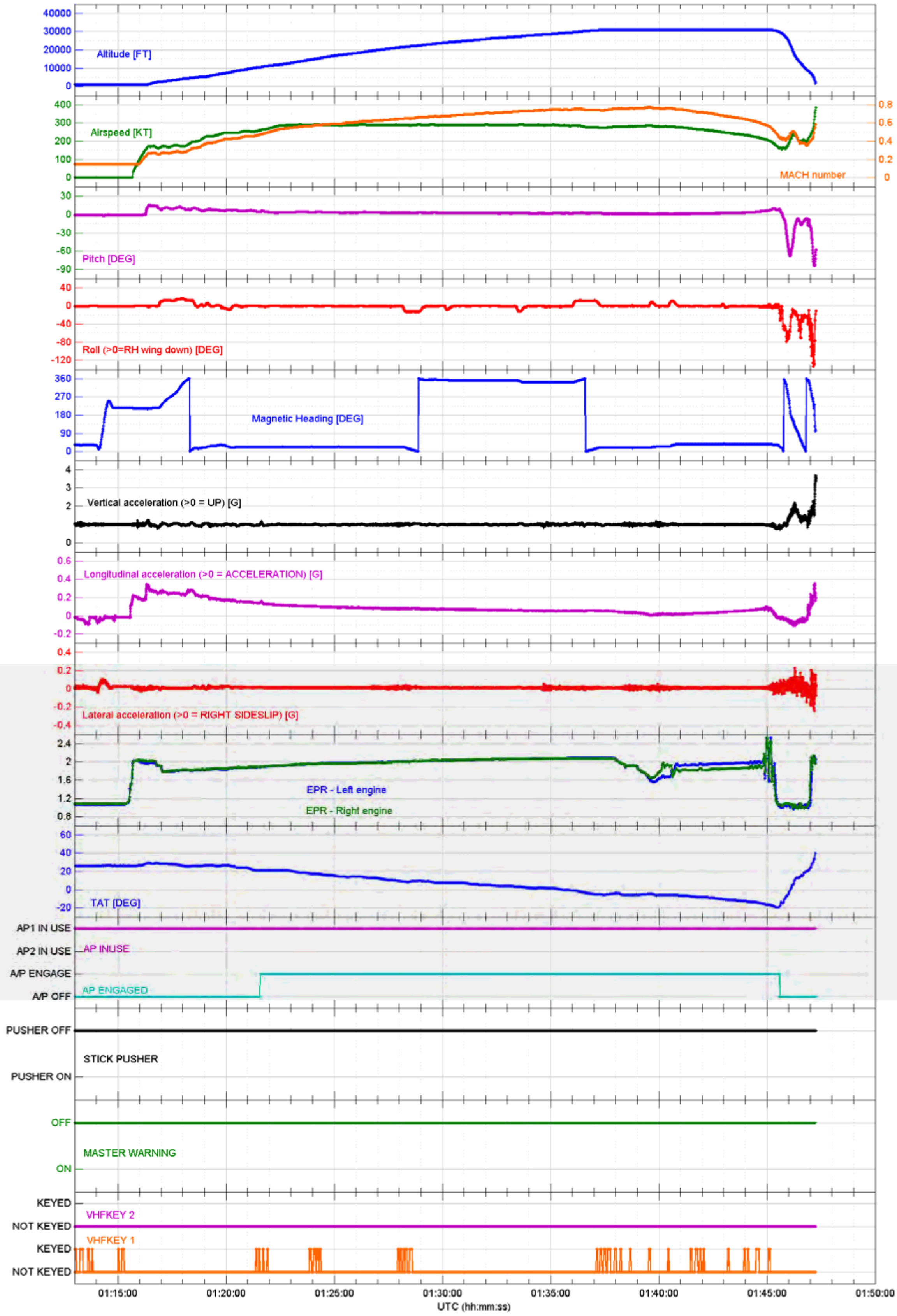
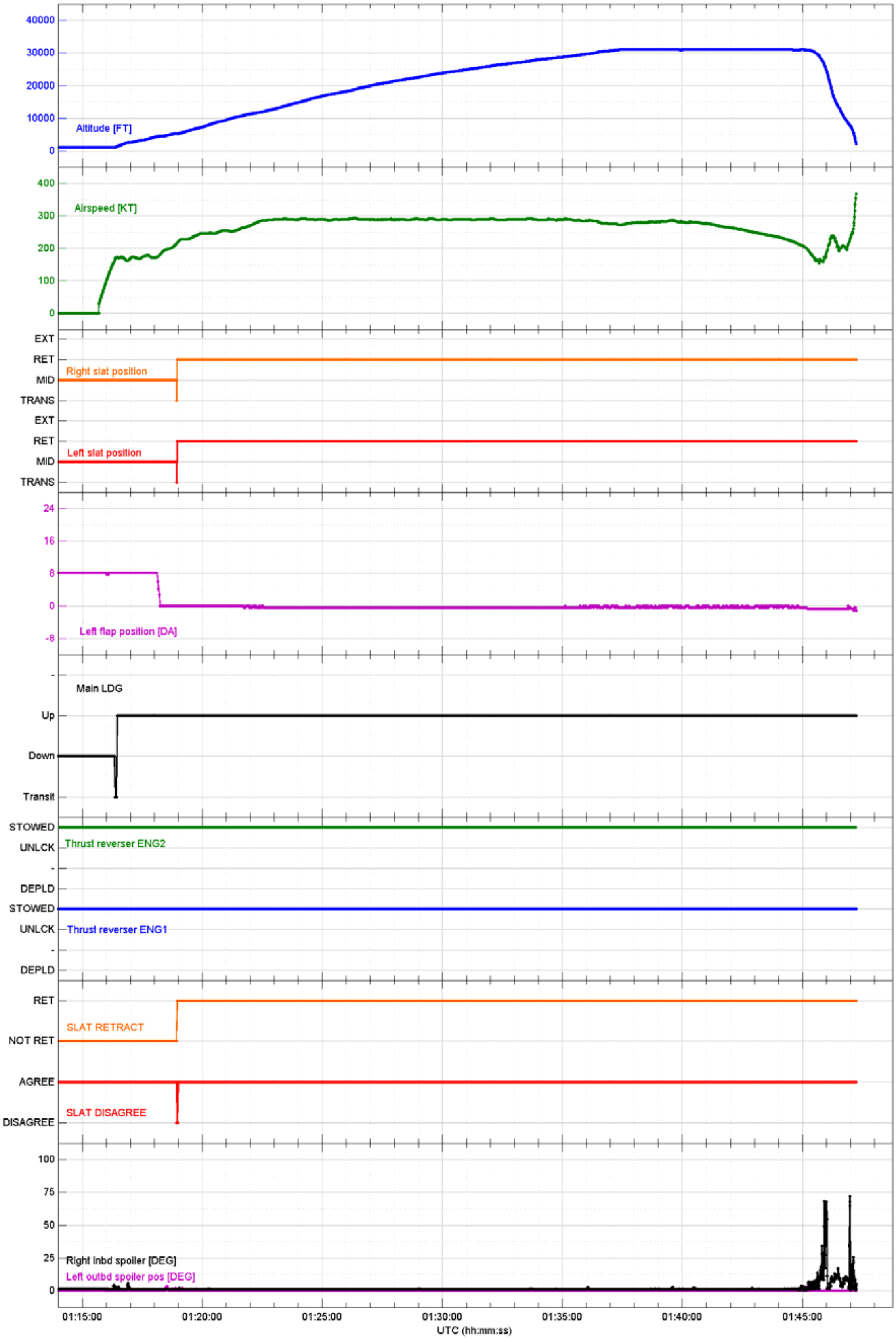
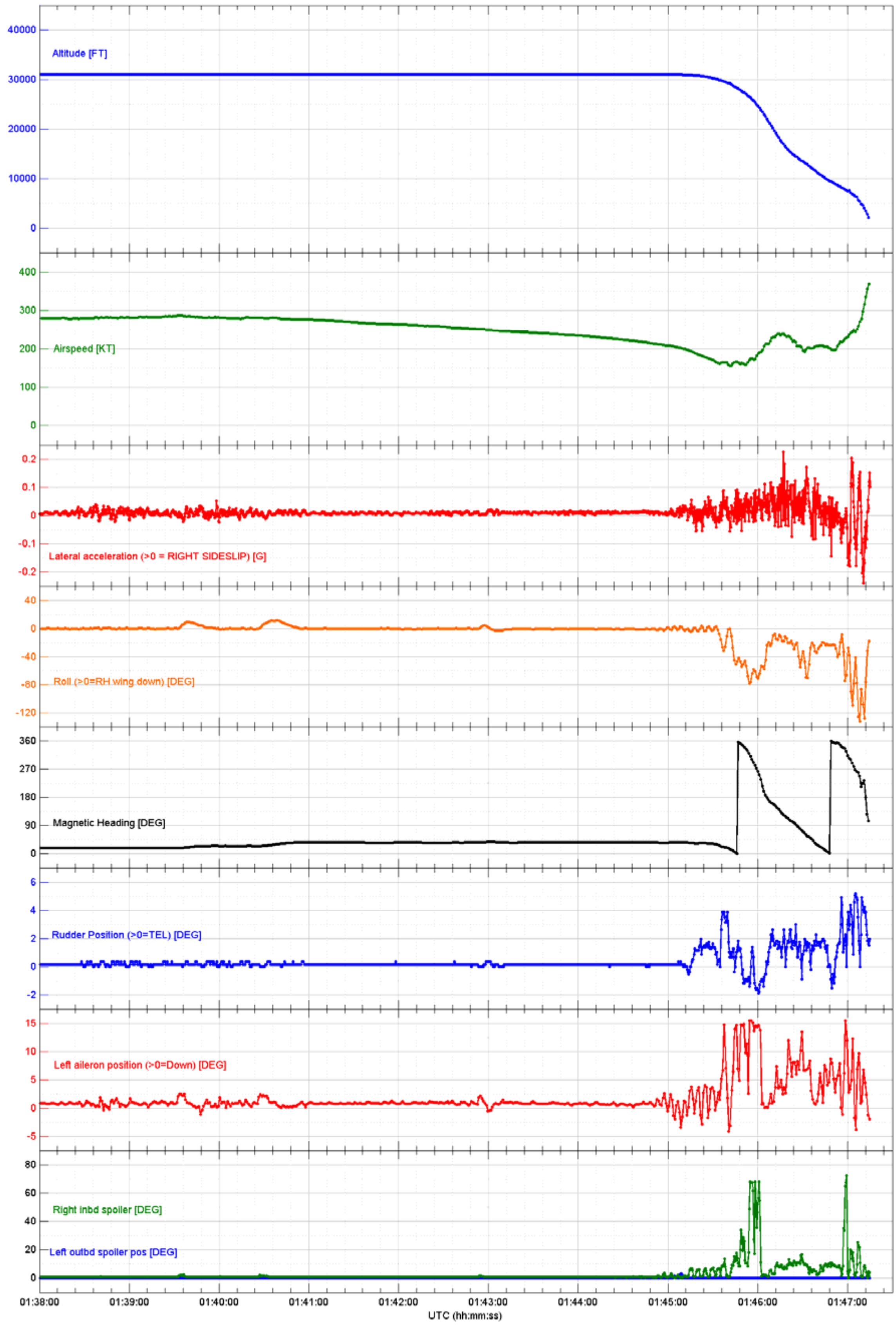
APPENDIX 1
FDR PARAMETERS



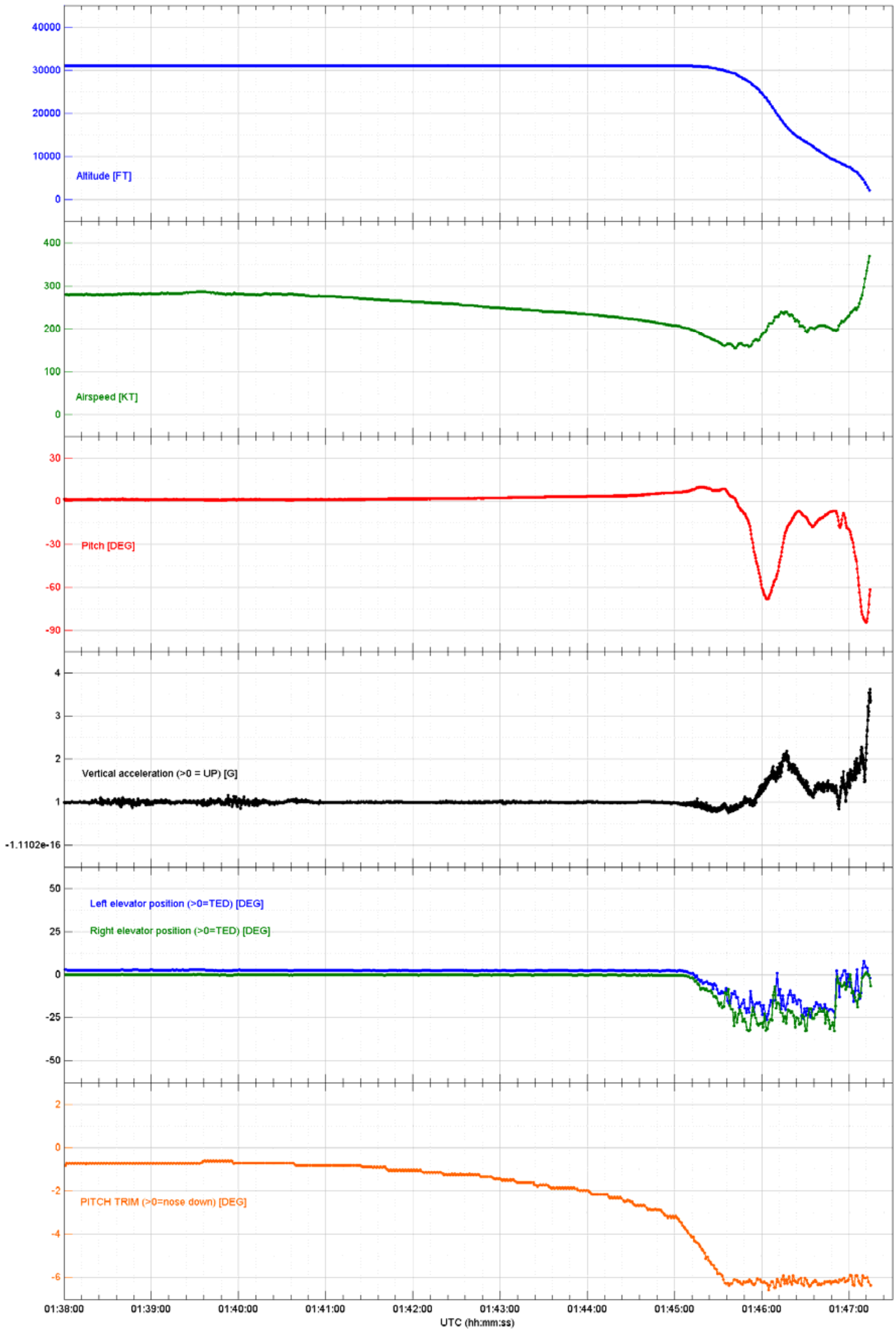
General Parameters



Aeroplane Configuration



Lateral Parameters



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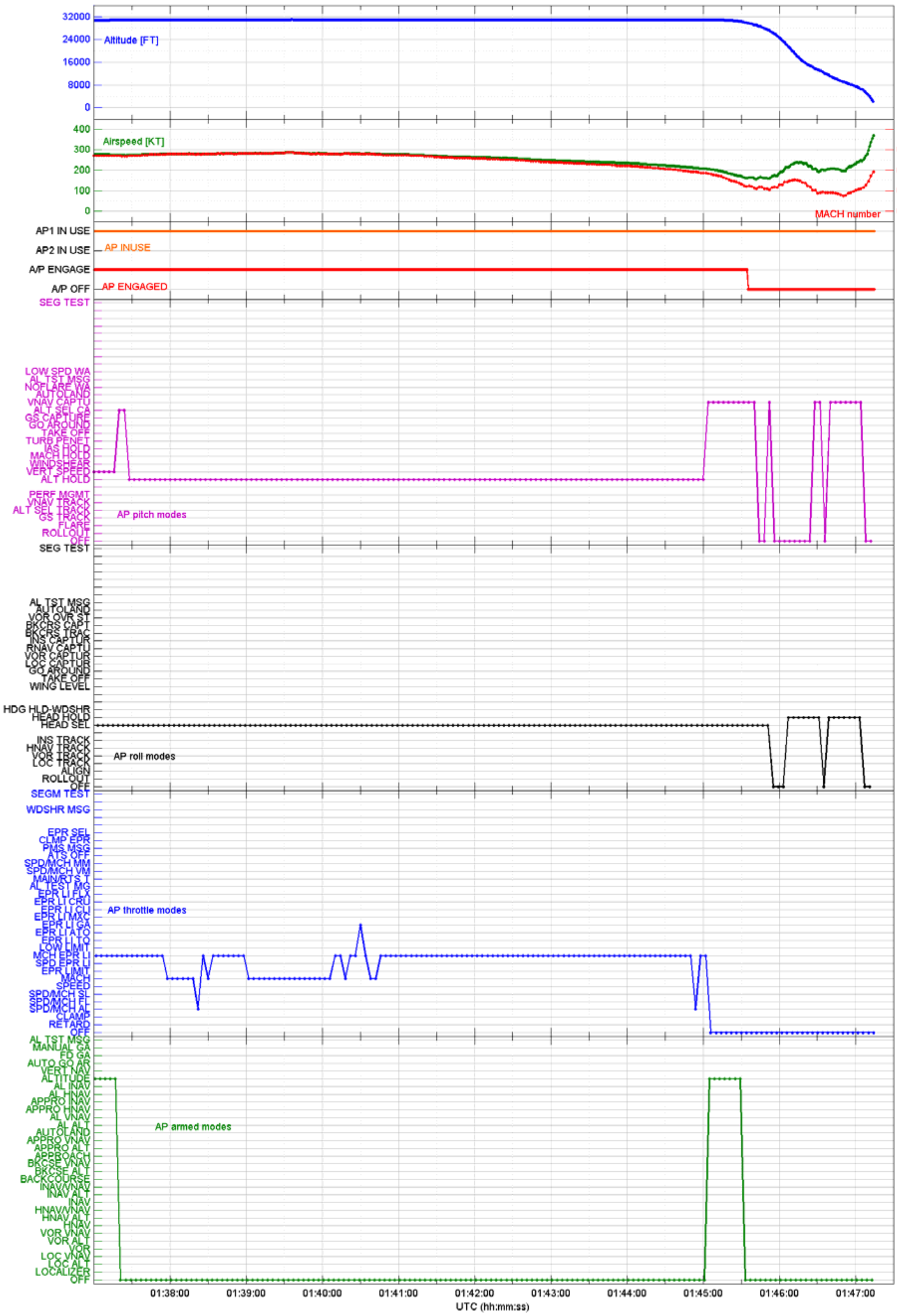
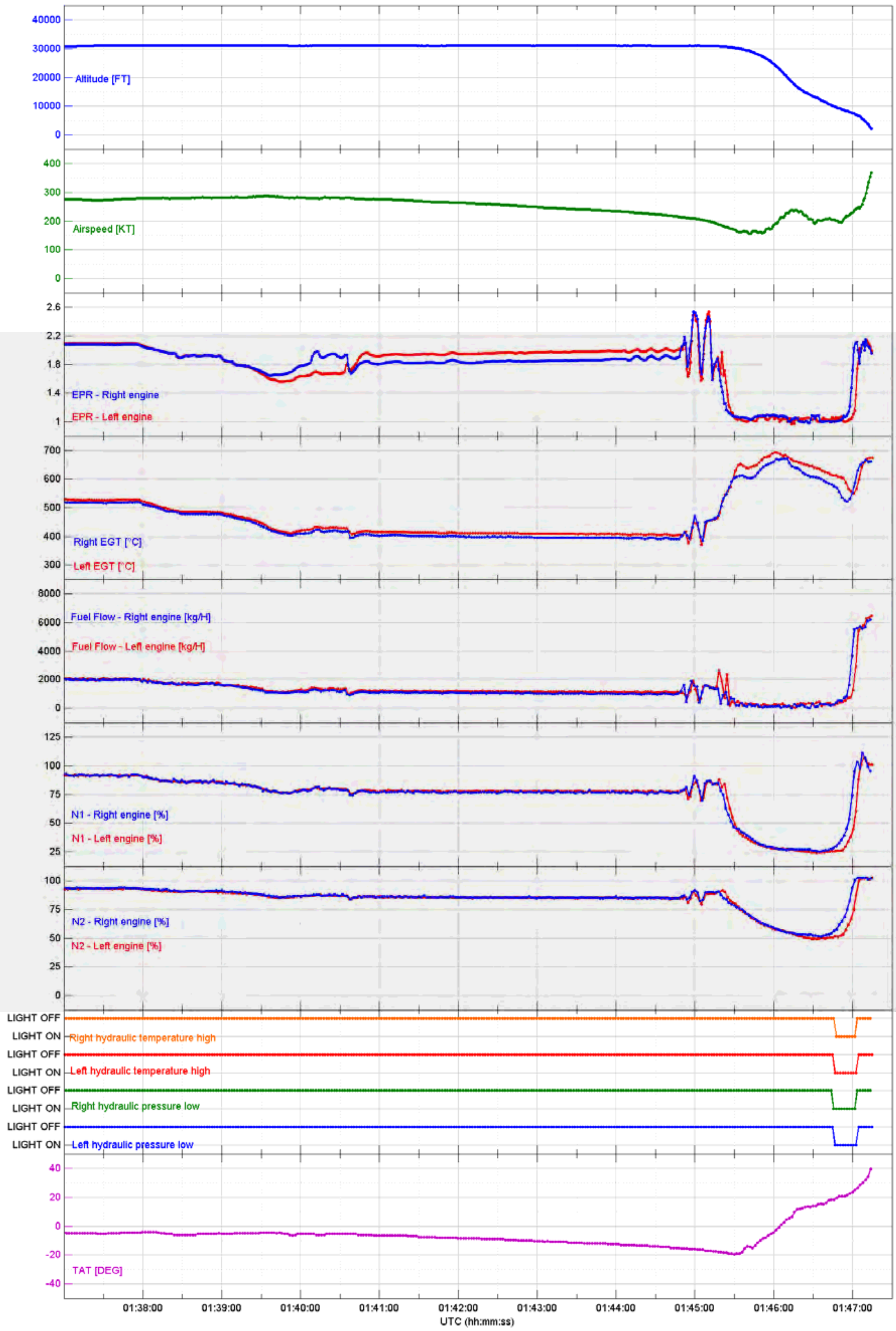
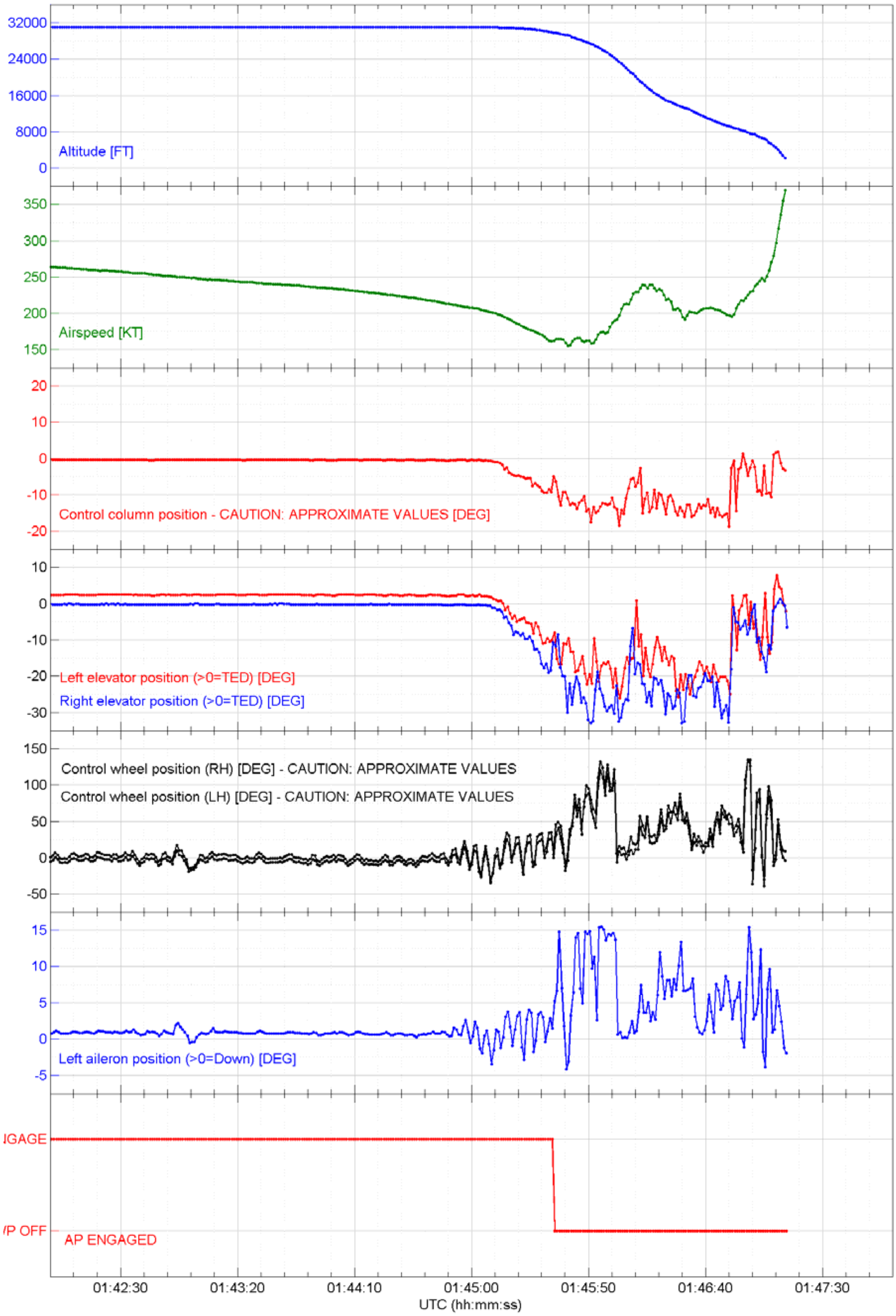


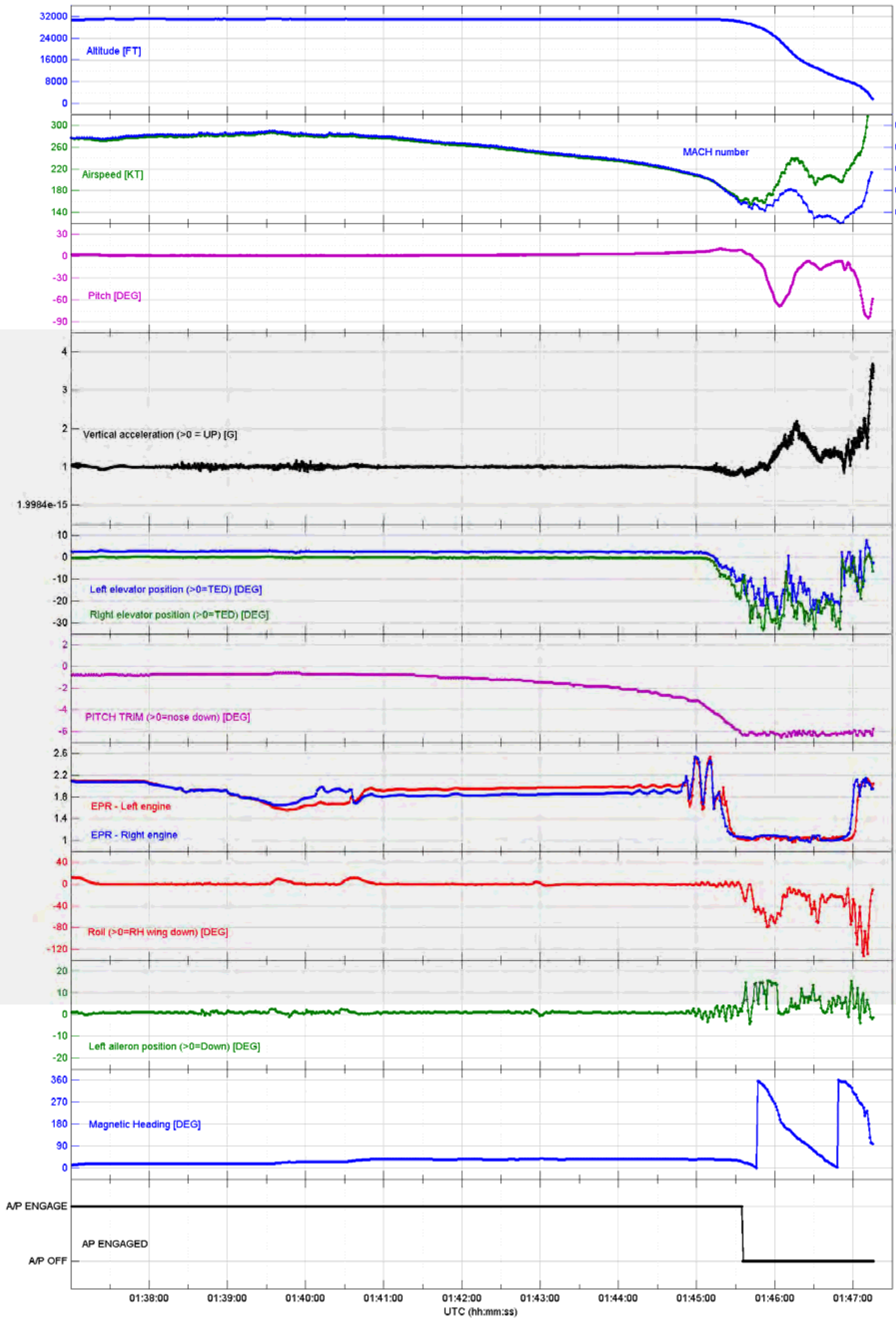
Automatic Systems



Engine Parameters



Flight Controls



Summary Graph

APPENDIX 2
TRANSCRIPT OF ATC COMMUNICATIONS FROM OUAGADOUGOU ATC SERVICES

FOREWORD

The following is the transcript of the elements which were understood during readout of the radio communications and ATC recordings.
The reader's attention is drawn to the fact that the ATC recording and transcript give only a partial reflection of events. Consequently, the utmost care is required in the interpretation of this document.
Note: The UTC times given are synchronised with the aeroplane's FDR.

GLOSSARY

Temps UTC	Universal Time Coordinated
[xxx]	Controller on the frequency used (For example: [TWR] for tower).
#xxx#	Conversation between two control centres
( )	Word or group of words in parentheses could not be determined with certainty
(*)	Word or group of words not understood

UTC time	Speaker	Messages	Notes, noises
00 h 48 min 47	Start of de transcript		
00 h 48 min 48	DAH 5017	Tower salam 'aleïkoum, Algérie five zero one seven	
00 h 48 min 54	**[Ouaga TWR] (118.1)**	Algérie five zero one seven, Ouaga Tower, good evening, go ahead	
00 h 48 min 58	DAH 5017	Yes, we will be ready for the start up in four minutes	
00 h 49 min 03	**[TWR]**	Err roger, copied. You copy runway 22 in use, wind is 250 degrees, 07 knots, visibility 10 km, temperature 26, dew point 23, QNH 1015. Time check 00 49. Report for start-up	
00 h 49 min 21	DAH 5017	We will call you ready for the start-up and QNH 1015, Algérie five zero one seven	
01 h 00 min 52	**[TWR]**	Cargolux 805, airborne 00 58, report for estimates	
01 h 00 min 57	CLX 805	Cargolux 805 I call you back	

UTC time	Speaker	Messages	Notes, noises
01 h 02 min 14	DAH 5017	Algérie four zero one seven, ready for the start up	
01 h 02 min 20	**[TWR]**	Algérie five zero one seven, start up is approved runway 22, wind 240 degrees, 10 knots. Temperature is 26, dew point 23, QNH 1015, time 01 03, report for taxi	
01 h 02 min 35	DAH 5017	Start-up approved Algérie four zero one seven, we will call you ready for taxi	
01 h 02 min 47	CLX 805	Ouaga Cargolux 805	
01 h 02 min 52	**[TWR]**	805, go ahead	
01 h 02 min 53	CLX 805	So we estimate EPEPO at 01 15, GAO 01 33 and MOKAT 02 10 and we climbing now... we passing out of flight level 155 to... for climbing for flight level 370.	
01 h 03 min 12	**[TWR]**	And say estimates for destination	
01 h 03 min 18	CLX 805	Estimate destination 06 00, Cargolux 805	
01 h 03 min 24	**[TWR]**	Roger, contact Control, 120.3, good bye	
01 h 03 min 27	CLX 805	At 120.3, bonne nuit Cargolux 805	
01 h 04 min 04	CLX 805	Ouaga Control good morning Cargolux 805	
01 h 04 min 10	**[Ouaga CCR] (120.3)**	805, Ouaga Control, good morning, cleared EPEPO, flight level 370, report EPEPO	
01 h 04 min 20	CLX 805	Cleared to EPEPO and climbing flight level 370, I you call back EPEPO, Cargolux 805	
01 h 07 min 07	*#Ouaga CCR#*	Allô	
01 h 07 min 08	*#Niamey CCR#*	Oui Ouaga pour le Cargolux qui va au 370, oui allez-y	
01 h 07 min 12	*#Ouaga CCR#*	Oui EPEPO à 01h15, GAO à 33, niveau 370	
01 h 07 min 21	*#Niamey CCR#*	D'accord alors à quelle heure il a décollé, s'il vous plait?	
01 h 07 min 23	*#Ouaga CCR#*	Il a décollé à 00h58 et puis Air Algérie derrière... qui demande niveau 350	
01 h 07 min 33	*#Niamey CCR#*	C'est Algérie cinq mille cinq?	
01 h 07 min 36	*#Ouaga CCR#*	Cinq mille..., cinq mille... Algérie five zero one seven, cinq mille dix-sept, il va à Alger	
01 h 07 min 41	*#Niamey CCR#*	Heu d'accord, lui le 350 approuvé pour lui	

UTC time	Speaker	Messages	Notes, noises
01 h 07 min 46	*#Ouaga CCR#*	Hum d'accord	
01 h 09 min 54	DAH 5017	Algérie five zero one seven, ready to taxi	
01 h 10 min 02	**[TWR]**	Five zero one seven taxi, enter and backtrack runway 22, confirm level	
01 h 10 min 14	DAH 5017	Taxi... taxi for holding point runway 22 and backtrack. We request flight level 320... 330	
01 h 10 min 23	**[TWR]**	Roger call you back	
01 h 10 min 29	DAH 5017	By the moment 310, too heavy, Algérie five zero one seven	
01 h 10 min 45	**[TWR]**	Please say again, Algérie	
01 h 10 min 46	DAH 5017	Yes, flight level 310, 310, Algérie five zero one seven	
01 h 10 min 51	**[TWR]**	Roger	
01 h 12 min 12	*#Niamey CCR#*	Allô	
01 h 12 min 13	*#Ouaga CCR#*	Allô Niamey	
01 h 12 min 15	*#Niamey CCR#*	Oui Ouaga	
01 h 12 min 16	*#Ouaga CCR#*	Oui heu, le Cargolux demande le niveau 410 et Air Algérie niveau 310	
01 h 12 min 21	*#Niamey CCR#*	Non le 370 s'il vous plait, j'ai du trafic c'est pour cela que je l'ai limité initialement au 370	
01 h 12 min 27	*#Ouaga CCR#*	D'accord... et l'Air Algérie, 310?	
01 h 12 min 30	*#Niamey CCR#*	Air Algérie, 350 initial	
01 h 12 min 32	*#Ouaga CCR#*	310 qu'il demande	
01 h 12 min 35	*#Niamey CCR#*	3-10?	
01 h 12 min 35	*#Ouaga CCR#*	Voilà	
01 h 12 min 37	*#Niamey CCR#*	Ok lui c'est 3-10 et le Cargolux 370	
01 h 12 min 40	*#Ouaga CCR#*	Ok	
01 h 12 min 42	*#Niamey CCR#*	Ok merci	
01 h 13 min 01	DAH 5017	Algérie five zero one seven, we are ready to copy	

UTC time	Speaker	Messages	Notes, noises
01 h 13 min 05	**[TWR]**	Algérie five zero one seven, clear Ouagadougou to Alger via EPEPO, level 310, after departure runway 22, right turn	
01 h 13 min 15	DAH 5017	Heu... clear destination, initially flight level 310. After takeoff, right turn to (GUPOV)	
01 h 13 min 31	**[TWR]**	Algérie five zero one seven heu... right turn to EPEPO	
01 h 13 min 37	DAH 5017	Heu copied, right turn to EPEPO	
01 h 13 min 41	**[TWR]**	Correct, report ready	
01 h 13 min 49	DAH 5017	We will call you ready	
01 h 15 min 01	DAH 5017	Ready, Algérie five zero one seven	
01 h 15 min 03	CLX 805	Ouagadougou, Ouaga Control, Cargolux 805	
01 h 15 min 06	**[TWR]**	Algérie five zero one seven, clear for takeoff runway 22, wind is 230 degrees, 09 knots, right turn	
01 h 15 min 12	DAH 5017	Clear for takeoff, 22 and when airborn, right turn, Algérie five zero one seven	
01 h 15 min 13	**[Ouaga CCR]**	Cargolux 805, Ouaga, you contact Niamey for higher, Niamey is one three one decimal three. Safe flight	
01 h 15 min 21			AH5017 V1 callout (pressed alternat)
01 h 15 min 23	CLX 805	Niamey one three one decimal three for higher. Have a good night Cargolux 805. Au revoir.	
01 h 15 min 29	**[Ouaga CCR]**	Au revoir	
01 h 18 min 25	*#BIA#*	Oui allô	
01 h 18 min 26	*#Ouaga CCR#*	Oui Algérie 5017 en vol à 01h17	
01 h 18 min 28	*#BIA#*	17 minutes...	
01 h 20 min 36	RAM 543K	Tower, Air Maroc 543 Kilo, request taxi	
01 h 20 min 44	**[TWR]**	543 Kilo taxi, enter and backtrack runway 22 and follow... do you have a marshaller?	
01 h 20 min 52	RAM 543K	We have the marshaller, we follow marshaller instruction and we... enter and backtrack runway 22, Royal Air Maroc 543 Kilo	

UTC time	Speaker	Messages	Notes, noises
01 h 21 min 01	**[TWR]**	Hum confirm level requested	
01 h 21 min 05	RAM 543K	270, Royal Air Maroc 543 Kilo	
01 h 21 min 09	**[TWR]**	Roger, I call you back for ATC clearance	
01 h 21 min 12	**[TWR]**	Algérie five zero one seven, airborn time 01 17, report for estimates	
01 h 21 min 22	DAH 5017	Are you calling, Algérie five zero one seven?	
01 h 21 min 25	**[TWR]**	Algérie five zero one seven, correct, report for estimates	
01 h 21 min 31	DAH 5017	Say again, Algérie five zero one seven	
01 h 21 min 34	**[TWR]**	Air Algérie five zero one seven, airborn time 01 17, report for estimates	
01 h 21 min 42	DAH 5017	Standing by, Algérie five zero one seven	
01 h 21 min 49	**[TWR]**	Five zero one seven, standing by for estimates, standing by	
01 h 21 min 54	DAH 5017	Standing by, Algérie five zero one seven	
01 h 22 min 53	RAM 543K	Tower, Royal Air Maroc 543 Kilo, ready to copy (ATC)	
01 h 22 min 59	**[TWR]**	Maroc 543 Kilo is cleared Ouagadougou Niamey via DEKAS level 270, after departure runway 22, climb runway heading, 5 miles, then left turn	
01 h 23 min 13	RAM 543K	Clear to Niamey via DEKAS, we climb flight level 270, after takeoff we maintain runway heading then left t urn (*) Royal Air Maroc 543 Kilo	
01 h 23 min 26	**[TWR]**	543 Kilo correct, report ready	
01 h 23 min 29	RAM 543K	Call you back when ready, Royal Air Maroc 543 Kilo	
01 h 23 min 48	**[TWR]**	Air Algérie five zero one seven, say level passing	
01 h 23 min 51	DAH 5017	We are passing flight level 145, Algérie four zero one seven	
01 h 23 min 57	**[TWR]**	Roger... and say estimates EPEPO... and arrival time Alger	
01 h 24 min 05	DAH 5017	...PO at 01 38, Algérie five zero one seven	
01 h 24 min 10	**[TWR]**	Please, say again estimates EPEPO?	
01 h 24 min 12	DAH 5017	01 38, 01 38	

UTC time	Speaker	Messages	Notes, noises
01 h 24 min 16	**[TWR]**	Roger. Estimate arrival time Alger?	
01 h 24 min 20	DAH 5017	Estimated time Alger, stand by please	
01 h 24 min 51	RAM 543K	Tower, Royal Air Maroc 543 Kilo, ready for take off	
01 h 24 min 55	**[TWR]**	543 Kilo, clear for takeoff runway 22, wind is 240 degrees, 06 knots	
01 h 25 min 00	RAM 543K	Cleared take off 22, Royal Air Maroc 543 Kilo,	
01 h 25 min 38	*#Niamey CCR#*	Allô?	
01 h 25 min 39	*#Ouaga CCR#*	Oui Algérie 5017, en vol à 01h17	
01 h 25 min 42	*#Niamey CCR#*	Une seconde	
01 h 27 min 10	*#Ouaga CCR#*	Allô	
01 h 27 min 12	*#Niamey CCR#*	Oui Ouaga, je t'ai mis en stand-by, tu as préféré quitter?	
01 h 27 min 14	*#Ouaga CCR#*	Voilà, comme tu étais pris	
01 h 27 min 17	*#Niamey CCR#*	D'accord, oui on y va	
01 h 27 min 18	*#Ouaga CCR#*	Donc 01h17 en vol, Algérie 5017	
01 h 27 min 22	*#Niamey CCR#*	5017, oui	
01 h 27 min 23	*#Ouaga CCR#*	EPEPO à 01h38, niveau...	
01 h 27 min 26	*#Niamey CCR#*	S'il te plait, il a décollé à quelle heure?	
01 h 27 min 28	*#Ouaga CCR#*	01h17	
01 h 27 min 30	*#Niamey CCR#*	Oui	
01 h 27 min 31	*#Ouaga CCR#*	EPEPO à 01h38, niveau 310. Et derrière tu as Maroc 543 K, niveau 270 sur DEKAS	
01 h 27 min 44	*#Niamey CCR#*	D'accord, il n'a pas encore décollé?	
01 h 27 min 45	*#Ouaga CCR#*	Heu il vient de décoller mais je n'ai pas... il a décollé juste à 27	
01 h 27 min 49	*#Niamey CCR#*	27? D'accord, reçu.	
01 h 27 min 53	*#Ouaga CCR#*	Toute à l'heure pour ses estimées	

UTC time	Speaker	Messages	Notes, noises
01 h 27 min 56	DAH 5017	Heu Radar, Algérie five zero one seven	
01 h 28 min 01	**[TWR]**	Heu... go ahead	
01 h 28 min 02	DAH 5017	The estimate is Alger at 05 06	
01 h 28 min 09	**[TWR]**	Contact Control, one two zero decimal three	
01 h 28 min 11	DAH 5017	One two zero three, Algérie four zero one seven, choukrane (“merci” en langue arabe)	
01 h 28 min 16	DAH 5017	Radar, salam ’aleïkoum, Algérie five zero one seven, climbing 310	
01 h 28 min 24	**[Ouaga CCR]**	Algérie five zero one seven, cleared EPEPO level 310, report EPEPO	
01 h 28 min 29	DAH 5017	Yes, we'll call you EPEPO, we are turning left heading 356 to avoid	
01 h 28 min 37	**[Ouaga CCR]**	Roger	
01 h 29 min 22	*#BIA#*	Allô	
01 h 29 min 22	*#Ouaga CCR#*	Oui, Marco 543 Kilo en vol à 27	
01 h 29 min 25	*#BIA#*	27? Reçu	
01 h 29 min 29	**[TWR]**	Maroc 543 Kilo airborn time 01 27 report for estimates	
01 h 29 min 34	RAM 543K	We estimate BULSA at 01 38, DEKAS at 01 42 and destination Niamey at 02 08	
01 h 29 min 46	**[TWR]**	Estimates are copied, climb level 270, report passing 140	
01 h 29 min 48	DAH 5005	Ouaga, Ouaga, Air Algérie five zero zero five, bonjour	
01 h 29 min 55	**[Ouaga CCR]**	Algérie 5005 bonjour	
01 h 29 min 57	DAH 5005	Bonjour, position TUMUT, 370	
01 h 30 min 04	**[Ouaga CCR]**	Roger clear TUMUT, Oscar Golf, EPEPO 370, say estimates Oscar Golf, EPEPO	
01 h 30 min 10	DAH 5005	Roger, Oscar Golf and EPEPO and we estimate Oscar Golf at 01 41 EPEPO 01 56 and we need heading by the right 045 to avoid	
01 h 30 min 31	**[Ouaga CCR]**	Confirm 045 nautical miles right	
01 h 30 min 34	DAH 5005	Yes in heu... 8 nautical miles, 8 nautical miles	
01 h 30 min 41	**[Ouaga CCR]**	Roger, that's approved, report back on	

UTC time	Speaker	Messages	Notes, noises
		course	
01 h 30 min 47	DAH 5005	Roger	
01 h 31 min 03	RAM543K	140 passing, Royal Air Maroc 543 Kilo	
01 h 31 min 07	**[TWR]**	Roger, contact Control 120.3, good bye	
01 h 31 min 10	RAM 543K	Two zero three, bye bye	
01 h 31 min 13	RAM 543 K	Le Contrôle bonsoir, Royal Air Maroc 543 Kilo	
01 h 31 min 18	**[Ouaga CCR]**	Maroc 543 Kilo, bonsoir, cleared DEKAS level 270, report DEKAS	
01 h 31 min 24	RAM 543K	Call you DEKAS for Air Maroc 543 Kilo	
01 h 32 min 00	*#Niamey CCR#*	Allô?	
01 h 32 min 01	*#Ouaga CCR#*	Oui Niamey, on a deux trafics	
01 h 32 min 04	*#Niamey CCR#*	Oui?	
01 h 32 min 06	*#Ouaga CCR#*	Maroc 543 Kilo, heu en vol à 01h27, DEKAS 01h42, Niamey à 02h08, niveau 270	
01 h 32 min 20	*#Ouaga CCR#*	Le deuxième	
01 h 32 min 25	*#Niamey CCR#*	02h08... oui?	
01 h 32 min 28	*#Ouaga CCR#*	Deuxième, Algérie 5005, EPEPO	
01 h 32 min 31	*#Niamey CCR#*	5005?	
01 h 32 min 34	*#Ouaga CCR#*	EPEPO à 01h56	
01 h 32 min 37	*#Niamey CCR#*	5005 ou 5017?	
01 h 32 min 40	*#Ouaga CCR#*	5005, tu as le 5017, ça c'est un autre, 5005	
01 h 32 min 41	DAH 5005	Ouaga, Algérie 5005, we take...take by the right, heading 050	
01 h 32 min 49	**[Ouaga CCR]**	Roger 5005, copied	
01 h 32 min 53	*#Ouaga CCR#*	Algérie 5005, EPEPO à 01h56, niveau 370	
01 h 33 min 01	*#Niamey CCR#*	1-56, niveau?	
01 h 33 min 03	*#Ouaga CCR#*	370	
01 h 33 min 06	*#Niamey CCR#*	Ok	

UTC time	Speaker	Messages	Notes, noises
01 h 34 min 04	*#Niamey CCR#*	Allô?	
01 h 34 min 05	*#Ouaga CCR#*	Allô les deux Algérie sont en train de dévier, cause météo, j'espère que tu les vois au radar	
01 h 34 min 11	*#Niamey CCR#*	Heu je les av... je ne les vois pas encore	
01 h 34 min 14	*#Ouaga CCR#*	Ok Algérie 5005 dévie à droite et 5017 aussi à droite	
01 h 34 min 22	*#Niamey CCR#*	Ok c'est bon	
01 h 37 min 07	DAH 5017	Algérie five zero one seven, Radar	
01 h 37 min 14	**[Ouaga CCR]**	Algérie five zero one seven, go ahead	
01 h 37 min 17	DAH 5017	(*)	
01 h 37 min 25	**[Ouaga CCR]**	Roger, contact Niamey, one three one decimal three, good bye	
01 h 37 min 28	DAH 5017	One three one three, Algérie five zero one seven, choukrane (*) (“merci ” en langue arabe)	
01 h 40 min 44	DAH 5005	Ouaga, Air Algérie 5005, we take by the left to ARBUT	
01 h 40 min 55	**[Ouaga CCR]**	5005 roger, report position ARBUT	
01 h 41 min 01	DAH 5005	Roger, we will report position ARBUT and at ARBUT we... I call you back to avoid by the left	
01 h 41 min 11	**[Ouaga CCR]**	Copied	
01 h 41 min 33	RAM 543K	Check in DEKAS, Royal Air Maroc 543 Kilo	
01 h 41 min 41	**[Ouaga CCR]**	Maroc 543 Kilo, contact Niamey, 131.3, good bye	
01 h 41 min 46	RAM 543K	Heu one three one three, bye.	
01 h 45 min 07	DAH 5005	Ouaga, Algérie 5005, we take left heading three five zero and I call you back (*) ARBUT	
01 h 45 min 23	**[Ouaga CCR]**	Roger copied… and Algérie 5005, copy Niamey weather... heu sorry, copy Niamey frequency, 131.3, 1 3 1 3, and report contacting Niamey	
01 h 45 min 36	DAH 5005	131.3 with Niamey and will report contacting with Niamey, Air Algérie 5005	

UTC time	Speaker	Messages	Notes, noises
01 h 45 min 43	**[Ouaga CCR]**	Roger	
01 h 45 min 46	End of transcript		

APPENDIX 3: TRANSCRIPT OF ATC COMMUNICATIONS FROM NIAMEY CONTROL CENTRE

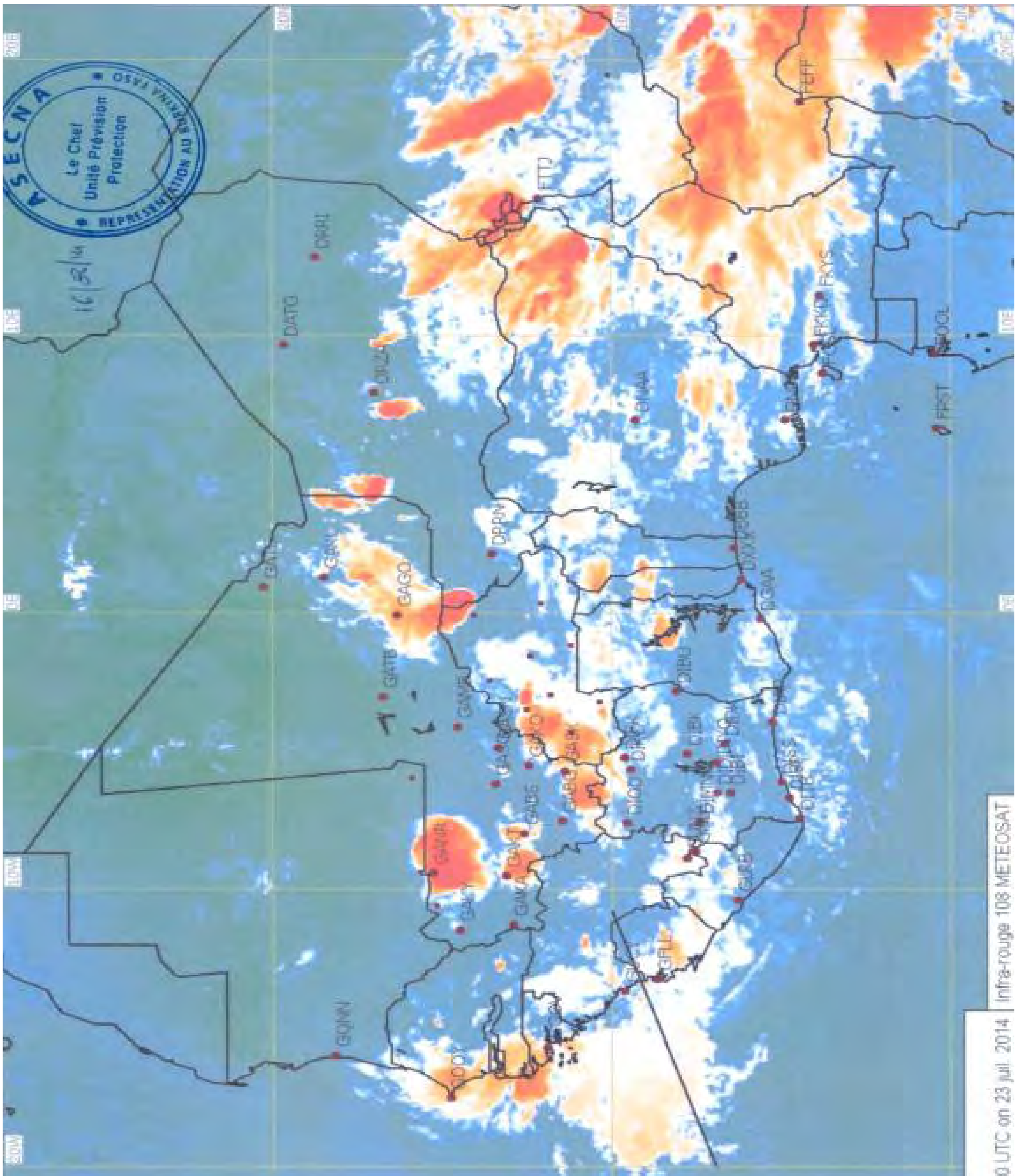
UTC time	Speaker	Messages	Notes, noises
01 h 41 min 38	[Niamey APP]	Algerie five zero one seven Niamey?	
01 h 41 min 49	[Niamey APP]	Algerie five zero one seven Niamey?	
01 h 42 min 13	RAM 543K	Niamey Air Maroc five four three kilo, bonsoir	
01 h 42 min 16	[Niamey APP]	Maroc 543 K Niamey bonsoir (your squawk is) one two two two one two two two climb to maintain maintain level two seven zero copy Niamey last report wind is two two zero degrees zero four knots CAVOK temperature two six dew point two three Q N H one zero one three (*) nosig go ahead	
01 h 42 min 42	RAM 543K	One zero one three (to the) zero niner for landing at Niamey we estimate Niamey at zero two zero five euh RITAT at zero two zero two and we request a right track to avoid	
01 h 43 min 01	[Niamey APP]	Roger deviation is approved report back on track and report ready for descent	
01 h 43 min 08	RAM 543K	..call you Air Maroc five four three kilo	
01 h 43 min 13	DAH 5017	(*) Algerie five zero one	
01 h 43 min 22	RAM 543K	Eh Niamey euh pour information il y a Air Algérie qui vous appelle	
01 h 43 min 53	[Niamey APP]	Algérie five zero one seven Niamey?	
01 h 44 min 02	[Niamey APP]	Algérie five zero one seven Niamey?	
01 h 44 min 09	[Niamey APP]	Maroc five four three kilo I read I need a relay	
01 h 44 min 13	RAM 543K	Allez-y pour le relais pour Air Algérie	
01 h 44 min 18	[Niamey APP]	Oui donc qu'il m'appelle sur cent trente un point trois	
01 h 44 min 21	RAM 543K	Qu'il vous appelle sur cent trente et un trois il euh...	

UTC time	Speaker	Messages	Notes, noises
01 h 44 min 25	RAM 543K	Alger... Air Algerie allez-y pour votre message	
01 h 44 min 29	DAH 5017	Yes Algérie five zero one seven we are maintaining flight level three one zero we are (*) (interruption) (*) to avoid	
01 h 44 min 39	RAM 543K	Heu Niamey, Air Maroc five four three Kilo?	
01 h 44 min 42	[Niamey APP]	Oui merci beaucoup, Algérie five zero one seven squawk three two three five three two three five report passing GAO, report passing GAO and say estimate MOKAT	
01 h 44 min 56	RAM 543K	(Vous avez) reçu Air Algérie?	
01 h 45 min 12	RAM 543K	Air Algérie d'Air Maroc cinq cent quarante trois vous avez reçu le message de Niamey?	
01 h 45 min 22	RAM 543K	Algérie, Air Maroc cinq quarante trois?	
01 h 45 min 30	RAM 543K	Niamey Air Maroc five four three Kilo request descent	
01 h 45 min 36	[Niamey APP]	Five four three Kilo, Niamey descend level zero five...zero five zero I call you back	
01 h 45 min 41	RAM 543K	Down, flight level zero five zero Air Maroc five four three Kilo	
01 h 45 min 53	DAH 5005	Niamey Niamey Air Algérie five zero zero five good morning	
01 h 45 min 59	[Niamey APP]	Five thousand five morning go ahead	
01 h 46 min 01	DAH 5005	Five thousand five we are... at two eight miles... euh to... ARBUT and heading three five zero to avoid	
01 h 46 min 16	[Niamey APP]	Five thousand five squawk three two two six three two two six report back on track	
01 h 46 min 23	DAH 5005	Three two two six and euh... we come back with Ouaga control roger Air Algérie five zero zero five	
01 h 46 min 49	DAH 5005	Niamey Air Algérie five zero zero five released by Ouaga	
01 h 46 min 57	[Niamey APP]	Algerie... Royal Maroc five four three Kilo descent level one two zero initial one two zero initial for euh LILAM VOR D M E runway two seven report at (*)	

UTC time	Speaker	Messages	Notes, noises
01 h 47 min 14	RAM 543K	Called Royal Air Maroc five four three Kilo?	
01 h 47 min 16	[Niamey APP]	Affirm	
01 h 47 min 18	RAM 543K	Down, flight level one two zero heading zero nine zero and request runway zero nine	
01 h 47 min 28	[Niamey APP]	Runway two seven in use due to arrival	
01 h 47 min 32	RAM 543K	We take two seven Royal Air Maroc five four three Kilo	
01 h 47 min 36	[Niamey APP]	Algerie five thousand five Niamey?	
01 h 47 min 38	DAH 5005	(*) five thousand five euh... we are released par Ougadougou and euh we are taking by the left heading three five zero to avoid	
01 h 47 min 50	[Niamey APP]	Five thousand five copied report back on track	
01 h 47 min 55	DAH 5005	Roger five zero zero five	
01 h 52 min 37	RAM 543K	Air Maroc five four three Kilo?	
01 h 52 min 39	[Niamey APP]	Go ahead	
01 h 52 min 40	RAM 543K	Approaching lower routing to ETROT and down to one two zero	
01 h 52 min 47	[Niamey APP]	Continue with Tower one one nine decimal seven	
01 h 52 min 50	RAM 543K	Nine seven merci bye bye	
01 h 55 min 33	[Niamey APP]	Algerie five zero one seven Niamey?	
01 h 55 min 37	DAH 5005	Five zero zero five Ouaga go ahead?	
01 h 55 min 40	[Niamey APP]	I'm calling five zero one seven Algerie five zero one seven	
01 h 55 min 56	[Niamey APP]	Algerie five zero one seven Niamey?	
01 h 56 min 25	[Niamey APP]	Portugal two eight nine Niamey?	

UTC time	Speaker	Messages	Notes, noises
01 h 56 min 28	TAP 209	Two eight nine go ahead?	
01 h 56 min 30	[Niamey APP]	(*) a relay to Algerie five zero one seven	
01 h 56 min 37	TAP 209	Euh say again the call sign?	
01 h 56 min 40	[Niamey APP]	Algerie five zero one seven	
01 h 56 min 45	TAP 209	Okay five zero one seven go ahead for him	
01 h 56 min 49	[Niamey APP]	Please ask Algerie five zero one seven to contact Niamey on eight eight nine four	
01 h 56 min 58	TAP 209	(*) (eight nine)	
01 h 57 min 00	TAP 209	Algerie five zero one seven algerie five zero one seven this is Air Portugal to eight nine	
01 h 57 min 13	TAP 209	Algerie five zero one seven this is Air Portugal to eight nine calling Algerie five zero one seven	
01 h 57 min 29	DAH 5005	Air Algerie five zero one seven from Air Algerie five zero zero five?	
01 h 57 min 36	TAP 209	I have a relay for Algerie five zero one seven to call... Niamey on eight eight nine four	
01 h 57 min 46	DAH 5005	Air Algerie five sero one seven from Air Algerie five zero zero five?	
01 h 58 min 35	TAP 209	Niamey Portugal two eight nine?	
01 h 58 min 39	[Niamey APP]	Go ahead	
01 h 58 min 40	TAP 209	I was unable to contact with Algerie five zero one seven	
01 h 58 min 44	[Niamey APP]	Thank you so much maintain level three five zero report passing BATIA	
01 h 58 min 48	AH5017 End of transcript		

APPENDIX 4
IR SATELLITE IMAGE OF METEOROLOGICAL SITUATION



Source ASECNA, document sent on 16 August 2014

APPENDIX 5
SUMMARY OF TRAINING AND CHECKS UNDERTAKEN BY THE CREW

	Operator's conversion course	Training and recurrent training			
		2nd semester 2012	1st semester 2013	2nd semester 2013	1st semester 2014
Captain (joined airline in Spring 2012)	Theoretical part : Ended10 May 2012 Type rating extended: 09 May 2012 Base check: 21 May 2012 Line flying under supervision from 03 May to 04 July 2012 Line check: 3 and 4 July 2012	Not undertaken. (see § 1.5.6.2)	Theoretical part : May 2013 Type rating extended: 14 April 2013 Base check: 04 April 2013 Line check: 13 August 2013	Theoretical part : October 2013 Base check: 23 October 2013	Theoretical part : March 2014 Type rating extended: 24 March 2014 Base check : 25 March 2014 Line check planned in August 2014 **(**after the date of the accident)
Copilot (joined airline in Spring 2013)	Theoretical part: May 2013 Commercial Pilot's License: 17 May 2013 Base check : 17 May 2013 Line flying under supervision from 9 March to 25 June 2013 Line check: 25 June 2013	Pilot not yet employed by airline	Pilot not yet employed by airline	Theoretical part : October 2013 Base check: 16 October 2013	Theoretical part : March 2014 Commercial Pilot's License: 24 March 2014 Base check: 25 March 2014 Line check: 29 June 2014

APPENDIX 6
REGULATORY LIMITATIONS

Limitations on duty period
The operator shall ensure that a crew member's total duty time does not exceed:

- 190 duty hours for any period of 28 consecutive days, spread out as evenly as practicable throughout this period; and
- 60 duty hours for any period of 7 consecutive days.

Limitations on flight duty period
The operator shall ensure that the total block flying time of the flights on which a crew member is assigned as an operating crew member does not exceed:

- 900 block hours in a calendar year;
- 100 block hours in any 28 consecutive days

Limitations on daily flight duty period
Maximum flight duty period: 13 hours, reduced by 30 minutes per sector starting from the 3rd leg, 11 hours for 6 sectors or more.

- Possible extension of one hour (less than 6 sectors, 2 times/week, increase of rest time before and after)

Minimum rest period:
This shall be of a duration at least equal to the duty period preceding it, and at least:

- 12 hours at the home base,
- 10.30 hours[52] away from the home base; the crew must be able to sleep 8 hours
- weekly rest time of 36 hours including two local nights (8 hours between 22h and 8h).

Minimum rest days at the home base:
In its article 8, the ministerial letter dated 17/12/2010 requires operators to allow a rest period of at least 8 days per month at the home base.
If scheduling makes this impossible, these rest days at the base may be carried over to the following month, in which case they will be added to the rest days at base of the following month, with no further postponing possible.

[52] Duration mentioned in the ministerial letter dated 17 December 2010. European Regulation n° 859/2008 of the European Commission provides for a duration of 10 hours.

APPENDIX 7
CHRONOLOGY OF EVENTS AT THE NIAMEY ACC

- At 01 h 27, the Niamey ACC was informed, by the Ouagadougou ACC, of the takeoff of flight AH5017 at 01 h 17.
- At 01h30, the Niamey ACC created a "local" flight plan for AH 5017 as the flight plan did not exist in the EUROCAT-X system
- At 01h31, the radar plot for AH 5017 appeared. The aeroplane was climbing (FL233) on route 350 approximately, 12 NM west of the ARBUT-EPEPO route and about 20 NM from ARBUT. It was about 190 NM from NY.
- At 01h33, the radar plot for AH5017 disappeared from the control screen while it was approaching the Niamey control sector. The aeroplane was at that time outside of the range of the Niamey radar as it was flying away from Niamey towards the west.
- At 01h34, coordination of flight AH 5017 was performed between the Ouagadougou ACC and the Niamey ACC.
- At 01 h 37 flight AH5017 was transferred from Ouagadougou ACC to Niamey ACC on 131.3
- At 01h42, the radar plot for AH 5017 reappeared. The aeroplane was west of the EPEPO-GAO route (about 35 NM).
- During the following 5 minutes, the radar plot from AH5017 appeared with various symbols thus indicating that the aeroplane was located at the edge of the Niamey radar range.
- At 01h44 min 20, the Niamey ACC "accepted"[53] the AH5017 flight plan strip.
- At 01h44 min 28, AH5017 called the Niamey ACC stating that it was stable at flight level 310 and in an avoidance manoeuvre. The Niamey ACC requested it to squawk transponder code 3235, to give its estimated time for MOKAT and to re-contact it at GAO.
- At 01h47 min 28, the AH5017 radar plot disappeared once and for all. The aeroplane was abeam the EPEPO-GAO route for about 30 NM. It was situated 95 NM from GAO and 215 NM from NY.
- At 01h52 min 45, the AH5017 flight plan track passed GAO. The controller who was in contact with the flight informed the controllers in the adjacent position orally that AH5017 did not re-contact it at GAO as requested.
- At 01h53 min 58, the Niamey ACC called the Algiers ACC to inform them that the estimated time of AH5017 at MOKAT was 02 H 50.
- At 03h07, the Algiers ACC called the Niamey ACC to inform them that they had not had any radio contact from AH5017 at MOKAT and suggested the Niamey ACC trigger an emergency phase.

[53] This is an action by ATC that means that the AH5017 flight plan strip was "accepted" but that the flight plan strip had not yet been correlated with the aeroplane’s radar plot. This correlation occurs when the aeroplane squawks the transponder code provided by the Niamey control centre.

Chronology of SAR events

- At 03h30, the Niamey ACC triggered the alert phase (ALERFA). It sent the message ALERFA to the Algiers ACC which transmitted it to the Algiers Rescue Coordination Centre (RCC). The content of this message relating to flight AH5017 stated: "loss of contact at GAO and MOKAT".
- The Niamey ACC tried in vain to contact the Niamey RCC to inform them of the ALERFA.
- At 03h55, the Niamey ACC contacted the Ouagadougou ACC and specified that the contact with AH5017 could not be established but that the emergency phases had already been triggered.
- At 04h04, the Algiers ACC suggested to the Niamey ACC to trigger the DETRESFA phase.
- the Niamey ACC stated that they had questioned the Bamako, Ouagadougou and Nouakchott aerodromes about the presence of AH5017 and that they had encountered problems transmitting the DETRESFA message with the Eurocat-X system.
- At 04h38, the Niamey ACC sent the DETRESFA message.
- At 04h48, at the request of the Algiers ACC concerning "the last radar contact" of DAH 5017, the Niamey ACC stated "about 01h55 and abeam GAO".
- At 05h28, the Algiers RCC notified the SAR coordinator of the Niamey RCC, who had also just been called by the Niamey ACC, that "the last contact" with AH5017 took place "across GAO at 01h55" for "estimated time at MOKAT at 02h33".
- At 06h00, the SAR coordinator of the Niamey RCC arrived at the duty office to recover the departure information of the AH5017 flight plan and the meteorology on its trajectory. He then went to the Niamey RCC premises where he arrived at 06h20 to trace the first likely accident area: he estimated this area to be between GAO and MOKAT further to the information received at 05 h 28 by the Algiers RCC.
- He asked the command of airbase 101 to put 2 of the Nigerian air force Cessna 208 on alert.
- At 06h32, he requested assistance from the French Air Force support operations, stationed at airbase 101, which answered positively.
- At 07h52, he contacted the Niamey BDP to obtain the latest information on DAH 5017. The Niamey BDP stated that a screenshot of the aeroplane radar trajectory was underway, that the aeroplane had diverted to the left of its route at the ARBUT reporting point and that a brief radar trace of the aeroplane had appeared abeam ARBUT.
- At 08h16, he was informed that a French Air Force aeroplane was carrying out a search while the 2 Nigerian Cessna 208 were kept on alert.
- At 08h17, a Burkina Faso crisis management team was activated by Burkina Faso. The first elements recovered indicated focussing the search in the north-east of Mali towards the Algerian border.
- At 08h50, the Niamey and Algiers RCC agreed to use Algerian air resources to carry out searches in the probable area north of the accident coinciding with the Algerian south (in the area around Bordj Mokhtar towards GAO).
- At 08h51, the Head of Bamako RSC was informed of the disappearance of AH5017 by the Bamako ACC.
- At 10h07, the Niamey RCC SAR mission coordinator informed the French Air Force operations support and specified that the last radar contact of the aeroplane was at ARBUT and that a radio contact took place via GAO at 01h55. The search was therefore focussed in the area estimated by the Niamey RCC.
- At 11h00, a crisis cell was set up at Bamako RSC. According to the latest information transmitted, particularly the loss of radar contact at the following point: radial 227° of GAO for 90 NM, the RSC determined a search area which stretched from the Mali and Burkina Faso border to the aeroplane's last point of radar contact.

- At 12h30, the Bamako RSC received information locating the accident area in the north-east of GAO, an area which had already been searched by 2 French Air Force Mirages. Attempts by the Bamako RSC to contact the neighbouring ACC and RSC were all unsuccessful.
- At 12h50, an Algerian C130 took off from Tamanrasset to search the route planned by AH5017 over a distance of 200 km from the south of MOKAT.
- At 13h08, the Burkina Faso crisis management team validated the position of the accident area in the vicinity of Boulekessi (Mali) from a witness report and AH5017 radar plots recorded by the Ouagadougou ACC radar.
- At 14h30, the Bamako RSC received information from a witness report of an aeroplane crash in the vicinity of Gossi.
- At 15h00, a Burkina Faso air force helicopter took off from Ouagadougou for Djibo (Burkina Faso) then took off again at 17h00 and identified the crash area at 18h23. The absence of survivors was reported. A report was made to the Burkina Faso crisis management team at about 19h00.
- At about 22h00, the search operations ended with the positioning of air resources and military personnel in the accident area.

U.S. Department
of Transportation
Federal Aviation
Administration

InFO

Information for Operators

InFO 08033
DATE: 5/16/08

Flight Standards Service
Washington, DC

http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/info

An InFO contains valuable information for operators that should help them meet certain administrative, regulatory, or operational requirements with relatively low urgency or impact on safety.

SUBJECT: High Altitude Icing Conditions

Purpose: This InFO provides guidance and information for pilots and operators regarding icing encounters at high altitudes.

Background: This InFO has been developed in response to NTSB recommendation A-04-34 and supersedes Flight Standards Information Bulletin (FSAT) 04-02.

On June 4, 2002, a McDonnell Douglas MD-82, in cruise flight at flight level 330, experienced a gradual loss of power in both Pratt & Whitney JT8D-219 engines. The right engine was shut down when the exhaust gas temperature reached 600 °C. The airplane experienced activation of the aural stall warning and stick shaker. The pilots disengaged the autopilot and began a descent. At 17,000 feet, the engine was restarted and the flight diverted to the Wichita Mid-Continent Airport, Wichita, KS, and landed without incident.

Discussion:

a. Radar weather images of the area that the airplane was flying in, just before the engines lost power, show weak weather radar echo intensities at 33,000 feet that are consistent with high altitude ice crystals. High altitude ice crystals can affect airplanes with engines that use engine pressure ratio (EPR) power settings (such as the JT8D-219 engines on the MD-82) because they can occasionally adhere to engine inlet pressure probes, partially blocking the opening and causing a false high engine power indication. A similar circumstance that demonstrated the effect of ice blocking the JT8D engine's inlet pressure probes was the January 13, 1982, crash of Air Florida Flight 90, a Boeing 737 that crashed into the Potomac River after taking off from Washington National Airport.

b. Although flight data recorder data from the MD-82 indicated that engine power was increasing just before the engines started to lose power, the loss of airspeed and increase in pitch indicates that engine power was actually decreasing. A note in the MD-80 Flight Crew Operating Manual (FCOM) states that icing of the engine inlet pressure probes may cause the throttles to retard when the auto-throttle is in the EPR limit mode. The National Transportation Safety Board's (NTSB) investigation concluded that because the engine anti-ice system was not activated when the MD-82 entered the icing conditions, the ice crystals were able to adhere to and partially block the inlet air pressure probes, causing the EPR indication to increase until reaching the auto-throttle EPR limit. Meanwhile, engine power and airspeed were actually decreasing and the airplane was pitching up, resulting in a stall condition.

c. The NTSB believes that the pilots should have activated the engine anti-ice system before the airplane began transiting an area that would have had visible moisture present and in which the temperature was less than 6 °C. Also, despite the guidance in the MD-80 FCOM, the pilots failed to recognize indications that the engine inlet probes were accreting ice. The NTSB is concerned that the infrequency with which high altitude ice crystals impact engine operation may result in flightcrews not fully understanding the risk associated with high altitude ice crystals and how they can affect flight operations.

Recommended action: Directors of safety, directors of operations, fractional ownership program managers (as applicable), and flightcrew members of turbine aircraft need to understand, be aware of, and maintain constant vigilance for signs of high altitude icing conditions, for the effect these conditions can have on airplane and engine performance, and the need for the appropriate use of the engine anti-ice system.

APPENDIX 9
EASA SIB

EASA Safety Information Bulletin

SIB No.: 2015-07
Issued: 15 April 2015

Subject: **Prevention of Hazardous Low Speed at High Altitude Cruise**

Ref. Publication: None

Applicability: All aeroplane type designs with a maximum altitude above flight level (FL) 300.

Description: Recent civil aviation accidents have resulted from a loss of control where the aeroplane was initially cruising at high altitude (above FL 300).

Upset recovery training programs developed by the Aviation Industry resulting from EASA recommendations provide pilot training, which puts emphasis on stall recovery.

However, these training programs may be usefully complemented by information helping crews to prevent the development of hazardous low speed situation at high altitude.

At this time, the safety concern described in this SIB is not considered to be an unsafe condition that would warrant Airworthiness Directive (AD) action under EU 748/2012, Part 21.A.3B.

Recommendation(s): Flight crews should be reminded of some basic flight physics principles to better manage the aeroplane speed (Mach number) when flying at high altitudes to prevent entry into upset situations such as stall.

The following principles are reminded:

1. At high altitude, the maximum available thrust is considerably lower than at lower altitude.
2. Effects of speed reduction from the trimmed flight condition at cruise Mach:
   - When Mach decreases from the cruise Mach (as e.g. based on external disturbance like turbulence or gusts), the aeroplane drag initially decreases, consistently with Mach reduction. With constant thrust setting (and assuming level flight) the aircraft has a natural tendency

This is information only. Recommendations are not mandatory.

F O B

FLIGHT OPERATIONS BULLETIN

FLIGHT OPERATIONS

Boeing Long Beach

August 6, 2002
ATA: 22-00, Autoflight
Bulletin No. MD-80-02-02A

Applicable to: *All MD-80 Aircraft*

Subject: DESCRIPTION OF THE MD-80 AUTOPILOT MODES

On July 19, 2002, Long Beach Flight Operations issued Flight Operations Bulletin MD-80-02-02. This bulletin is a re-issue of the same with a deletion. Please destroy Bulletin MD-80-02-02 and replace it with MD-80-02-02A.

Boeing LBD is issuing this bulletin as a result of a recent MD-80 incident. The incident occurred after the subject aircraft was unable to maintain cruise airspeed, while level at cruise altitude. Over a period of some five or more minutes, the airspeed decayed to the point that stick-shaker was activated, and the STALL aural warning was annunciated. During the entire period of airspeed decay, the autopilot maintained the commanded cruise altitude. The intent of this bulletin is to examine the characteristics of the MD-80 autopilot system, as they pertain to this occurrence.

The MD-80 autopilot/autothrottle system operates in two basic modes, Speed on Thrust (SOT) or Speed on Pitch (SOP). When in the Speed on Thrust mode, elevator commands are used to control to a vertical flight path - either Altitude Hold or Vertical Speed, while the auto throttles adjust power to maintain the selected airspeed. In the Speed on Pitch mode, the elevator commands are used to maintain the selected airspeed, while the autothrottles will normally go to idle or the thrust limit and remain fixed.

While in the Speed on Thrust mode, pilots must monitor the selected airspeed to ensure that the thrust available is sufficient to control speed. For example, if too high a vertical speed is selected in descent, the airplane will overspeed since the throttle can only retard to idle thrust. Similarly, if too high a vertical speed is selected in climb, the airplane could decelerate into a stall warning before the autopilot trips off. The thrust available may be insufficient to maintain the selected airspeed even at the thrust limit.

Flight Operations, Boeing Long Beach, 3855 Lakewood Boulevard, M/C: (D041-0055)
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BOEING

[redacted]

EPR ERRATIC OR FIXED

NOTE: This condition may occur due to icing or EPR indication malfunction.

Flight Conditions

◆ **Icing**

ENG IGN Selector/Switch . . . . SYS A OR SYS B / GRD START & CONTIN / CONTIN

Airplanes with SYS A / SYS B Selectors: Rotate ENG IGN selector to SYS A or SYS B for a maximum of 10 minutes.

ENG Anti-Ice Switches. . . . . ON

EPR Indications and Other Parameters

◆ **Normal**

[END]

Still abnormal

No icing

Throttle/Indications . . . . ADJUST/OBSERVE

Move throttle and observe EPR, EGT, N1, N2, and FUEL FLOW indications.

◆ **Normal response/EPR erratic**

Assume EPR circuit malfunction. Use N1 for setting power.

[END]

EPR fixed

Associated PRESSURE RATIO C/B (Upper EPC) (If Tripped) . . . . .RESET

CAUTION: One reset of a tripped circuit breaker may be attempted after a cooling period of approximately 2 minutes. If the circuit breaker trips again, do not attempt another reset.

If EPR indication remains fixed, use N1 indication for setting power.

[END]

APPROACH TO STALL OR STALL RECOVERY

<u>WARNING:</u> During takeoff, a stick shaker, STALL warning light, horn, or, in some airplanes "STALL" aural warning at rotation may indicate an improper flap/slat configuration. PF immediately call out "SLATS EXTEND," and PNF confirm "SLATS EXTENDED."

If conditions permit, accept an altitude loss while accelerating to an appropriate speed for the existing configuration.

NOTES: Do not use flight director commands during the recovery.

Premature recovery may result in a secondary stall or inability to accelerate with thrust available.

Immediately do the following at the first indication of stall warning (buffet or stick shaker).

(CONTINUED)

APPROACH TO STALL OR STALL RECOVERY (Continued)

FIRST INDICATIONS OF APPROACH TO STALL

PILOT FLYING	PILOT NOT FLYING
Initiate the recovery: • Hold control column firmly. Simultaneously, • Disconnect autopilot and autothrottles. Apply takeoff/ go-around or MCT thrust as applicable. If ground contact is imminent, apply thrust to mechanical stops. • Reduce angle of attack by applying nose down elevator until buffet and stick shaker stop. ***<u>WARNING:</u> In some cases, control column may not immediately provide needed pitch response. In such cases, it may be necessary to apply up to full forward control input, enhancing that input with pitch trim if necessary.*** ***Excessive use of pitch trim or rudder may result in one or more of the following:*** ***– Aggravation of the condition.*** ***– Loss of control.*** ***– High structural loads.***	• Monitor altitude and airspeed. • Verify all required actions have been accomplished and call out any omissions. • Call out any trend toward terrain contact.

(CONTINUED)

APPROACH TO STALL OR STALL RECOVERY (Continued)

PILOT FLYING	PILOT NOT FLYING
Continue the recovery: • If in a turn, roll in the shortest direction to, and maintain, wings level. • Confirm speed brakes stowed. • If conditions permit, accept an altitude loss while accelerating to an appropriate speed for existing configuration. • If flaps/slats or landing gear are extended, do not change configuration during stall recovery.	• Monitor altitude and airspeed. • Verify all required actions have been accomplished and call out any omissions. • Call out any trend toward terrain contact.
Complete the recovery: • Accelerate to an appropriate speed for existing speed for existing configuration, then adjust configuration as desired. Return to appropriate altitude and airspeed. • Re-engage autopilot and autothrottles if desired	• Monitor altitude and airspeed. • Verify all required actions have been accomplished and call out any omissions. • Call out any trend toward terrain contact.

[END]

AIRFOIL ICE PROTECTION OPERATION

NOTES: Engine anti-ice should be on whenever icing conditions exist or are expected. Airfoil anti-ice should also be used if conditions warrant.

When icing conditions exist in immediate vicinity of departure airport, airfoil anti-ice should be on prior to start of takeoff roll.

Airfoil icing conditions can exist when ram air temperature is below 6°C (42°F) and there is visible moisture in the air. In addition to temperatures below 6°C (42°F), be alert for ice buildup on windshield wiprs or edges of windshields.

The higher the temperature, the higher the cloud liquid water content and the more severe will be the icing conditions. At temperatures below –20°C (–4°F), icing conditions encountered should be less severe. However, heavy icing has on occasion been reported at temperatures as low as –60°C (–76°F).

ENG Anti-Ice Switches . . . . ON

PNEU X-FEED VALVE Levers . . . . OPEN

AIR FOIL Anti-Ice Switch. . . . . ON

WING ANTI-ICE ON Light. . . . . CHECK ILLUMINATED

When airborne,

PNEU PRESS Gage . . . . ABOVE YELLOW ARC

(CONTINUED)

AIRFOIL ICE PROTECTION OPERATION (Continued)

NOTES: AIRFOIL ICE PROT PRESS / AIRFL ICE PRES ABNML lights/annunciations may illuminate but will go extinguish within 1 minute. This is a normal indication. However, the ICE PROTECT TEMP LOW / L/R ICE PROT TEMP LOW lights/annunciations may also illuminate with engines at low power. In order to provide adequate ice protection, power should be increased enough for light(s) to extinguish.

Once each 15 minutes of operation of wing anti-ice system, tail de-ice system will automatically be operated for 2-1/2 minutes. During that time, the wing will not be anti-iced. At completion of the 2-1/2 minute period, system will revert to wing anti-ice and start a new 15-minute cycle.

Manual tail de-ice should be initiated 1 minute prior to extension of landing flaps (normally just prior to landing gear extension).

When icing conditions no longer exist,

AIR FOIL Anti-Ice Switch . . . . OFF

NOTE: With X-FEED valves open, tail de-ice will be provided for 2-1/2 minutes after AIR FOIL anti-ice switch is moved to OFF.

When TAIL DE-ICE ON light extinguishes,

PNEU X-FEED VALVE Levers. . . . . CLOSE

NOTE: One or both L/R ICE PROT TEMP HIGH annunciations or ICE PROTECT TEMP HIGH lights may illuminate upon completion of the 2-1/2 minute tail de-ice cycle if PNEU X-FEED VALVE levers are left in OPEN.

ENG Anti-Ice Switches . . . . OFF

[END]