Republic of Lebanon

Ministry of Public Works & Transport

Investigation Report on the Accident to

Ethiopian 409 – Boeing 737-800
Registration ET-ANB
at
Beirut - Lebanon
on
25th January 2010

Presented by the IIC on 17th January 2012

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Ministry of Public Works & Transportation
Beirut
Lebanon

17th January 2012

His Excellency Mr. Ghazi El-Aridi
Minister of Public Works & Transportation

Dear Mr. Minister,

I have the honor to submit the report on the circumstances of the accident to the Ethiopian 409 flight, a Boeing 737-800, registration ET-ANB, that crashed into the Mediterranean Sea, SW of Beirut Rafic Hariri International Airport on 25 February 2010.

Yours sincerely,

Captain Mohammed Aziz
Investigator In Charge

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FOREWORD

Lebanon is a signatory to the Convention on International Civil Aviation (Chicago 1944) and a founding member of the International Civil aviation Organization (ICAO). In line with Article 26 of the Convention, the Lebanese Government launched an investigation into the accident that occurred to Ethiopian Airlines flight 409 (ET409), a Boeing 737-800 type aircraft registered ET-ANB. An Investigation Committee (IC) and an Investigator in Charge (IIC) were appointed by the Lebanese Minister of Public Works & Transportation. The State of Registry/Operator and the State of Manufacturer were both invited to appoint accredited representatives to the IC.

A Preliminary Report was presented to the Lebanese Government on February 25, 2010. Two Investigation Progress report were presented to the Lebanese Minister of Public Works & Transportation on February 10, 2011 and on August 25, 2011; both reports were released to the public and have been posted on the Lebanese CAA website www.lebcaa.com. The final draft report was presented as a confidential document to HE the Lebanese Minister of Public Works and Transportation on 10th September2011 and circulated to all parties (the NTSB -USA, ECAA - Ethiopia & BEA - France) for comments, as per ICAO Annex 13 requirements. The comments were received in due time and discussed with all parties prior to the issue of this final report. Some differences remained between the views of the Ethiopian party and the rest of the Investigation Committee's members. These differences are appended as "Appendix Z" to this report.

In accordance with Annex 13 to the Convention and with the Lebanese Air Regulations (LAR), the investigation has not been conducted so as to apportion blame, or to assess individual or collective responsibility.

Consequently, the sole objective of this investigation into the tragic accident of ET 409 is to establish what happened, to analyze how and why the occurrence took place, and from this analysis to determine what the occurrence reveals about the safety health of the aviation system. Such information is used to arrive at conclusions and make safety recommendations aimed at drawing lessons from what happened in order to prevent similar reoccurrences, and where appropriate, to increase the overall safety of the aviation system.

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

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Symbols and Abbreviations

A/C	Air Conditioning
ACC	Area Control Centre
ADD	Addis Ababa Bole International Airport
AFM	Airplane Flight Manual
AOA	Angle of Attack
APU	Auxiliary Power Unit
ATC	Air Traffic Control
ATHR	Auto Throttle
ATIS	Automatic Terminal Information Service
ATPL	Airline Transport Pilot License
AVSEC	Aviation Security
BEA	Bureau d'Enquêtes et d'Analyses
BITE	Built-In Test Equipment
BRHIA	Beirut Rafic Hariri International Airport
CAM	Cockpit Area Microphone
CB	Cumulonimbus Cloud
CG	Centre of Gravity
CPL	Commercial Pilot's License
CSMU	Crash Survivable Memory Unit
CVR	Cockpit Voice Recorder
°	Degree
DGCA	Directorate General of Civil Aviation
DFDR	Digital Flight Data Recorder
DFSD	Director of Flight Safety Department
D/IIC	Deputy Investigator in Charge
DNA	Deoxyribonucleic Acid
ECAA	Ethiopian Civil Aviation Authority
ECAR	Ethiopian Civil Aviation Regulations
ET 409	Ethiopian Airlines flight 409
FCL	Flight Crew Licensing
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
Ft or '	Feet
FIR	Flight Information Region
FL	Flight Level
FMC	Flight Management Computer
F/O	First Officer/Co-pilot
FOPM	Flight Operations Policy Manual

GD	Crew General declaration
IASL	Integrated Aircraft Systems Laboratory
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFSO	In-Flight Security Officer
IIC	Investigator in Charge
IOSA	IATA Operational Safety Audit
Knots / Kts	Nautical Miles per Hour
LARs	Lebanese Air Regulations
LAT	Lebanese Air Transport
LCAA	Lebanese Civil Aviation Authority
LIS	Lebanese Investigation Committee
LT	Local Time
NLG	Nose Landing Gear
MAC	Mean Aerodynamic Chord
M-Cab	Multi-purpose engineering simulator Cab
MCP	Mode Control Panel
MEL	Minimum Equipment List
MET	Meteorology
METAR	Meteorological Airport Report
MHz	Mega Hertz
MTOW	Maximum Takeoff Weight
NM	Nautical Mile
NOTAM	Notice to Air Men
NTSB	National Transportation Safety Board (USA)
PA	Public Address
%	Percent
PF	Pilot Flying
PIC	Pilot in Command
PM	Pilot Monitoring (Ethiopian Airlines)
P/N	Part Number
RCC	Rescue Coordination Centre
ROV	Remotely Operated Vehicle
SAR	Search and Rescue
”	Seconds
SID	Standard Instrument Departure
SIGMET	Significant Meteorological Information
S/N	Serial Number
SSCVR	Solid State Cockpit Voice Recorder
SSFDR	Solid State Flight Data Recorder

STD	Scheduled Time of Departure
TAF	Terminal Area Forecast
TEMSI	Significant weather chart
TU	Pitch Trim Units
ULB	Underwater Locator Beacon
UTC	Universal Time Coordinated
Vd	Dive Velocity
VHF	Very High Frequency
VOLMET	Meteorological Information for Aircraft in Flight

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Synopsis

Date of accident
25th January 2010 at 00:41:30 [1]

Site of accident
About 5 NM South West of BRHIA, Mediterranean Sea

Type of flight
International public transport of passengers.
Scheduled flight ET 409

Aircraft
Boeing 737-800

Registered ET-ANB

Owner
CIT Aerospace International Corporation

Operator
Ethiopian Airlines

Persons on board

Flight crew: 2
Cabin crew: 5
IFSO: 1
Passengers: 82

Summary

On 25 January 2010, flight ET409 took off from Beirut Rafic Hariri International Airport (Lebanon) bound for Addis Ababa Bole International Airport (Ethiopia) on a regularly scheduled revenue flight. Less than five minutes after take-off the plane crashed into the sea.

Consequences

	People			**Equipment**
	Fatally Injured	Injured	Unhurt	
Crew	8	-	-	Destroyed
Passengers	82	-	-	
Third parties	-	-	-	

(1) All times in this report are UTC, except where otherwise specified. 2 hours should be added to obtain the local time (LT) applicable in Lebanon on the day of the accident.

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Executive Summary

On 25 January 2010, at 00:41:30 UTC, Ethiopian Airlines flight ET 409, a Boeing 737-800 registered ET-ANB, crashed into the Mediterranean Sea about 5 NM South West of Beirut Rafic Hariri International Airport (BRHIA), Beirut, Lebanon.

ET 409 was being operated under the provisions of the Ethiopian Civil Aviation Regulations (ECAR) and as a scheduled international flight between BRHIA and Addis Ababa Bole International Airport (ADD) - Ethiopia. It departed Beirut with 90 persons on board: 2 flight crew (a Captain and a First Officer), 5 cabin crew, an IFSO and 82 regular passengers.

The flight departed at night on an instrument flight plan. Low clouds, isolated cumulonimbus (CB) and thunderstorms were reported in the area. The flight was initially cleared by ATC on a LATEB 1 D departure then the clearance was changed before take-off to an *"immediate right turn direct Chekka"*. After take-off ATC (Tower) instructed ET 409 to turn right on a heading of 315°. ET 409 acknowledged and heading 315° was selected on the Mode Control Panel (MCP). As the aircraft was on a right turn, Control suggested to ET 409 to follow heading 270° *"due to weather"*. However, ET 409 continued right turn beyond the selected heading of 315° and Control immediately instructed them to "*turn left now heading 270°"*. ET 409 acknowledged, the crew selected 270° on the MCP and initiated a left turn.

ET 409 continued the left turn beyond the instructed/selected heading of 270° despite several calls from ATC to turn right heading 270° and acknowledgment from the crew. ET 409 reached a southerly track before sharply turning left until it disappeared from the radar screen and crashed into the sea 4' 59" after the initiation of the take-off roll (4'17" in the air). The aircraft impacted the water surface around 5 NM South West of BRHIA and all occupants were fatally injured. Search and Rescue (S&R) operations were immediately initiated.

The DFDR and CVR were retrieved from the sea bed and were read, as per the Lebanese Government decision, at the BEA facility at Le Bourget, France. The recorders data revealed that ET 409 encountered during flight two stick shakers for a period of 27" and 26". They also recorded 11 *"Bank Angle"* aural warnings at different times during the flight and an over-speed clacker towards the end of the flight. The maximum recorded AOA was 32°, maximum recorded bank angle was 118° left, maximum recorded speed was 407.5 knots, maximum recorded G load was 4.76 and maximum recorded nose down pitch value 63.1°.

The DFDR recording stopped at 00:41:28 with the aircraft at 1291'. The last radar screen recording was at 00:41:28 with the aircraft at 1300'. The last CVR recording was a loud noise just prior to 00:41:30.

The investigation revealed that the probable causes of the accident were the flight crew's mismanagement of the aircraft's speed, altitude, headings and attitude through inconsistent flight control inputs resulting in a loss of control and their failure to abide by CRM principles of mutual support and calling deviations. The other contributory factors that could have lead to probable causes are the increased workload and stress levels that have most likely led to the captain's reaching a situation of loss of situational awareness similar to a subtle incapacitation and the F/O failure to recognize it or to intervene accordingly. The root causes for these failures are discussed in the analysis phase of this report.

Safety recommendations are made affecting the operator, the ECAA, ICAO and Lebanon.

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Organization of the investigation

On Monday 25th January 2010 at around 00.47, the Lebanese DGCA was informed of the loss of radio and radar contact with flight ET 409 a few minutes after take-off from Beirut.

After having established without doubt that the airplane had disappeared, the Lebanese Authorities launched a technical investigation. In accordance with article 26 of the Convention and ICAO Annex 13 *"Aircraft Accident and Incident Investigation"*, an Investigation Committee (IC) from Lebanese investigators was formed by a ministerial decree issued by the Minister of Public Works and Transport in order to conduct the technical investigation. An investigator-in-charge (IIC)[2] was designated in the same decree to lead and initiate immediately the investigation. As per Annex 13 provisions, the USA as State of Manufacture, and Ethiopia as State of the Operator/Registry, were invited to appoint accredited representatives and to be associated with the IC.

Following the existence of a Memorandum of Understanding between the French Bureau d'Enquêtes et d'Analyses (BEA) and the Lebanese DGCA, the BEA was also invited to assist the Lebanese authorities to conduct the investigation.

The Investigation Committee composition was as follows:

Lebanon – State of occurrence
France – Technical Advisor to the State of Occurrence
Ethiopia – State of Registry / Operator
USA – State of Manufacture

Two working groups were formed as follows:

- Operations
- Engineering & Maintenance

A Sea Search & Rescue (SSR) team was formed by Lebanese Army in conjunction with the Ministry of Public Works & Transportation. All Sea Search & Rescue operations were conducted in full coordination with the IC including daily briefings given by the SSR team to the members of the IC.

As per the Lebanese Government decision and in accordance with the Memorandum of Understanding (MOU) signed between the Lebanese DGCA and the French BEA, the DFDR and CVR were read at the BEA facilities at Le Bourget, near Paris, France. Both recorders were transported directly to the BEA under the custody of the State of Occurrence accompanied by members from the IC and readings were performed by BEA personnel in association with and under the direct supervision of the IC.

It was also decided that media relations till the release of the final investigation report were to be handled by the Lebanese Minister of Public Works & Transportation with factual data and information relayed through the IIC directly to the Minister.

[2] Dr. Hamdi Chaouk was appointed as IIC in January 2010. He was replaced as IIC by Captain Mohammed Aziz, Ph.D., as of January 2011.

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1. FACTUAL INFORMATION

1.1 History of Flight

On 25 January 2010, the accident airplane departed BRHIA, Beirut, Lebanon, as Ethiopian Flight 409 (ET 409), destined for ADD, Addis Ababa, Ethiopia.

The following chronological history of flight was reproduced from verified data retrieved from the aircraft DFDR and CVR, in addition to verified data from Air Traffic Control (ATC) recordings and radar transcripts. Eye witness reports and interviews have also been considered.

During the pre-flight preparation phase the crew was heard on the CVR discussing various operational issues within the crew and with the ground personnel. They were also heard receiving the ATIS on VHF and conducting the appropriate briefing and checklists. In addition to these operational issues, the crew was heard discussing their lay-over stay in Beirut and the meal which could have affected the quality of their sleep prior to operate the flight. However, their tone of voice and discussions were normal during that phase. The captain was also heard confirming that this was his first flight into Beirut.

Once boarding was finished and at time 00:30:49 the Flight Crew of Ethiopian Flight 409 received and read back the IFR clearance for a departure via LATEB 1 D[3] with an initial climb to 3000'. Between 00:30:14 and 00:30:29, ATC – Ground issued taxi instructions to ET 409. ET 409 was then handed over to the ATC - Tower frequency 118.90 and the Flight Crew advised the Tower controller that they were taxing on Lima .The Tower gave the clearance to line up runway 21 and report ready for departure.

At time 00:35:36 the Tower controller cleared Ethiopian 409 for takeoff and amended the departure clearance with an instruction to make an immediate right turn to CHEKA[4]. The Flight Crew read back the clearance. At 00:36:33, the takeoff thrust was set and N1 value reached 90%. The recorded FMC data showed an airspeed selection of 170 kts, an altitude selection of 3000' and a flaps setting at 5. Both Navigational Display (ND) ranges were set to 10 miles; the captain's display showed "Weather" while the F/O display showed "Terrain". The stabilizer that was recorded on the DFDR was approximately 5.94 units at the start of the takeoff roll.

During the take-off roll and as the aircraft was accelerating towards 80 Kts, sound similar to interferences on the radio were recorded and heard on the CVR. The captain was then heard saying (in Amharic) "*do you see that?"* 3" later, the F/O was heard on the CVR saying "*eighty knots".*

The rotation was initiated at time 00:37:08 and lift off recorded 7" later. The computed airspeed was 145 kts at rotation and 166 Kts at the time the main gear liftoff. The landing gears were retracted at 00:37:20 and at 00:37:35 sounds consistent with the trim wheel turning were recorded and heard on the CVR. The DFDR records did not show at that time any commanded trim input; however, it recorded an increase in nose up Pitch Trim (TU) from 5.9 to 6.1 units between 00:37:35 and 00:37:36, the recorded speed at that time was 171 Kts. The captain called

[3] The Lateb 1 D SID is attached as Appendix L to this report

[4] Chekka is a VHF Omni-directional Range (VOR) navigational facility located 31 miles North East (016°) of BRHIA

"NAV, Heading Select rather", the F/O replied *"Heading Select"*. A continuous pull back force on the control column was recorded throughout that period.

At time 00:37:39 the Tower controller instructed ET 409 to turn right initially heading three one five. The Flight Crew replied *"three one five, roger."* The heading selection on MCP changed at 00:37:49 from 210° to 315°. At time 00:37:51 the captain called "*N one flaps one speed, flaps up speed rather"*, to which the F/O replied by *"roger"*. At time 00:37:59 the MCP airspeed selection increased from 150 Kts to 216 Kts and a right wheel input was commanded while the pull back force was still recorded on the control column. The aircraft was passing 1450'.

At time 00:37:57 and 00:38:02 sounds consistent with trim wheel turning were recorded and heard on the CVR. The DFDR data show at the same time two separate pilot commanded nose up trim inputs for 1" each time. The DFDR recorded an increase in pitch trim from respectively 6.1 to 6.4 units and from 6.4 to 7.0 units and an airspeed of 173 Kts at 00:38:02. The continuous pull back force on the control column that had been recorded since take-off was released at that time.

At time 00:38:03 the F/O called "*N one flaps up speed"*, the speed at that time was increasing through 174Kts. 4" later the Tower instructed ET 409 to contact Beirut Control *"nineteen three"* and at 00:38:10 the captain ordered Flaps 1. A sound consistent with a flap lever movement was recorded and heard on the CVR. The DFDR recorded 8" later the flaps at detent 1. During that time no inputs to the control column, the wheel or the pedals were recorded on the DFDR. The aircraft continued on a right turn and the speed was increasing. At 00:38:13, sounds consistent with trim wheel turning were recorded and heard on the CVR. The DFDR recorded at the same time a speed trim[5] commanded nose up trim input for a period of 2". It also recorded an increase in pitch trim from 7.0 to 7.6 units and a speed of 192 Kts increasing at the beginning of that period.

At time 00:38:17 ET 409 contacted Beirut Control passing 2000'. The crew received and read back the clearance to climb to flight level 290 and the altitude was selected on the MCP. The aircraft was still on a right turn when at 00:38:22 sounds consistent with trim wheel turning were heard on the CVR. The DFDR records did not show at the same time any commanded trim input; however, it recorded an increase in pitch trim from 7.6 to 7.7 units at time 00:38:23, the recorded airspeed at that time was 206 Kts. The same sounds were heard again on the CVR 7" later, the DFDR records show at that time a speed trim commanded nose up trim input resulting in an increase in pitch trim from 7.7 to 7.8 units. The DFDR recorded airspeed at the time was 209 Kts.

The captain commanded *"flaps up"* at 00:38:31 and the F/O confirmed *"Roger flaps up"*. A sound consistent with flap lever movement was recorded and heard on the CVR and the DFDR records show that the flaps were retracted.

At time 00:38:35 Beirut Control advised ET 409, *"Sir, I suggest for you due to weather to follow heading two seven zero to be in the clear for fifteen to twenty miles then go to CHEKA and it's up to you, just give me the heading".* At that time the aircraft was still on a right turn and the roll angle had reached more than 35° triggering an automatic *"bank angle"* call recorded on the CVR at 00:38:41; the same automatic call was also heard at 00:38:43. At 00:38:44,

[5] The 737-800 stabilizer trim can be activated either through pilot electrical or manual command input, or under certain conditions it could be automatically triggered through the speed trim function. For full information on the subject refer to Appendix M.

sounds consistent with trim wheel turning were recorded and heard on the CVR. The DFDR recorded simultaneously a pilot commanded nose up trim input for a period of 3" while at the same time maintaining a control column push of 2° in the nose down direction. This resulted in a recorded increase in pitch trim from 7.9 to 8.7 units along with an airspeed of 196 Kts. (Beyond that point, no stabilizer trim manual command was recorded on the DFDR).

At time 00:38:48, the captain was heard on the CVR enquiring *"two one say again?"* and the F/O asking the Tower "*confirm heading two one zero?"* The aircraft heading at the time was beyond the selected 315° and reached a maximum recorded value of 003°.

Beirut Control replied *"Ethiopian 409, Sir, negative to proceed direct CHEKA, sir, turn left, fly heading two seven zero"*. The captain asked *"left heading two seven zero?"* and the F/O replied and read back *"roger, left heading two seven zero".* The heading selection on the MCP decreased to 270°and the F/O confirmed to the captain *"two seven zero is set"*. This was associated with a sharp left wheel input of approximately 40° commanded by the crew which resulted in a roll angle of 45°, reaching a maximum of 64° left and triggering 5 automatic *"bank angle"* calls recorded on the CVR between time 00:39:01 and 00:39:30. This left wheel input was followed by a right wheel input of 37° which initiated a roll back towards wings level. As the airplane was returning towards wings level, the speed was increasing and the column push was relaxed; the airplane began to pitch up and slow down. The airspeed had reached 243 Kts at 00:39:43 before starting to fall back. Sounds consistent with heavy rain were heard on the CVR during that same period. The aircraft altitude at that time was 4320' and the calculated temperature at that level on that day was +03° centigrade. Engine anti-ice selection was not recorded throughout the flight and no call for such a selection was heard on the CVR.

At time 00:39:40 the captain was heard saying in Amharic *"OK, engage autopilot"*. However, the DFDR data does not show any engagement of any auto-pilot throughout the flight. At the time of the call the DFDR shows the control wheel was Aft from the neutral position and the aircraft roll angle reaching 64° left bank with a heading of 237° and an altitude 4320'. During this time, a column push was also commanded which reduced the pitch attitude to approximately 5°. The column was then returned to neutral and pushed again resulting in the pitch attitude of 12°. The airplane was then returned to wings-level flight at a heading of 204°. However, the pitch attitude continued to increase and the airspeed continued to decrease without any nose down column inputs.

At time 00:39:46 ACC issued ET 409 the following instruction: *"Ethiopian 409 follow heading two seven zero, turn right heading two seven zero".* ET 409 read back *"right heading two seven zero, roger".* The F/O was heard confirming to the captain *"two seven zero set"*. No other action was recorded in compliance to that instruction.

At time 00:40:01, as the aircraft was crossing 7250' and the recorded airspeed 159 Kts decreasing, a speed trim commanded nose down trim input for a period of 7" was recorded on the DFDR associated with a pitch trim decrease from 8.7 to 8.1 units. At 00:40:03, the speed had dropped to 141 Kts and the stick shaker activated at that same time and remained on for a period of 27". AOA values were 18° (right) [6] and 17° (left). 2" later the aircraft pitch angle reached a maximum of 38.5° up and the automatic *"bank angle"* aural warning was heard twice on the CVR between time 00:40:06 and 00:40:08.

[6] The left AOA and right AOA are recorded at once per second at different time stamps on the DFDR data frame. The closest right AOA recorded after 00:40:01 is 18.8°

At time 00:40:09 & 00:40:13, the captain said (in Amharic) *"what is that?",* then repeated in a louder voice, *"what is that?"* At that time the aircraft altitude was approximately 7700', the recorded airspeed was 120 kts, the recorded pitch about 4° up, the AOA values 25.5° (left) and 23.6° (right), and the vertical acceleration is 0.6 g. The maximum AOA values were recorded at 00:40:14 as 32.0° (left) and 30.0° (right).

Then the pitch attitude of the aircraft began to decrease sharply. As the pitch attitude began to decrease, a left bank angle developed that reached a maximum of 68°to the left. Two "*bank angle"* aural warning occurred during the stall followed by right wheel and right rudder command. As the bank angle began to decrease towards wings level and the pitch attitude began to drop further, a nose-up column input was made, reaching a maximum of approximately 11° nose-up as the aircraft pitch attitude passed through zero° at time 00:40:25. The pitch attitude dropped below the horizon and the airspeed began to increase.

During the period of the stick shaker activation, and between 00:40:16 and 00:40:20, the captain was heard on the CVR calling *"go-around"* four times and the F/O replying *"roger, go around"*. The throttles were pushed full forward for a short instant then pulled back a little for a few seconds and then pushed again violently enough to be recorded on the CVR. The auto-throttle was disconnected. At the same time Beirut Control instructed ET 409, *"Ethiopian 409 follow heading two seven zero, sir, follow heading two seven zero, turn right heading two seven zero now".* To which ET 409 replied, *"roger, roger".* Sounds consistent with heavy rain are heard on the CVR.

The stick shaker sound stopped at 00:40:28. AOA values were 14.9° (right) and 11° (left). The nose up column input was still maintained associated with a left wheel input of 50° and a right rudder input of approximately 5° which were maintained for about 20".

With the airspeed increasing beyond 195 Kts, the speed trim system commanded at time 00:40:25 a nose-up trim input for a period of 12" and the pitch trim increased from 8.2 to 9.3 units. (Beyond that point, no stabilizer trim command is recorded on the DFDR or heard on the CVR). At time 00:40:30 a control column push was recorded for a few seconds, the speed kept on increasing and reached a maximum of 238Kts at 00:40:39. The column was then relaxed towards neutral, and the airplane began to pitch up and slow down again. The airplane altitude had reached a minimum altitude of about 6000' and began to climb again. No significant bank angle changes have been recorded over the next 20" as the airplane continued to pitch up and slow down while the left wheel input and right rudder input were maintained.

At approximately 00:40:45, the right rudder input was removed while the left wheel input was maintained. The airplane responded by rolling to the left while it continued to pitch up and slow down. The captain noticed that speed trend and was heard on the CVR saying at time 00:40:48 "*the speed is dropping",* the F/O replied (in Amharic) *"speed is going down"* and the captain immediately said (in Amharic) *"OK, try to do something".* At that moment the DFDR shows the speed dropping through two hundred knots. The pitch attitude increased to a maximum of 31° before beginning to pitch down. The airplane continued to roll left past 35°. The "*bank angle"* aural warning was recorded twice at 00:40:52 and 00:40:54 followed by a right wheel and right rudder command at time 00:40:57.

At time 00:40:56 the stick shaker activated again for a period of 26" while the airplane continued to roll left, eventually reaching 75° of left bank; the AOA values were 14.4° (left) and

13.5° (right); the AOA reached its maximum value of 26° at 00:41:09. A full left wheel was commanded while the right rudder input was maintained. A nose-up column was commanded and gradually increased over the next 17" while the airplane pitched down. Between 00:40:59 and 00:41:08, the altitude stabilized at about 9000 feet. The airspeed reached 150 kts. At approximately time 00:41:08, the wheel returned to neutral and the rudder was commanded 3° left; the bank angle continued to increase to the left.

During this time, Beirut Control called *"Ethiopian 409, Ethiopian 409 you're going to the mountain, turn right now heading two seven zero".* The crew did not respond verbally, but rather activated the microphone for approximately 3" as recorded on both the CVR and the ATC Control tape.

At time 00:41:14, with the wheel and pedal inputs near zero, the airplane continued rolling to the left the roll angle reached a maximum value of 118.5° with a pitch attitude of 48° nose-down. The recorded airspeed at that time was 228 kts increasing and the altitude about 7370 ft decreasing. Over the next 10", as the pitch attitude reached 63.1° nose-down, large left and right wheel inputs were made, and the bank angle decreased to between 35° and 75° to the left.

The stick shaker stopped at time 00:41:22. The AOA values were 18.6° (left) and 18.1° (right), the recorded airspeed was 283 kts increasing and the altitude about 5110 ft decreasing. Right wheel input was made with left rudder input.

Immediately after, at 00:41:26, sounds similar to over-speed clacker were heard on the CVR followed by an additional loud sound as the CVR recording stopped just before 00:41:30.

The DFDR last recorded data was at time 00:41:28 and it shows an airspeed of 407.5 knots (above the maximum dive speed of 400 Kts), an altitude of 1291 ft rapidly decreasing together with a pitch of 32.2° airplane nose down, a left bank roll angle of 61.5°, 3.75 G and engines number 1 & 2 at respectively 93.6% and 93.4% N1 .

Between 00:41:28 and 00:45:10 Beirut Control made several calls to ET 409 with negative response. The AT|C immediately activated the emergency response plan.

No indication of the aircraft being hit by a lightning strike was recorded on the CVR or any interference affecting the flight instruments recorded on the DFDR, apart from the short interference recorded during the take-off roll, prior to the aircraft reaching 80 Kts.

Throughout the time the aircraft spent in the air, the DFDR recorded the control column steady in neutral position between time 00:38:05 and 00:38:41. It also recorded the control wheel steady in neutral position between time 00:38:05 and 00:38:40 and the rudder pedal in neutral between 00:38:05 and 00:39:05. Apart from these periods, the control column and the control wheel were always recording variable pressure from the crew, as well as the rudder pedals, which was continuously used, sometimes in opposite direction to the control wheel inputs.

The standard call "After- Take-off checklist" done by the PF, as stipulated in ET Normal Operations (FCOM v.1, NP.21.42), was not heard on the CVR; neither were the checklist items carried by the PNF heard on the CVR.

Eye witness reports including a Tower controller reported seeing *"a light", "an orange explosion", "a ball that lasted 2-3 seconds"*, or a *"ball of fire"* around the time of the accident.

The following two figures developed by the French Bureau d'Enquêtes et d'Analyses (BEA) reproduce the entire flight horizontal and vertical tracks as derived from the DFDR data:

Figure 1: ET 409 horizontal tracks

Figure 2: ET 409 vertical tracks

1.2 Injuries to Persons

Injuries	Crew Members	Passengers	Others
Fatal	8[7]	82[8]	0
Serious	0	0	0
Light/none	0	0	0

[7] Including 1 IFSO listed on the passengers' manifest with a coded name
[8] Including 2 children

1.3 Damage to Aircraft

The aircraft was completely destroyed.

1.4 Other Damage

Not applicable.

1.5 Personnel Information

1.5.1 Flight Crew

The flight crew consisted of the captain and the first officer. Five flight attendants and an In-Flight Security Officer (IFSO) were also on duty aboard the airplane. All crew were certified in accordance with the ECAA requirements.

1.5.1.1 Captain

Male, according to records provided by Ethiopian Airlines, he joined the company on 27 January 1989 and started operations on agricultural spraying aircraft. He then flew as co-pilot on DHC 6, B 737-200 and B 757/767 type aircraft prior to be promoted to captain on Fokker 50 in 2008.

He holds an Ethiopian ATPL number AA 333, issued 10 June 2008, showing the date of birth as 17 October 1965 and ratings as PIC for Multi-Engine Land on 22 December 1988, for Single Engine Land on 4 January 1989, for Fokker 50 on 10 June 2008 and for Boeing 737-700/800 on 16 October 2009. It also shows ratings as co-pilot for DHC 6 on 31 December 1998, for B 737-200 on 23 July 2002 and for B757/767 on 4 September 2003.

According to records provided by Ethiopian Airlines the captain completed company command training and was released to operate solo as PIC on F-50 as of 7 July 2008. He also completed company training consisting of 120 hours of ground school, 56 hours of simulator and 1 hour of base training prior to commence and then complete his route training and be released to operate solo as PIC on B737-700/800 type aircraft on 3 December 2009. His last recurrent/type rating training was satisfactorily completed on 14 October 2009 and last proficiency check was satisfactorily completed on 15 October 2009. His last CRM was done on 11 December 2007 and the last Adverse Weather and Upset Recovery training done on 15 December 2007. His total flying experience is 10,233 hours including 3,718 hours as PIC of which 2,488 hours are on different light and spray aircraft, 1,042 hours on Fokker 50 and 188 hours acquired since his release to operate solo as PIC on B 737-700/800, 51 days prior to the accident.

Records provided by Ethiopian Airlines show his flying hours in the previous 6 months as 340 hours, 3 months as 236 hours, 30 days as 99 hours and 24 hours as 4.7 hours. His most recent medical certificate was issued on 25 November 2009 and he was found to be medically fit to fly in accordance with the standards specified in ICAO Annex 1, "Medical Standards and Certification."

The Captain arrived in Beirut, Lebanon on the early morning (around 01:30 LT) of 24 January 2009 while serving as PIC on Ethiopian Airlines flight 408. That was his first flight into BRHIA.

Interviews conducted with the captain's superiors, trainers and Next of Kin (NoK) revealed that he had a nice personality, was very polite, open to take criticism, healthy, did not smoke or drink alcohol, was keen on reading and sports and had many sports equipment in his house. Records provided by Ethiopian Airlines do not show any reported sickness or any medical surgery. The only medication he was having was related to a hair fungus treatment.

1.5.1.2 First Officer

Male, according to records provided by ET, he joined the company on 16 January 2009. He holds an Ethiopian Commercial Pilot license number AC 1012, issued 7 April 2009, showing the date of birth as 16 September 1986 and ratings for Single Engine Land on 7 April 2009 and for B 737 700/800 on 25 June 2009. He held a first-class ECAA airman medical certificate with no limitations or restrictions, dated 11 June 2009.

According to records provided by ET, the First Officer graduated from Ethiopian Aviation Academy on 15 January 2009 and was transferred to the ET Flight Operations Division on 16 January 2009. His initial operation training consisted in part of 80 hours course in Jet Conversion, 60 hours of Basic Instrument Flying (Simulator) completed on 16 March 2009 and Adverse Weather Upset Recovery training done on 12 March 2009. He completed company training on B737-700/800 consisting of 120 hours of ground school, 60 hours of Simulator, 1 hour of base training and 64 hours of route training and was fully released to fly solo as First Officer on B737-700/800 on 30 August 2009. His most recent re-currency and proficiency checks were satisfactorily completed respectively on 16 and 17 December 2009.

His total flying experience was 673 flying hours, of which 350 were as released First Officer on B737-700/800 type aircraft. The records show his total flying hours in the previous 6 months as 394 hours, 3 months as 178 hours, 30 days as 56 hours and 24 hours as 4.7 hours.

The First Officer arrived in Beirut, Lebanon on the morning (around 01:30 LT) of 24 January 2009 while serving as First Officer on Ethiopian Airlines flight 408.

Interviews with the F/O superiors, trainers and friends revealed that he had a nice personality, was a good student who graduated among the best 6 in the Flight Academy. He had good family life and relations, no particular medical conditions, save for an appendectomy at some point, an occasional/social smoker who loved his company and carefully prepared his flights. One of the pilots who trained the F/O and flew with him described him in the following terms: *"he seemed like a senior FO on his callouts and performance in flight, he says what he needs to say, he was not the quiet type and I was surprised on the CVR*[9]*."*

1.5.2 Cabin crew

According to records provided by ET, the cabin crew consisted of 5 female flight attendants. All

[9] That pilot was one of the technical advisors to the Ethiopian accredited representative, he had listened to the CVR in that capacity and helped in the translation of the Ethiopian words during the 2nd listening session at the BEA.

5 cabin crew were fully licensed in accordance with the provisions of the ECAA.

1.5.3 IFSO

The IFSO was seated in the front passengers' cabin amongst the passengers. He was counted for the load-sheet as a passenger and listed on the passengers manifest under a coded name. However, he was listed on the Crew General Declaration (GD) and his official status on board was "extra-crew". The IFSO was licensed in accordance with the provisions of the ECAA national regulations after completing the appropriate AVSEC courses and was authorized to fly on board of Ethiopian airplanes in the capacity of IFSO sitting and mixing with the regular passengers.

1.5.4 ATC Controllers

ET 409 was handled by 3 ATC services: ATC Ground for initial departure clearance, push-back and taxi, ATC Tower for take-off clearance and initial climb, and ATC Control for the remaining part of the flight. According to records provided by the BRHIA Navigation Section, all ATC controllers that dealt with the accident aircraft were properly licensed in according to LARs.

1.6 Aircraft information

The aircraft was owned by CIT Aerospace International Corporation. It had been operated by an Irish operator from its entry into service in 2002 until April 2009. Ethiopian Airlines had operated the aircraft since September 2009. The aircraft was configured to seat a maximum of 16 first class, and 138 economy-class passengers and also to carry cargo[10].

1.6.1 Airframe

Manufacturer	Boeing
Type	B737-800
Serial number	29935
Entry into service	February 2002
Change of registration	ET-ANB (11 September 2009)
Certificate of registration	12/09/2009
Registration	ET-ANB
Certificate of Airworthiness	valid until 11/9/2010
Utilization till 24 January 2010	26,459 flying hours and 17,823 cycles

1.6.2 Engines

Manufacturer: CFM International

Type: CFM56-7B27

[10] Refer to cabin map inserted as Appendix A

	Engine No. 1	Engine No. 2
Serial number	890932	890963
Engine time since new	18,110	18,137
Engine cycles since new	11,728	11,757

1.6.3 Weight and balance

The weight and balance form for the event flight was provided by ET and listed a gross takeoff weight of 70,443 kg (155,300 lb). This is consistent with the gross weight that was recorded on the DFDR.

The engine N1 that was applied during takeoff was consistent with a 22k de-rate thrust setting[11]. With a 22k de-rate thrust setting, a weight of 70,443 kg (155,300 lb), and a center of gravity of 18%, the Airplane Flight Manual (AFM) for ET-ANB defines the recommended takeoff stabilizer as approximately 6.9 units. The event weight and balance form listed the stabilizer setting as 5.26 units[12]. This is 1.64 units in the airplane nose-down direction beyond that recommended in the AFM. In addition, the stabilizer that was recorded on the DFDR was approximately 5.94 units at the start of the takeoff, which is still within the certified range for take-off (green-band range).

1.6.4 Condition of the aircraft before departure

No defect or deferred maintenance item was reported on the technical log after the arrival and before departure of the plane from Beirut.

1.6.5 Maintenance operations follow-up

The last four months of the maintenance records were examined within the framework of the investigation.

Ethiopian Airlines have conducted two maintenance checks since the introduction of ET-ANB to the fleet on 12 September 2009. The first check, conducted during November 20-22 timeframe, included a '2A' and a '3A' check. The second check, conducted during the December 24-25 timeframe, included a '1A' and a '4A' check.

Transit checks are conducted after each flight segment and include review of the technical log for any discrepancies noted during the flight. A flight mechanic may be included with the Flight crew for stations with no Ethiopian airlines ground personnel. There was no flight mechanic on board the accident flight as Ethiopian airlines has a technical station engineer stationed in Beirut.

Daily checks are completed prior to the first flight of the day and include routine examination of the serviceability of the airplane for the day's flights.

[11] While the "Notes for the CG Limits" mentioned on the ET 409 Balance Chart (refer to Appendix V) only shows ratings of 24K, 26K and 27K, Appendix 2 of the Airplane Flight Manual (AFM-D631A001.8AS4) applicable to the accident plane includes provisions for the 22K trust rating.

[12] Refer to Appendix V for a copy of the Load-Sheet

Weekly checks are similar to daily checks however include more detailed tasks and are conducted on 50 flight hour intervals. Documentation is retained only for the most recent checks; older check documents are destroyed per the Ethiopian documentation retention policy.

As pertinent to the accident airplane, Ethiopian airlines conduct 'block' checks. There are 'A' checks (system zonal and structural), each with a defined interval of flight hours and cycles. Typical 'A' checks include a general visual inspection of the airframe components (systems and interior components), filter changes, general visual inspection (including baroscopic) of the engines, etc…

A review of the maintenance records for the above mentioned 'A' checks denoted activities associated with airplane preparation (panel access), routine maintenance actions (filter changes, engine oil and hydraulic fluid quantities, etc…), and results of inspection items. Inspection items are noted either as 'no finding' or 'finding' with a reference to a non-routine task card which outlines the anomalous finding and the corrective action taken. All items are signed by both the mechanic and the inspector.

A summary review of all non-routine findings from both the November and December checks noted no significant airframe component issues or interior component issues.

Ethiopian airlines are also certified for 'C' checks. There are 'C' checks (system zonal and structural) and, like 'A' checks, are in 'blocks'. 'C' checks are conducted on an interval of flight hours and cycles. Such checks include detailed airframe and component checks. The accident airplane had not been subject to a 'C' check whilst being operated by Ethiopian airlines as it was not due for one.

The engines logbooks and the airframe and engines airworthiness directives (AD) status were also examined and did not reveal any significant anomalies.

1.7 Meteorological Information

The Lebanese Civil Aviation Authority reviewed the data from the Lebanese Meteorological Services that was collected on 25 January 2010 after the accident. Meteorological data revealed some significant meteorological conditions in the area at the time of the accident. Relevant meteorological documents are included in Appendix B of this report.

1.7.1 General meteorological situation

At the time of the accident, there was thunderstorms activity southwest and west of the field, as well as to the northwest and southwest on the localizer path for runway 16.

1.7.2 Local meteorological situation

The meteorological conditions at the airport were fair and the surface wind recorded at the take-off time was calm, no rain over the field and visibility 8 km. Few CB clouds was recorded at 2000 feet and scattered clouds at 2600 feet.

METAR and TAFOR reports indicate significant meteorological conditions were in the area South West, North West and North East of the airport with isolated CB and thunderstorm activities beyond 10 km from the airport. The D-ATIS was transmitting the METAR. Reports

from arriving traffic at the time of the accident confirmed the reported meteorological conditions.

A SIGMET number 03, valid 242020/250220 was also issued by the Met office. The SIGMET stipulated *"Beirut FIR TS OBS and over OLBA FIR top CB ABV FL 250 moving NE"*. The ATIS weather information transcript is found in Appendix B and was heard by the Flight Crew prior to start-up.

1.7.3 Information collected by the crew

A weather package which includes the METAR, TAF of the departure airport and airports along the flight plan route, wind/temperature charts for FL300, 340 and 390 and significant weather chart for FL100-450 was delivered to the handling agent who acknowledged relaying the same to the ET 409 operating crew. SIGMET number 03, valid 242020/250220 was also issued by the MET office and made available to flight crews through VOLMET.

1.8 Aids to Navigation

The Lebanese Civil Aviation Authority reviewed that the Primary and Secondary radars, including the weather function, were checked and verified for accuracy. All systems tested normal. No other navigation aids were reported to be abnormal.

1.9 Communications

ET409 has been in contact consecutively with the ATC Ground controller (Ground), the tower controller (Tower) and the radar controller (Control). All communication between ET 409 and the 121.9 Ground, 118.9 Tower, and 119.3 Control and Emergency frequency 121.5, have been recorded by the ATC facilities and on the CVR and have been used to produce this report.

1.10 Aerodrome Information

BRHIA, (OLBA) is an international airport with a field elevation of 85' MSL. It is located on the western Lebanese sea shore line to the South of the city of Beirut. The area surrounding the airport is composed of the Mediterranean Sea to the West, the city of Beirut to the North and the mountains of Lebanon to the East. These mountains reach a height of more than 3,000 feet less than 5 NM East and 6900 feet 13 NM East.

Due to this constraint, no departure or approach is allowed from the East. Furthermore, due to the area as of 15 NM South of BRHIA is a military restricted area; no approach to BRHIA is allowed from that area. This leaves a window of opportunity for arriving and departing traffic between a westerly heading and a bearing of 016° from BRHIA to Chekka VOR on the Northern Lebanese sea shore line. All departing and arriving traffic should be channeled through that area.

The airport has three runways:

- Runway 03-21 is 12, 467' long, 3,800 meters.
- Runway 17-35 is 10,663' long, 3,250 meters.
- Runway 16-34 is 11,138' long, 3,395 meters.

Runways 03, 16, 17 are served by an Instrument Landing System (ILS). An Airport lay-out map is included in this report as Appendix C.

The airport is also served by a primary Raytheon Radar system, ASR-10SS and a Secondary radar system, MMSR Condor, MK-2 with automatic Auto tract 2 Display and weather display. All radars and equipment were fully operational on the night of the accident.

1.11 Flight Recorders

The DFDR was recovered from the Mediterranean Sea by the Lebanese Navy divers and turned over to the IIC in presence of members from the IC on 7 February, 2010. The DFDR was immediately packed in water to prevent/delay the onset of corrosion and transported to the BEA laboratory in Paris France under the custody of the IIC accompanied by a Lebanese and an Ethiopian IC members.

The CVR chassis was recovered from the Mediterranean Sea on 10 February, 2010 but was missing the Crash Survivable Memory Unit (CSMU). A thorough hand search of the sea bed was then carried out the Lebanese Navy divers who finally succeeded in retrieving the CSMU and handing it over to the D/ICC in the presence of members from the IC on 16 February. The CSMU was immediately packed in water to prevent/delay the onset of corrosion and transported under the custody of the D/IIC and an Ethiopian member of the IC to the BEA laboratory in Paris France, for readout on 16 February, 2010. A second readout was also conducted at the BEA on 17 September 2010 in the presence of members from the IC in order to validate more data.

1.11.1 Digital Flight Data Recorder (DFDR)

The DFDR installed on the accident airplane was a Honeywell Aerospace Electronic SSFDR, Make & Model Allied Signal 4700, P/N 980-4700-042, and S/N 3986. This model records at least 25 hours of flight data on a solid state memory. The opening and read-out operations were performed following BEA procedures and Honeywell "*Reference Procedure for SSFDR Data Recovery after an Incident or Accident*" document. The memory extraction operations were successful and videotaped.

The CSMU was attached to the chassis. The chassis was damaged but the CSMU was in good condition. A complete set of accident flight data, from take-off through the last recorded DFDR parameters was prepared. There were 1000+ parameters available for the analysis.

Flight performance parameters recorded by the DFDR included but were not limited to the following: pressure altitude; airspeed (computed); engine N1; pitch; roll; heading; AOA (Angle of attack – both left and right sensors); normal (vertical), longitudinal, and lateral acceleration (load factors); left and right elevator positions; left and right aileron positions; left and right trailing edge flap positions; rudder position; horizontal stabilizer position, stabilizer trim operations and stick shaker activation (both left and right stall warning systems). In addition, the DFDR recorded speed brake handle position, both left and right throttle resolver angles, autopilot engagement/disengagement, engine low oil pressure, and engine fuel cut signals. A graphical plot of essential parameters is included in this report as Appendix D.

Figure 3: ET 409 DFDR

A trajectory was computed based on the "*LATITUDE POSITION*" and "*LONGITUDE POSITION*" parameters recorded on the DFDR. These parameters, recorded every 4 seconds, generated to represent this trajectory starting at 00 h 30 min until the end of the DFDR recording at 00 h 41 min 28 s. These files are published in this report as Figures 1 and 2. Another file was generated to represent the flight trajectory in 3D and is published in this report as Figure 11.

Initially, there was a concern related to the DFDR data for the Captain and the F/O control inputs, as many of the control inputs registered by the DFDR as F/O actions were known to have been accomplished by the Captain and vice versa. The issue at hand involved a software revision for the Digital Flight Data Acquisition Unit (DFDAU) and is addressed in details in section 3 of the M-Cab session report appended as Appendix K to this report. Nevertheless, tests and research discussed in section 3 of Appendix K confirmed *"that the pilot in the left seat was flying during the event".*

1.11.2 Cockpit Voice Recorder (CVR)

The CVR installed on the accident airplane was a Honeywell Electronic Systems SSCVR Make and Model Honeywell 6022, P/N 980-6022-001, S/N 05449. The CSMU of the CVR exhibited P/N 617-6096-006, S/N 8922. This model records at least 2 hours of flight on a solid state memory.

The CVR unit chassis exhibited external and internal structural damage with the CSMU detached from the chassis; the CSMU was in good condition. The opening, extraction of the double memory board from the CSMU and the read-out operations were performed following BEA procedures and Honeywell "*Reference Procedure for SSCVR Data Recovery after an*

Incident or Accident" document. The memory extraction operations were successful and videotaped.

The CVR recording consisted of five audio files identified as follows: 3 files containing at least 30' of recording of Captain, First Officer and PA, everyone mixed with VHF communication channels 1, 2 & 3; 1 file containing a mix of at least 2 hours of recordings of the 3 tracks described above; and 1 file containing at least 2 hours of recording of the CAM.

The quality of the audio information recorded by the CAM was good. Synchronization with the DFDR was performed using VHF communications recording on the DFDR allowing a preliminary transcription. Nevertheless, 1 memory chip (presumably U16, on which a crack was visually detected) out of 24 memory chips was still unreadable and prevented getting the full audio CAM track, creating a gap of 10" of missing recording on the CAM channel approximately every 4 minutes. An attempt to recover these lost 10" was carried out at the BEA and is addressed in section 1.16 of this report.

The CVR recording was heard a first time on 17 February 2010 and a preliminary transcript developed in the presence of BEA personnel, Lebanese, USA and Ethiopian members of the IC and Captain Haile Belai as an independent expert requested by the Lebanese party to translate the Amharic conversation recorded during the event.

A second hearing of the CVR was conducted on 17 September 2010 at the same BEA location in the presence of BEA personnel, Lebanese, USA and Ethiopian members of the IC. Amharic conversation was translated by Captain Gedlu Melesse and Captain Tensae Berhanu from Ethiopian Airlines. The purpose of that hearing was to cover in more details the discussions that occurred during the pre-flight phase.

Figure 4: CVR Chassis

Figure 5: CVR chassis with CSMU

1.12 Wreckage and Impact Information

1.12.1 Recovery Operations

The airplane wreckage was located in debris field about 300 meters long and 100 meters wide centered about a latitude of 33^0 44.6' North and a longitude of 035^0 24.58' East on a heading of 210^0 magnetic. The water depth in this area was approximately 45 meters.
About 8% of the airplane was recovered during the initial recovery operations, which began along with the S&R operations and continued till the morning of 25 January and ended on 19 February 2010.

The largest pieces found consisted of the tail section including the horizontal and vertical stabilizer and aft fuselage section extending forward to the #2 left entry door. These sections were found at the north eastern portion of the wreckage field.

A number of pieces of floating wreckage were recovered from the water's surface near to the last recorded radar point and to various distances north east of that point. One of these pieces was the winglet panel that was identified by the logo paint scheme and by the part number located on the interior surface. This panel was from the side lower closeout panel at the wingtip as shown in figure 6. That part is of composite material. It was found floating near the beach of Beirut, about 8 NM NE of the impact site.

Many evaluation visits to examine the wreckage were conducted by the Airworthiness Group. They included a thorough examination of the left and right elevators shown in figures 7 and 8. As a result of these visits, the Group also recommended to the IC to further evaluate the

stabilizer trim tab and black soot detected near the APU exhaust. The IC approved these recommendations and both parts were sent for further evaluation through the NTSB as described in section 1.16 of this report.

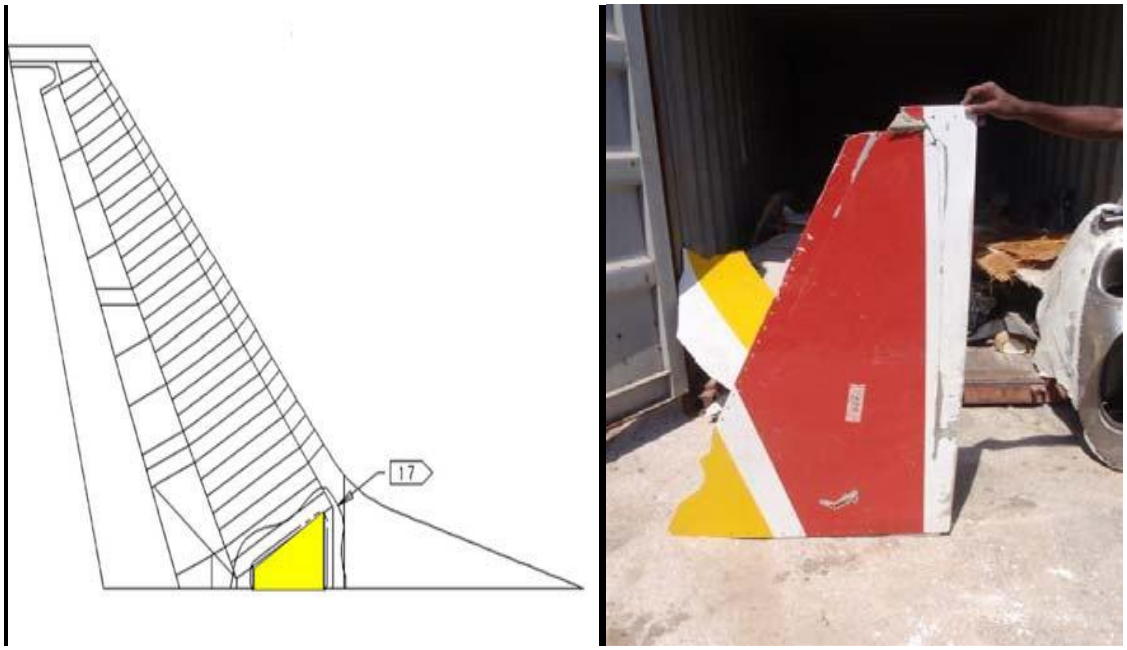

Figure 6: Winglet Panel and its installed location

1.12.2 Identification of the floating items recovered

As of 4 February 2010, 97 pieces of debris were recovered and recorded by the Lebanese Navy. The debris consisted of airplane interior and exterior items as well as items not belonging to the airplane. The following observations were made:

Identified interior components:

- Two bulkheads associated with lavatories (sink & toilet). One tentatively identified as from the forward section of the airplane. The other then must be from the rear section of the airplane (it is equipped with one fwd and two aft lavatories)
- Galley floor mat (rubber)
- Miscellaneous interior floor panels (location in airplane not identified)
- A number of seat covers and cushions from first and economy class
- Crew oxygen cylinder (valve installed but stem broken off)
- One escape slide and two life rafts (independent from escape slides)

Identified exterior components:

- One winglet upper portion (fractured approximately 2/3 way towards the attach point). Logo on both sides of winglet.
- A/C pack door
- NLG door (partial) – left side

- Two composite panels from vertical stabilizer (with logo paint)
- 1 MLG wheel + tire (inflated)
- Portion of elevator and elevator tab

General observations of wreckage:

- Significant impact damage to most components as there is a high degree of fragmentation. Most components were not found fully intact
- Identified seats consisted mainly of loose padding and covers. No seat structure was identified
- No observed damage consistent with heat/ soothing/ smoke. Components appeared clean except for some black soot traces found around the APU exhaust which are addressed in section 1.16 and analyzed in the analysis part of this report.

Figure 7: Left Elevator

Figure 8: Right Elevator

1.12.3 Additional wreckage observations

Based on underwater video recorded from a ROV, the following was observed:

- Aft fuselage section extending from the # 2L passenger door to approximately the rear pressure bulkhead
- Vertical Stabilizer (composite rudder missing)
- Horizontal Stabilizer (centre section & both stabilizer surfaces with approximately 1 meter missing from each end)
- Trailing Edge Flap portion
- Portions of the forward fuselage cockpit section (cockpit window frames and structure)

The horizontal stabilizer section was recovered (during the search for the DFDR and CVR); this portion was relocated to Beirut Naval Station. The Airworthiness Group has recommended the removal of the Trim Tab section and sending it to the NTSB for further investigation. That recommendation was approved by the IC and the Trim Tab analysis is discussed in section 1.16 of this report with he full report attached as Appendix O.

Figure 9: Recovery of the Stabilizer Section

1.13 Medical and Pathological Information

A visual examination of the bodies showed that most of them were severely affected by the high speed impact with the water. All of the bodies and remains were handed over to the Beirut Rafic Hariri Governmental Hospital morgue. DNA analysis and a DNA bank were established by the Medical Authorities to facilitate the positive body identification process.

The IC has had access to autopsy and body examination data made available by the Lebanese Ministry of Health, they included 10 full legal medical autopsies of bodies which were found in conditions allowing this operation to be conducted, and of DNA analysis of all recovered human remains allowing the identification of all persons who were on board the flight.

All the reports observed through clinical exams the absence of burns, wounds and cyanosis. Some of them concluded that *"the death is the consequence of a violent trauma, with projection of the passengers against a hard surface, resulting in severe vital lesions that led to immediate death before the drowning.*

Most passengers suffered even more severe physical consequences that did not allow any autopsy to be carried out. However DNA was extracted from all recovered human remains and all passengers and crew were identified.

The medical forensic reports concluded that passengers died as a result of *"multiple fractures and contusions with consequent acute hemorrhage and immediate death."*

1.14 Fire

A small section of fuselage which normally surrounds the Auxiliary Power Unit (APU) remained attached to the inboard side of the left stabilizer. During examination of the recovered wreckage, the airworthiness team identified a black soot near the APU exhaust. The IC decided to send that part for examination at the NTSB labs in order to determine its source. The analysis is discussed in section 1.16 of this report and the result confirmed that the black soot was not related to excessive heat or fire.

Based on the on-site and lab examination of the recovered wreckage, on the medical and pathological information and on the under-water pictures and video taken of the remaining wreckage, there is no evidence of any pre-impact fire.

1.15 Survival Aspects

Beirut Control contacted Beirut Tower to inform them they felt something went wrong with Ethiopian 409 due to loss of contact. Beirut Control asked Beirut Tower to activate the emergency response plan.

The alarm bell was activated and the Tower contacted the Fire Fighting and Rescue to give them information about the airplane with souls on board and possible emergency at 00:43. The medical department was notified at 00:45. Others were notified in accordance with the chain of command by 00:47.

A brief description of the S&R operations was prepared by the Lebanese Army Command and is included in this report as Appendix E.

Due to the vertical and lateral speed at which the aircraft impacted the water, survival aspects in this accident are irrelevant.

1.16 Tests and Research

1.16.1 Reconstruction of the aircraft track based on the Radar recorded data

Prior to the retrieval of the CVR and DFDR data, a reconstruction of ET flight path was carried out by the Lebanese CAA IT technician in synchronization with the ATC transcript data. This is shown in figure 10 below.

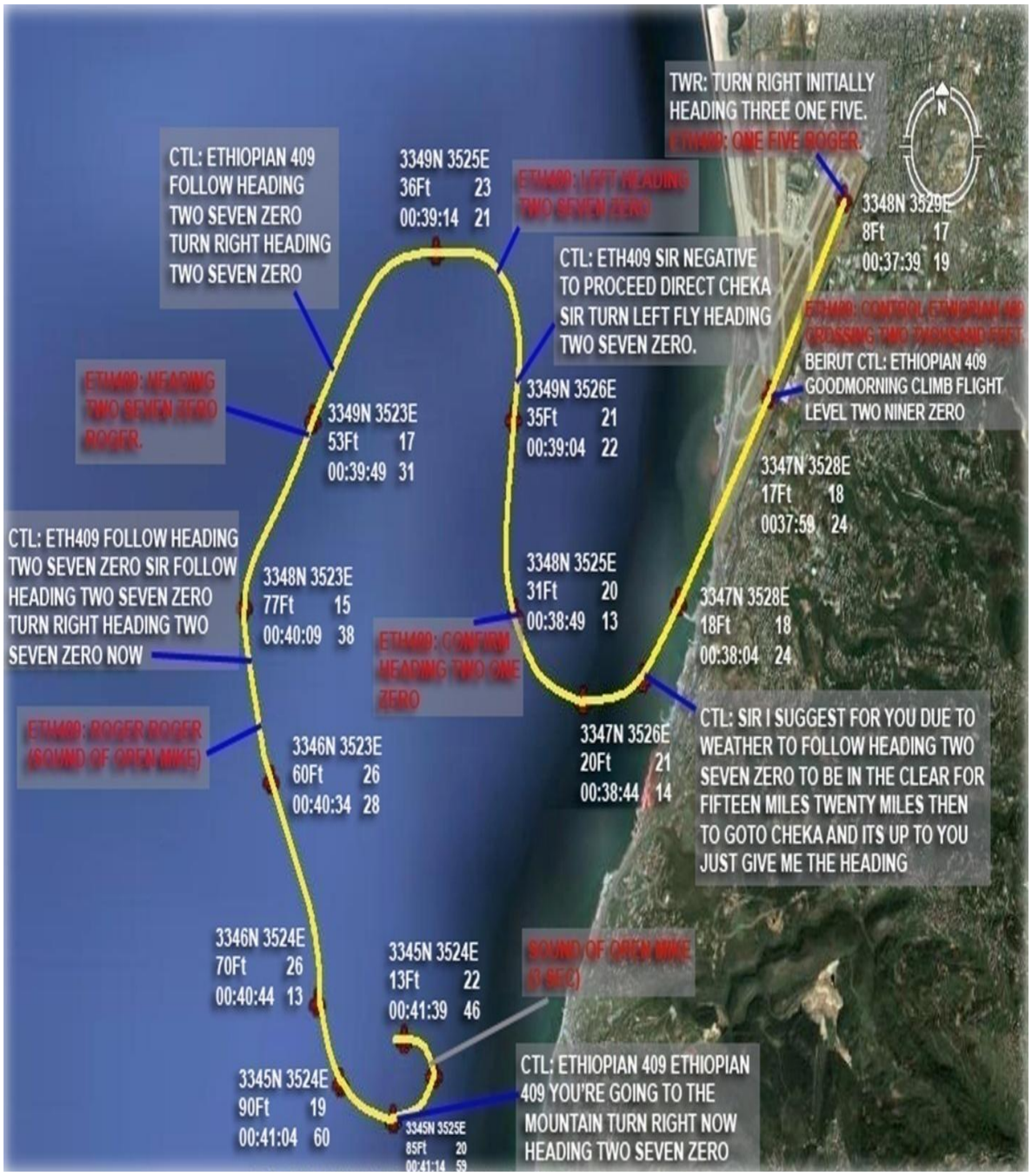

Figure 10: ET 409 Radar Tracks with ATC transcripts

Further reconstruction of ET flight path was later on carried out by the Lebanese CAA IT technician in synchronization with the meteorological office at BRHIA and the ATC weather data. This is shown in figure 11 below.

Figure 11: ET 409 Radar Tracks with cloud information

1.16.2 Reconstruction of the aircraft track based on the DFDR recorded data

A reconstruction of ET horizontal and vertical track were developed by the BEA based on the data retrieved from the DFDR recording. These reconstructions are incorporated as Figure 1 and Figure 2 of this report. The following Figure 12 reproduces in 3D the flight profile associated with the major events points.

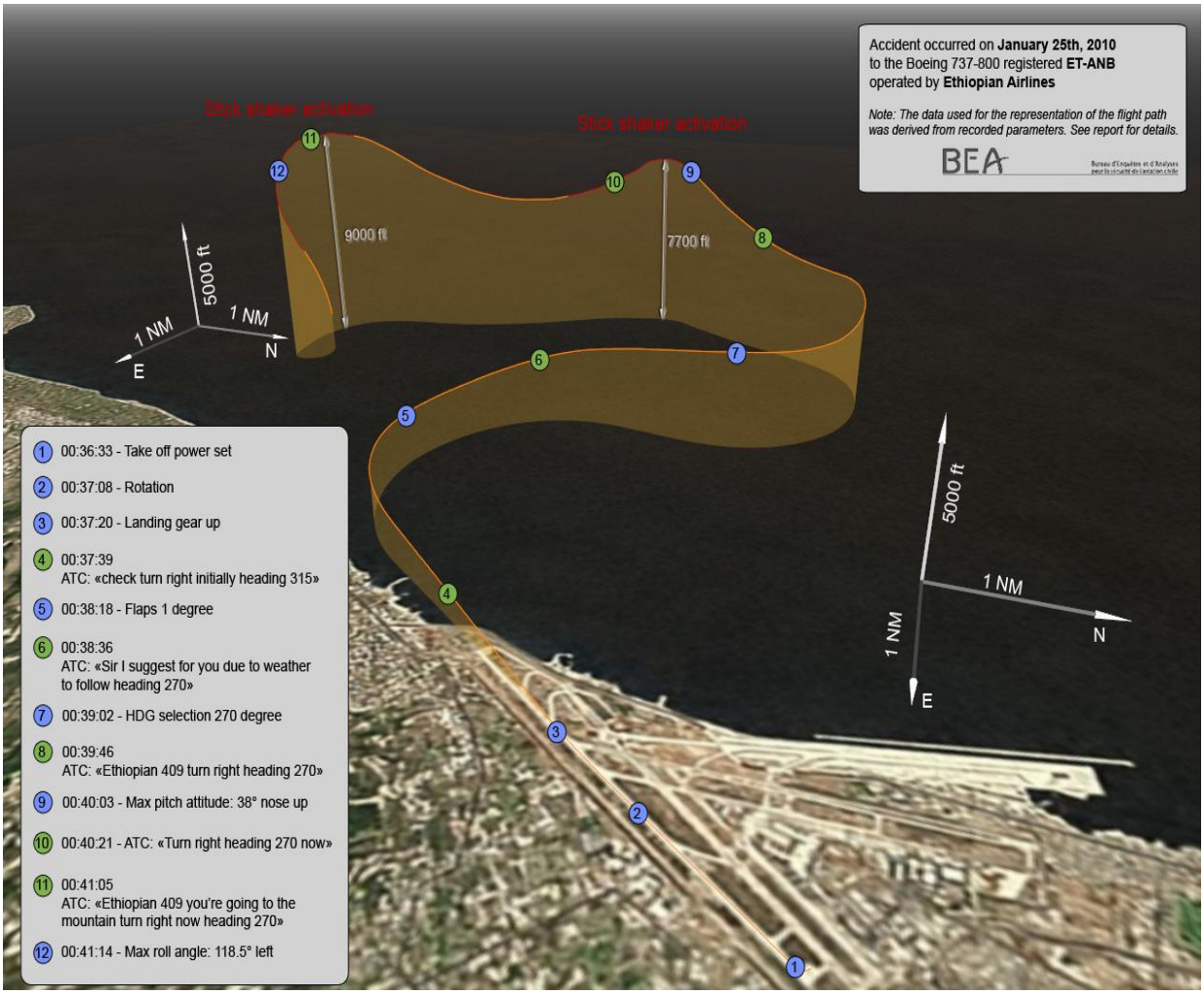

Figure 12: ET 409 Flight 3 D profile

1.16.3 Simulation of the Accident (M-Cab)

Upon the Investigation Committee decision and in cooperation with the NTSB, 3 simulation sessions were conducted at the Integrated Aircraft Systems Laboratory (IASL) located within the Boeing facilities in Seattle, WA on September 22-23, 2010. The sessions were conducted in the Multi-purpose engineering simulator-Cab (M-Cab) in order to simulate the accident based on the recorded data, to verify if the airplane reacted as expected to the recorded control inputs and to perform operations that could help during the analysis phase.

All parties participating in the investigation were notified of the dates and invited to participate in these sessions. Only the USA and Lebanese parties participated. The BEA had advised the Investigation Committee that it was not necessary for them to attend. The Ethiopian party had notified the IIC that they will attend but did not show up.

The M-Cab is an engineering simulator that is capable of supporting 707, 727, 737, 747, 767, 777, & 787 Boeing models. The cab itself is a 767 flight deck shell with a generic interior, 2 pilot seats, 3 observer seats, and a wrap-around 180-degree visual system on a 6-degree of freedom motion system platform. It utilizes a simulation running the same aerodynamic model as the crew training simulators as well as the desktop engineering simulation which was used in

the analysis of the event. The cab is able to be run in open-loop mode (normal mode) where the pilots make inputs in the cab flight deck which control the airplane simulation. However, the cab is also able to be run in "back-drive" mode where external data are used to drive the simulation and move the controls in the flight deck. A breakout capability allows cab occupants to interrupt the back-drive and resume control of the simulator in normal mode. This breakout capability allows investigators to perform recovery evaluations at various points along the event flight profile.

During the sessions, 3 back-drive run were conducted, one with dark, 2600' ceiling conditions to reproduce the accidents conditions, one with day-light, 2600'ceiling conditions to be able to see the aircraft behavior in similar cloud conditions and one with day-light and no clouds in order to see the aircraft behavior throughout the accident. Another 11 run were initiated with the back-drive and investigators had the opportunity to interrupt the sequence of events and control the simulator in the normal mode to perform recovery evaluations at various points along the flight profile. The following table illustrates these 11 M-Cab interrupted runs:

Run	Left Seat	Right Seat	Other Occupants	Goal/Phase of flight
1	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout during initial right turn to 315°
2	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout during left turn towards 270°
3	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout at A/P engage call on CVR
4	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout ~25" into 1st stick shaker
5	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout after 2nd stick shaker activates
6	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout after *"speed is dropping"* call on CVR
7	*PF - Lebanon*	*Boeing*	*NTSB - Boeing*	Breakout at 118° bank angle fron left hand seat
8	*Lebanon*	*PF - Boeing*	*NTSB - Boeing*	Breakout at 118° bank angle fro right hand seat
9	*PF - Lebanon*	*NTSB*	*NTSB - Boeing*	Breakout after A/P engage call, & engaging A/P
10	*PF - Lebanon*	*NTSB*	*NTSB - Boeing*	Breakout after A/P engage call, & engaging A/P
11	*PF - Lebanon*	*NTSB*	*NTSB - Boeing*	Breakout @ 3000 feet in dive, aircraft reached ~600 ft

Table 1: M-Cab Demonstration Run Log

In all 11 runs where the investigators had the opportunity to interrupt the sequence of events and control the simulator in the normal mode to perform recovery evaluations, the PF was able to recover control of the aircraft from every mentioned stage using the standard Boeing recovery techniques.

The M-Cab sessions report is attached to this investigation report as Appendix K.

1.16.4 Recovery attempt of the CVR U16 Memory Chip

The IC had agreed to perform a recovery attempt of the U16 memory chip. In line with Honeywell documentations and procedures, the CVR board examination was performed in February 2011 at the BEA Labs in Le Bourget based on the agreed test plan referenced "*ET-ANB CVR action plan / Date of issue November 2nd 2010*".

The test report was issued by the BEA on 5 March 2011 and confirmed the assumption based on the visual inspection performed in 17 February 2010 that "*U16, the memory chip with the crack, is the non-functioning memory chip."*

The BEA report concluded that: "*Based on the external visual inspection and the asymmetrical results of the electrical characterization, it is very probable that the internal die is cracked and the data from U16 cannot be retrieved."*

The CVR U16 Memory Chip Recovery Attempt report is attached to this investigation report as Appendix Q.

1.16.5 Trim-Tab Analysis

The Airworthiness Group inspected and examined both tab mechanisms in details with specific emphasis on the Boeing Service Bulletin 737-27A1297 issued at a later date from the accident (original release 16 April 2010; revision 1 released 2 August 2010) and the associated FAA Airworthiness Directive. This bulletin examines for any looseness or gaps in the swaged bearing lugs and spacer which attach the mechanism to the rear spar of the horizontal stabilizer.

On the accident aircraft, both sides of the horizontal stabilizer were accessed and the inspections revealed no discrepancies for the inspected components. The spacers were tight and could not be rotated by hand pressure. Although a feeler gage was not available, there were no observed gaps in between the lugs or the lug and the spacer. A fingernail could not be inserted between the pieces inspected.

The inspection also noted that the left mechanism inboard attach point could be displaced 0.25 inches laterally and vertically using hand force and that the inner race of the bearing appears to be damaged. However, the tab hinges (three hinges on the right tab; all hinges on the left tab), tab rods and their connections were inspected and found to have all hardware present. All hinge points move freely and without noticeable play or looseness.

In order to clear that issue and to verify consistency with the DFDR recorded data, which showed no uncommanded movement or oscillation of the elevator or horizontal stabilizer surfaces, the Airworthiness Group recommended the removal of the mechanism for further evaluation. The IC approved that recommendation and decided to send the Trim Tabs of flight ET 409 Boeing 737-800 aircraft to the NTSB for analysis in order to verify consistency with DFDR recorded data.

The Right Trim Tab was removed by technical advisors to the Ethiopian accredited representative and under the supervision of the IC, it was then sent to the NTSB and an examination was carried out on March 21st at the Boeing facilities in Seattle under the supervision of the IIC and technical advisors from the investigation committee. The Left Trim Tab was also removed by technical advisors to the Ethiopian team and under the supervision of

the IIC, it was then sent to the NTSB and an examination was conducted at the same Boeing facilities on May 11th under the supervision of technical advisors from the investigation committee.

Figure 13: Left Outboard Lugs & Spacer

The analysis was then carried out by Boeing. An initial draft report on the "*Investigation of Left Hand (LH) Elevator Tab Mechanism Assembly of Airplane YC490 (737-800)"* was received on July 18, 2011 and up-dated by the US Accredited Representative on July 27, 2011. The final report was completed on August 9, sent to the US Accredited Representative on August 11, circulated to all IC members on August 15th. A revised version correcting some editorial mistakes was then sent by the US accredited representative on September 8. The revised final report is included as Appendix O and analyzed in this investigation report.

1.16.6 Analysis of the Black Soot near the APU Exhaust

Upon the observation made by the Airworthiness Group on the presence of a "black soot" near the APU exhaust area and some wrinkle on the metal, the IC decided to send a section of fuselage skin from the APU compartment comprising that black soot to the Materials Laboratory of the NTSB for examination. The reason was to determine whether the "black soot" identified in that area was heat related and to determine its origin.

The section of fuselage was extracted by a team of technical advisors to the Ethiopian accredited representative, under the supervision of the IIC. It was then sent to the NTSB. The extracted section was 16 inches (in) long, 2.5 in wide at the narrowest end and 5 in at the widest end.

The NTSB report was received from the US Accredited Representative on July 29, 2011. The report specified that "*There was no discoloration to the primer paint and the surface was uniformly covered with a light coating of sand or dirt. Zinc chromate primer paint changes color when exposed to heat."* It goes to conclude that "*Since there was no change in the color of the paint on the primer side, there was no indication that this section of fuselage was exposed to heat/high temperatures."*

As for the origin of the black soot it determines after examining the material associated with the black soot that *"The spectrum obtained from the submitted unknown sample suggests that the material was organic as evidenced by the presence of characteristic carbon-hydrogen bonding peaks between ~3000 cm-1and ~2800 cm-1 as well as a small group of peaks between 2300 and 1400 cm-1. This peak configuration is indicative of a straight chained, aliphatic hydrocarbon. When compared to the spectra of known materials, the unknown material most closely matched spectra from lubricating oils."*

Figure 14: The APU Exhaust area showing the Black Soot

N.B. Kindly note in Figure 13 above the aircraft wreckage part is set with the bottom of the aircraft up and the forward part of it pointing towards the left.

That NTSB Black Soot Analysis report concerning the work carried out during the analysis of the part is also addressed in the analysis and included as Appendix P to the final investigation report.

1.17 Information on Organizations and Management

1.17.1 Ethiopian Airlines

Ethiopian Airlines is a scheduled passenger and freight air operator incorporated in Ethiopia under the ECAA provisions and supervision to operate commercially in accordance with the Operations Specifications specified in their AOC. The airline has services to over 50 destinations worldwide as well as domestic services.

1.17.1.1 ET Air Operator Certificate (AOC)

Ethiopian Airlines operated under an AOC issued by the Ethiopian Civil Aviation Authority. The AOC number CATO – 001/270295 was delivered to Ethiopian Airlines Enterprise, P.O. Box 1755, Addis Ababa, authorizing the airline to conduct scheduled, non-scheduled and charter domestic and international commercial air transport operations. The AOC was current on the date of the accident. A Full copy of that AOC is attached as Appendix A to this report.

1.17.1.2 History

Ethiopian Airlines was founded on December 29, 1945, by Emperor Haile Selassie with assistance from TWA. It commenced operations on April 8, 1946, with a weekly service between Addis Ababa and Cairo with five Douglas DC-3 propeller-driven aircraft.

The airline started long-haul services to Frankfurt in 1958 and inaugurated its first jet service in January 1963 from Addis Ababa to Nairobi. In 1965, it changed from a corporation to a share company and changed its name from Ethiopian Air Lines to Ethiopian Airlines. In the early 1960s it provided some initial aviation support to the Ethiopia-United States Mapping Mission in its operation to provide topographic maps of Ethiopia. It is wholly owned by the government of Ethiopia and has 4,700 employees (at March 2007).

Although it relied on American pilots and technicians at the beginning, by its 25th anniversary in 1971 Ethiopian Airlines was managed and staffed by Ethiopian personnel. In 1998, it started transatlantic services. The airline was featured by *The Economist* as an example of excellence in late 1987, and Ethiopians Paul B. Henze recognized it in 2000 as being "one of the most reliable and profitable airlines in the Third World", In 2007, Ethiopia Airlines provided basic pilot and aviation maintenance training to trainees from African countries including Rwanda, Tanzania, Chad, Djibouti, Madagascar and Sudan. Other training was given to employees of Kenya Airways, Air Zimbabwe, Belleview Airlines, Cape Verde Airlines and Air Madagascar.

1.17.1.3 Personnel Training and Authorization

According to the documents provided by ET and interviews conducted at Addis Ababa 24-27 January 2011, all personnel involved with ET 409 were trained and authorized as per the provisions of the ECAA.

1.17.1.4 Preparation of flight ET 409 at Beirut

According to the documents provided by ET and their handling agent in Beirut LAT, all documents required in accordance with ET procedures were provided to the crew prior to departure from Beirut.

1.17.1.5 Work cycles and flight crew rest

The crew arrived to Beirut 25 hours before the Scheduled Departure Time (SDT) and had the opportunity to have their full rest at the Beirut Commodore Hotel. The crew work cycles and rest have also been investigated by the Investigation Committee during their visit to Addis Ababa 24-27 January 2011 to confirm compliance with the ECAA regulations and Ethiopian Airlines requirements regarding Flight Crew weekly, monthly and yearly limitations. According

to the ECAA regulations and the ET requirements, the crew was within the legal duty/flight time limitations.

1.17.1.6 Procedure for use of on-board Weather Radar

ET provided their procedure for the operation of the weather radar during departure; the procedure is inserted as Appendix G of this report. It calls for both Radars to be set to a range of 40 NM, with the Pilot Flying (PF) selecting "Weather" and the Pilot Monitoring (PM) selecting "Terrain". A Boeing procedure, also inserted in Appendix G, stipulates *"set the weather radar as needed".*

1.17.1.7 Procedure for Flight Crew pairing

ET provided their procedure for crew pairing; the procedure is inserted as Appendix H of this report. It stipulates under "Inexperience flight crews" that "*Captain who has less than 300 hours and F/O who has less than 100 hours on type should not be scheduled together."*

The captain of the flight had 188 hours as PIC on type, while the F/O had 350 hours on type.

1.17.1.8 Procedure for the use of Auto-Pilot

ET provided their procedure for the use of Auto-Pilot in flight. The procedure is inserted as Appendix W of this report. It stipulates that the PF should *"engage the autopilot when above the minimum altitude for autopilot engagement."* The minimum altitude for autopilot engagement is defined in the Limitations section of the ET FCOM as "*400 feet AGL."*

Furthermore, the introduction part of the company's B737 emphasizes on the use of the autopilot; however, it stipulates that "*manually following the FD commands below 10,000 ft AAL in good weather and low traffic areas may also be used to maintain proficiency".*

1.17.1.9 Procedure for Moderate to Heavy Rain, Hail or Sleet

ET provided their procedure for flying in moderate to heavy rain, hail or sleet. It stipulates in the FCOM v.1, page SP.16.18 *"Flights should be conducted to avoid thunderstorm or hail activity. If visible moisture is present at high altitude, avoid flight over the storm cell. (Storm cells that do not produce visible moisture at high altitude may be over-flown safely.) To the maximum extent possible, moderate to heavy rain, hail or sleet should also be avoided."*

1.17.1.10 Approach to Stall Procedure

ET provided their procedure for pilots' response to approach to stall. That procedure is stipulated in the QRH MAN 1.1 and attached to this report as appendix X. The procedure calls for the PF, when ground contact is no longer a factor, to adjust pitch attitude to accelerate while minimizing altitude loss, then to return to speed appropriate for the configuration. It also calls for the PM to verify maximum thrust; monitor altitude and airspeed; call out any trend toward terrain contact; verify all required actions have been completed and call out any omissions[13].

[13] For more information refer to Appendix X

During the interview conducted by the IC in Addis Ababa with 11 officials from ET representing the operations, training, safety and scheduling departments, these procedures were confirmed by the training pilots and were reflected in the records of the crew involved in the accident as being satisfactory completed during training.

1.17.1.11 Upset Recovery Procedures

ET provided their procedure for upset recovery. That procedure is attached as Appendix Y to this report. It starts by defining Upset situations as *"unintentionally exceeding the following conditions:*

- *Pitch attitude greater than 25 degrees nose up, or*
- *Pitch attitude greater than 10 degrees nose down, or*
- *Bank angle greater than 45 degrees, or*
- *Within above parameters but flying at airspeeds inappropriate for the conditions*."

Once such a situation is identified, the priority is to recover from the stall, if any, then to recover from the upset. The upset recovery calls first to *"roll in the shortest direction to wings level, unload and roll if bank angle is more than 90°, recover to level flight*." It also calls for the application of nose up trim if required. At the same time, it warns against the use of rudder "*as it might aggravate the situation*."

During interviews conducted in Addis Ababa with the training pilots, the IC was informed that upset recovery training is conducted through a briefing in addition to being part of a full flight simulator training session (FFS – 7). However, the ET VP Flight Operations advised the IC that the "*simulators don't support jet upset recovery training*". Nevertheless, one of the training pilots advised the IC that training pilots can induce a simulated upset by asking the trainee pilot "*to turn his head sideways while the training pilot sets the plane to high nose up, more than 25 deg, with no bank angle, high power setting and wings level, then asks the trainee to recover as per the procedure described in the QRH*"[14]. He also confirmed that this procedure was a memory item.

1.17.1.12 CRM Training

Ethiopian Airline conducts CRM program for crew. CRM issues are also included in the airline SOP in details.

The ET Flight Operations Policy Manual (FOPM) contains a section on CRM. That section divides the crew performance competences into 3 areas: technical competence, procedural competence and interpersonal competence. The technical competence includes manual flying skill, knowledge of systems and use of automation. The Procedural competence skill includes knowledge of the procedures and adherence to procedures. The interpersonal competence includes Threat & Error management, communication, leadership and teamwork, workload management, situational awareness and decision making.

In the interpersonal competence section, pilots are encouraged to announce ambiguities and uncertainties so an understanding can be gained. The PM is required to call attention to deviations from desired attitude, speed, heading, altitude or track using appropriate call outs as

[14] For the ET Jet Upset Recovery Procedure refer to Appendix Y

outlined in the B737 SOP[15]. If the deviation is not corrected he must again make the appropriate call.

The FOPM stipulates that *"the captain determines the assignment of PF and PM at the start of each flight*[16]". It also gives the captain the decision to re-assign himself as PF at anytime during the flight, with due considerations of all relevant circumstances.

Interviews conducted by the IC confirmed that the CRM facilitators as well as the training pilots emphasized on the F/O to be assertive. They also confirmed that they were required to take over control in case the captain becomes incapacitated. The review of the ET training program revealed that this situation was part of the training curriculum, information confirmed by the training pilots who clarified that it was done mainly during simulator sessions. Chapter 3 of the ET FOPM discusses the issue of incapacitation; both obvious and subtle. It clearly stipulates that subtle incapacitation is *"considered a more significant safety hazard, because it is difficult to detect and the effects can range from partial loss of function to complete unconsciousness".* It also provides guidance to recognize incapacitation through one of the following symptoms: *"Incoherent speech, strange behavior, irregular breathing, pale fixed spatial expression or jerky motion that is either delayed or too rapid."*

Training to identify cases of subtle incapacitation was further discussed with ET; the way to identify that situation was explained by the VP Flight Operations as "*callouts when deviations from norm; if not positive response, then PM takes over"*. The way to take over is explained in Chapter 3 of the ET FOPM and calls for the PM to take over control of the aircraft by announcing "I have control" and engaging the auto-pilot.

However, in one of the F/O early fixed base simulator training sessions (FBS – Lesson 7), the following remark was written about his performance as PM: *"As a PM interferes with PF duties unnecessarily. Has to be confident with his actions. Should stop asking irrelevant questions. Should stop repeating minor mistakes."*

During one of the interviews with a pilot who was very close to the F/O, that pilot recalled hearing from the pilot instructors that had taught the F/O that he was *"the best student"*. The same interviewed pilot replied to a question from the IC about the F/O assertiveness in the following terms: *"assertive with his peers, when he is flying, he will assert himself to defend what he is doing."*

Furthermore, in one of the captain's transition training report (FFS – 8), the training pilot mentioned about his trainee that "*generally lack of concentration is observed".*

1.17.1.13 Ethiopian Airline Safety Program

As an IOSA registered operator, Ethiopian Airlines has a safety program that was verified by the investigation during the visit to Addis Ababa. That program includes essential elements like the Flight Operations Quality Assurance (FOQA) program and the confidential reporting system.

Trends from the FOQA program are addressed and were also discussed with the IC. In accordance with the information relayed by the safety personnel of ET, no particular identified

[15] Refer to Appendix N for the Standard Deviation Table
[16] Refer to Appendix W of this report

trend could be related to the events of flight ET 409.

1.17.1.14 The Maintenance Organization

In accordance to documents provided by ET, the company is a FAR 145 Approved Maintenance Organization (AMO). It covers the maintenance from light checks (e.g. transient checks) to heavy checks (C checks). The operator's maintenance program data, drawn up on the basis of the manufacturer's recommended maintenance program, is approved by the ECAA and subject to its oversight. It is also audited by the FAA in line with their FAR 145 approval requirements.

1.17.2 Review of oversight by the ECAA

The IC has had access to relevant oversight documents by the ECAA during their visit to Addis Ababa 24-27 January 2011.

1.17.3 The ATC

The Lebanese DGCA controls the ATC Services located at BRHIA. According to documents provided by the Lebanese DGCA, the ATC system consists of a Manager, a chief for the ACC and a chief for the Aerodrome Control. Thirty six air traffic controllers work as three groups; each group works for twenty four hours and rests for forty eight hours. The working hours and rest periods within each shift are planned by the supervisor; typically an ATC controller would work between 2 - 3 hours then take his rest at the designated area.

Each group working at the ACC consists of a supervisor and six air traffic controllers who work as Area and Approach controllers and as assistants. The Tower group consists of a supervisor and four controllers who work as Tower and Ground controllers. In addition there is the Flight Information Centre where there are some personnel from the ATC staff & Telecom department handling the work.

Typically, the Ground controller would handle flights on taxiways and at gates. He will also issue the initial ATC clearance, start-up and taxi permissions. The Tower controller issues the departure and landing clearances and controls the air traffic within the airport airspace up to 3,000 feet. Above that altitude, the ACC is responsible for the control of arriving, departing and overflying air traffic.

According to ATC records, at the time of the accident there was one ground controller, one tower controller and a supervisor handling the traffic in the Tower. There was also an Approach controller, an assistant controller and a supervisor handling the traffic in the ACC. All controllers reported for duty at 0700 LT on the morning of 24 January 2010 and were scheduled to come off duty at 0700 LT on 25 January 2010. During this twenty four work period, the supervisor scheduled all shift and rest times. The Lebanese CAA confirmed these times as correct.

All the controllers handling Ethiopian Airlines flight 409 (ETH409) on 25 January 2010 have licenses issued by Lebanon DGCA in accordance with the LARs provisions and ICAO standards. Records provided by the Lebanese CAA, all the above mentioned controllers completed the required initial and recurrent training. Their last recurrent training was completed in March 2009.

The relevant controllers' most recent medical certificates were checked. They carried a certification stipulating they were conducted in accordance with the standards specified in ICAO Annex 1, "Medical Standards and Certification."

1.18 Additional information

1.18.1 Location of Wreckage

Based on the Radar track recorded at the ATC, the IC estimated the aircraft wreckage to be located 4-5 miles SW of BRHIA.

The search and Rescue operations started in a dominantly stormy weather and rough sea. This has forced the S&R operations to be suspended from time to time. Floating parts of the aircraft and some bodies were collected and found at different locations NE of the calculated wreckage area.

The IC requested from the ships conducting the S&R operations to try to locate the exact area where the wreckage could be found. This was done through a survey of the sea bed where the wreckage location was calculated and through trials by a ship equipped with submarine identification technology to try to locate the signal transmitted from the CVR and DFDR. The equipment on board that ship was adjusted to enable it to pick up the signals sent from the pingers attached to the DFDR or CVR.

On 27 January, one of the S&R ship reported picking a signal 14 Km to the west of BRHIA. The sea bed in the area where the signal was located is 1400 m deep. The Lebanese Government decided to contract the Ocean Explorer ship to come to Lebanon in order to retrieve the wreckage, the recorders and the human remains from that deep location; the estimated time for the arrival of that ship was 10 days. In the mean time, a team from the BEA equipped with the proper technology was dispatched to that same area in order to determine with greater precision the location of the wreckage. The BEA team was unable to receive any signal at the location reported previously as 14 Km West of BRHIA.

However, the team decided to sail back to the area originally calculated by the IC. This time the BEA team succeeded in locating precisely a signal. The Ocean Alert ship took underwater pictures of that area and the location of the aircraft wreckage was successful. The depth of the sea bed in that area is 45m. However, the pictures and videos did not reveal the location of the DFDR or the CVR. Navy divers were sent with the proper equipment and the signal was located under the tail of the aircraft.

The USNS Grapple ship picked up the tail from the sea bed, which allowed the Navy divers to retrieve the DFDR, which was delivered to the IC.

The CVR was emitting no signal. Photos of the CVR were issued to the divers who continued a physical search of the sea bed to locate that equipment. On 10 February the CVR Chassis was located, but the CSMU was missing. The physical search continued and the CSMU was finally located by the Navy divers and delivered to the IC on 16 February.

1.18.2 Search & Rescue Operations

Once the accident was acknowledged, the S&R operations were launched under the command

and control of the Lebanese Army. The Directorate General of Internal Security Forces, The Directorate General of Civil Defense, the Lebanese Red Cross and the Beirut Fire Brigade were all incorporated into the S&R efforts. However, due to lack of advanced equipment, the Army command decided to seek the assistance of the UNIFIL Naval Forces located in the area, this included ships and helicopters belonging to Germany, Italy, Turkey and Greece. The government also requested the assistance of the USA, France and the UK. Two civilian ships properly equipped for underwater search, the Ocean Alert and the Odessey Explorer, were also contracted by the government and put at the disposition of the S&R team.

The reason the Army was tasked to lead the S&R operations are three fold: the 24 hours level of preparedness available at the Army Operations center, the necessity to protect the accident site and the lack of resources available to the other governmental entities. The Army also entertains good relationship with other forces operating in the region, especially the UNIFIL. This cooperation provided the government with supplemental developed tools that helped achieve the required S&R operations to a high standard, considering the prevailing weather and the logistics available to the Lebanese government. A report describing the S&R operations has been prepared by the Lebanese Army and is attached as Appendix E to this investigation report.

The total time spent carrying the S&R operations was 25 days, out of which 3 days where the operations ceased because of rough sea and bad weather. The equipment designed to detect the signals from the black boxes was sent by the BEA and became operational on the 30th of January.

1.18.3 Testimonies

Many eye witnesses, including a Tower controller and arriving aircraft crew reported concerns about the weather and seeing a "ball of fire" or an "orange light" or an "orange explosion" at the time of the accident. Testimonies from these eye witnesses were recorded. Some of these testimonies are included in this report, particularly the ones of the ATC controllers and crew in the vicinity of the flight.

1.18.3.1 ATC Controller

Testimonies from ATC controllers revealed that ET 409 was cleared on a standard Lateb 1 D departure by Ground frequency 121.9. The flight was then released to Tower frequency 118.9 who issued ET 409 a clearance for take-off with a direct right turn to Chekka VOR as the controller specified in his testimony that he *"noticed that this is a good heading to avoid weather observed to the south west of the airport"*. However, when the Tower controller contacted ACC to advise them of the new clearance issued to ET 409, ACC advised him that they had arriving traffic and suggested heading 300° or 315°. ACC testimony advised that these two suggested headings *"permit Ethiopian flight to be away from the bad weather and the clouds … also they ensure the safety of the flights landing on runway 16".*

The Tower controller re-cleared ET 409 on a heading of 315° after being airborne, then transferred the flight to Control frequency 119.3. Once with ACC the controller suggested to the crew a heading of 270° for 15-20 miles in order to avoid weather; he also gave the crew the choice of any other heading they deem necessary to accomplish such weather avoidance, as long as they advise the controller if that heading. However, when the controller saw the flight turning well beyond the 315° cleared to heading, he suspected they were proceeding direct to CAK and immediately changed his "suggestion" to turn to a heading of 270° to an "instruction" to turn

left to a heading of 270°. That heading was acknowledged by the crew and the aircraft started a left turn. Nevertheless, the aircraft was never steady on that heading and continued to turn further to the South, which instigated the controller to instruct the flight many times to turn right on to a heading of 270° till the end of the flight.

The testimony of the ACC controller is consistent with all what was recorded on the aircraft CVR and the ATC recordings till the aircraft disappeared from the Radar screen.

Following that disappearance, the controller tried several times to communicate with the aircraft on 119.3 and on the Emergency frequency 121.5 without success. He asked other arriving traffic to check for ET 409 on their TCAS, but that was also in vain. He called the Tower to advise them of the situation and to activate the emergency plan. One of the Tower controllers advised that he saw *"a light over the Costa Brava"* (SW of BRHIA). The ACC supervisor specified in his report that the Tower controller reported seeing: *"some orange light falling into the sea"*. The incident Notice filled by the Chief of the ANS mentions under "*Remarks*" that *"we saw an orange explosion on the sky over the sea before the aircraft fell down"*[17].

1.18.3.2 Crew in the vicinity of the flight

Testimonies from crew flying in the vicinity of the flight were requested and received by the IIC and reviewed by the IC. Three testimony reports were received from the following flights: Etihad Airways flight EY 533, Malev flight MA 240 and Olympic flight OA 463. EY 533 was arriving from the NE, MA 240 from the NW and OA 463 from the West.

These testimonies provide good weather and environmental information from a flight crew perspective. The EY 533 testimony states that *"during the approach there was bad weather all around the airport with reported thunderstorms and lightning".* They also reported seeing "*major lightning from the nearest cell, just off the coast"* and "*running into medium rain*". They also confirmed that ATC asked them to look for ET409 on the TCAS and that they had no trace on the flight. The crew provided a sketch of remembered storm in the area which is in accord with the weather recorded on the Radar at the time. EY eventually carried a go-around from runway 16 and landed on runway 03 due to tail-wind. During that go-around EY 533 was given by the Tower the standard go-around procedure for runway 16, which is turn right heading 270° climb 2000 feet. However, they maintained a heading of 250° to avoid the cell west of the field. It is worth noting that the go-around route is about 5-6 miles south of the point where the ET 409 was given instruction to turn left heading 270°[18].

The MA 240 testimony reported that they *"experienced light to moderate turbulence during the approach and observed embedded and isolated thunderstorms pits."* The aircraft was approaching the field from the North West.

The OA 463, approaching BRHIA from the West, reported that their path *"was clear of weather, but there was thunderstorms activity North and North West of the airport 5-15 NM from the coast."* The OA captain also reported seeing N/NW of the airport *"a ball which lasted for 2-3" and which I considered to be a lightning due to the thunderstorm activity at the area."*

[17] Refer to the ATC testimonies and incident notice in Appendix T
[18] Refer to EY 533 go-around diagram in Appendix U

1.18.3.3 Other eye witness

Many eye witnesses contacted the government officials stating that they saw at the time of the accident a “ball of fire” falling into the sea at the time and calculated location of the accident. These reports raised many speculations by the media who associated the eye witness reports with the aircraft accident and built various stories and theories based on these accounts. Some various declarations by people who were not associated with the investigation also contributed to fuel some media speculations.

1.18.4 Autopsy of Flight Crew

The recovered remains of the flight crew did not allow any autopsy to be conducted.

1.19 New Investigation Techniques

No new investigation techniques have been used apart from the technical work conducted by the BEA, the NTSB and Boeing.

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2. ANALYSIS

2.1 General

The flight crew was properly certificated and qualified and had received the training and off-duty time prescribed by the ECAA regulations. Data from the CVR and DFDR indicates that the captain was PF and the F/O was the PM. The FD was ON during all the flight and the AP was OFF during all the flight.

Apart from the crew comments during pre-flight on the meal that prevented them of sleeping properly, no other evidence reported to the IC indicated any pre-existing history of medical or behavioral conditions that might have adversely affected the flight crew's rest quality prior to the flight or their performance during the accident flight.

The airplane was certificated, equipped, and dispatched in accordance with the ECAA regulations and approved Ethiopian Airlines procedures. Neither the DFDR data, nor the CVR data showed any evidence of a warning linked to a system malfunction, or a major failure occurring during the flight.

At the time of the accident, there were light winds, isolated clouds and imbedded cumulonimbus extending between 2,000' and 24,000' to the area SW, NW and NE of BRHIA. This had generated some thunderstorm activities associated with changes in the wind direction and speed, in addition to some rain and light to moderate turbulence around the airport area. The temperature on ground was 11° indicating that icing conditions would most likely be encountered during climb, once flying into clouds at higher altitude and lower temperature. There was no record on the DFDR or the CVR for the use of anti-icing during the flight; however, there was no record of any system malfunction or failure normally associated with icing. Furthermore, the recorders data and the pieces of the wreckage retrieved from water did not show any evidence of a lightning strike that may have jeopardized the flight.

According to the DFDR data and the analysis of this data reproduced during the simulation performed at the Boeing facilities in September 2010 (refer to section 1.16.3 and Appendix K), the flight profile was not significantly affected by winds. The flight profile was the direct result of the flight controls inputs and of thrust settings; the simulation proved that the aircraft was recoverable at every stage of the flight till the last few seconds when passing 3,000' with a very high rate of descent and increasing speed beyond the maximum certified. Simulation beyond that point would not allow a realistic reproduction of the aircraft behavior under these excessive prevailing conditions.

The reports about seeing a "ball of fire" are not consistent with the aircraft flight pattern, the CVR or the DFDR recordings, nor with the wreckage examination and the autopsies conducted on recovered bodies. This issue is further discussed in part 2.2 of this analysis.

Therefore, the immediate reasons of this accident are to be found in the crew actions which are discussed in the following scenario. In that scenario we did break down the accident flight by event in order to analyze what happened at every stage of the flight, thus allowing us to conduct a step by step analysis prior to analyze the factual information based on the different areas that affect aviation safety.

2.2 Analysis of the Flight Events

The beginning of the flight is considered as normal until 00:38:30, despite the fact that the crew was flying the aircraft with the control column not in the neutral position for the first minute and a half of the flight. Events happening before that time, such as discussions prior to start, start-up operation and taxi out are correctly dealt with and do not reveal any indication that the crew had difficulties to run the flight. The crew seems aware of the weather conditions; just before take-off, and in line with ET procedures, the captain is heard on the CVR saying *"Weather on my side"* referring to the information he selected on his Radar. Although this is in-line with ET procedure for the PF to have Weather on his side, the fact the radar range was set to 10 NM instead of the 40 NM called for as per SOP is an indication that the crew suspected to encounter weather in the immediate vicinity of the airport.

In the following analysis, the flight scenario as reproduced from the DFDR and CVR recorded data has been broken down into 11 parts; a first phase followed by 10 events (from 2-11) in order to facilitate the analysis and allow a better understanding of each event within the operational context of the flight.

2.2.1 Phase 1: Take-off

During the take-off run, the CVR recorded a sound similar to interference on the radio followed by the captain saying *"did you see that?"* Those two events may refer to lightning activities somewhere in the vicinity of the airport. However, no reaction is recorded from the F/O apart from the standard *"8o Knots"* call when passing that speed on take-off. Which most probably implies that nothing which might affect the flight had happened; apart from the fact that bad weather was not far from the field, as broadcasted on the ATIS which was copied by the crew.

Apart from that recorded event, the aircraft take-off weight as listed on the weight and balance form was 70,443 Kg; which was consistent with the gross weight that was recorded on the DFDR. However, the AFM recommended take-off stabilizer setting under the flight conditions is 6.9 units. The event weight and balance form listed that setting as 5.26 units, while the actual setting recorded on the DFDR was 5.94 at the start of the take-off roll. As a result, the stabilizer position during take-off was more airplane nose-down than the stabilizer position recommended by the AFM; although that setting was still within the acceptable certified range for take-off (Green Band).

The investigation was unable to determine why the weight and balance form showed a difference of more than 1 unit in trim setting from the AFM or why the actual stab trim for the event flight was set almost ¾ unit from that listed on the weight and balance form.

Nevertheless, as a result of that miss-trim, the crew had to pull the column during the initial climb to maintain the desired climb attitude. That pull was maintained by the crew for nearly one and half minute after rotation. During that period, only a shy attempt to trim the aircraft is recorded more than a minute after rotation on the CVR, without being long enough to be recorded on the DFDR, bringing the pitch trim from 5.9 to 6.1 units, which was still far from the recommended take-off setting of 6.9 units.

2.2.2 Event 2: Turning beyond the cleared/selected heading 315°

The second unusual event is recorded at 00:38:30 when the actual heading of the aircraft

exceeded the 315° selected heading without any action from the PF on the control wheel to reduce the roll or to stop the turn, although the FD gives indication to reduce roll. That inaction was not met by a call from the PM as required by the ET SOP. This exceedance continued for 14" when the aircraft had exceeded the cleared/selected heading by 48° reaching a maximum heading of 003°. According to the CVR, in the time period around this precise moment, the crew workload seems to be focused on three things: to take into account the ATC clearance to climb to FL 290, the "flaps up" called by the captain, and a long ATC message to avoid weather.

As PM, the F/O had many things to do during that period, such as: reading back the climb clearance, setting FL 290 on the MCP, checking the speed before actuating flaps lever as commanded by the captain, and finally listening to an unexpected ATC message on suggested new heading and routing to avoid weather.

The Captain's workload was certainly lower, and his priority should have been to fly the aircraft and verify the weather on his Radar. However, his roll bank angle exceedance and his continued turn beyond the selected heading and against the FD command indicates that his attention was most probably diverted to other things, maybe monitoring what the F/O was doing and listening to what the controller was saying: the captain spontaneously asked to repeat the suggested heading leading the F/O to ask for a confirmation. The difficulties encountered by the captain were certainly aggravated by the fact that he was pushing down the control column while at the same time commanding at 00:38:44 for a period of 3" a trim up which resulted in an increase of pitch trim from 7.9 to 8.8 units and an airspeed of 196 Kts. That manual trim command was the last one commanded by the crew during the flight and resulted in the aircraft computer memorizing that speed as the one the crew wanted to maintain, despite the different speed selected on the MCP[19].

Thereafter, the Captain's workload was increased by flying an aircraft that is out of trim, which generally requires more efforts and attention. This explains that he only realized that the aircraft attitude was becoming unusual when the *"bank angle*" alarm was triggered because of excessive bank to the right. This also indicates that the captain was most likely momentarily unaware of the aircraft bank angle and heading. The use of the autopilot would have helped the crew to reduce its workload and would have improved piloting accuracy. The airline SOP emphasizes the use of the autopilot and states that *"manually following the FD commands below 10.000 ft AAL in good weather and low traffic areas may also be used to maintain proficiency"*. That encouragement implies the necessity to use the autopilot whenever the weather is not good and the traffic is not low, both conditions present during that dark night period. Therefore the captain's decision to fly manually was a major contributor towards the degradation of the situation. Technically, the autopilot could have been engaged after 400 feet, according to FCOM.

2.2.3 Event 3: Overbanks during left turn

At 00:39:01 two *"bank angle"* alarms were heard again. This time the bank angle was in excess to the left. Since 00:38:42, in reaction to the previous *"bank angle"* alarms, the captain had kept the control wheel to the left. Three seconds before this second series of alarm was heard, the captain had asked for a confirmation of heading. At this moment the selected heading was still 315°. Therefore the captain was turning to a heading target which was not yet updated. He may have felt uncomfortable with that and asking a confirmation of the heading may also be

[19] For more information on the different modes of operations of the stabilizer trim, please refer to Appendix M.

interpreted as a request to the F/O to update the selected heading. However, as he was paying attention to heading, he was not paying enough attention to bank angle. The captain reaction to those alarms showed that he was most likely unaware of the bank angle he was himself generating. It must be kept in mind that it was night time with large clouds bringing probably total darkness outside the aircraft which was turning above the sea, and depriving the captain of any external horizontal reference, which could lead to spatial disorientation.

The Primary Flight Display (PFD) is the main tool to display the aircraft attitude, therefore the main display used by the pilot to monitor and adjust that attitude, as required by the flight requirements. While this is normal flying practice in airline flight operations, it is vital in Instrument Meteorological Conditions (IMC), similar to which the accident flight was in (night, clouds and no outside visual references). During this left turn, the FD vertical bar, displayed on the same instrument, moved from left to right to indicate that the pilot should reduce roll. The selected heading 270° was set by first officer at 00:39:04 providing the captain with an updated heading target. This indication, as well as the excessive bank angle, seems to have been unnoticed by the captain.

2.2.4 Event 4: 3rd series of overbanks

At 00:39:29 a third series of "bank angle" alarms was heard on the CVR. The bank angle was again in excess to the left because the captain initial reaction to the right to the previous "bank angle" alarms was neither consistent nor sufficient and did not significantly reduce the bank angle. Furthermore, he had kept the control wheel slightly to the left after his initial action to the right, contrary to the FD indications. Additionally, the actual aircraft heading was crossing the 270° selected heading, indicating that the captain missed this target; both as heading reading or FD command.

After initially reacting to the overbank warning while turning left by applying more left wheel input, as recorded on the DFDR, the captain applied a roll input to the right. All this information tends again to tell that the captain's attention had been insufficiently paid to the basic flying parameters. An explanation could be that his attention was diverted by the sudden rain the aircraft encountered at 00:39:22. At this time the weather condition may have been a significant preoccupation for the crew, especially that it must have been displayed on the captain's radar which was selected to "Weather".

A few seconds later, the captain said *"OK engage autopilot"*, indicating that he felt uncomfortable with manually controlling the aircraft and that he was looking for a solution. Despite this call, there was no recorded autopilot engagement. The reason why it did not engage was that the pilot was applying some forces on the controls, which is outside the engagement conditions of the auto-pilot[20]. It must be noted that throughout the flight, with the exception of the period between 00:38:05 and 00:38:40, there had been continuous forces applied on the control column due to the fact that the last speed the aircraft was trimmed to was 196 Kts and the flight crew did not adjust the stabilizer trim manually in order to keep their aircraft in trim at the required speed. That surely increased the PF's workload and was surely not compatible with basic flying skills requiring the aircraft to be continuously in trim when flying manually in order to relieve the pressure on the control column, allowing the pilot to focus on managing the flight.

As no reply from the F/O was heard on the CVR, it is likely that he hadn't heard the captain's

[20] The Boeing FCTM clearly stipulates that *"the airplane should be in trim and the Flight Director commands should be satisfied before autopilot engagement".*

call concerning the auto-pilot, or that he did not make the confirmation call because the autopilot did not engage. If so, the captain should then have detected that his call (and action?) had not led to the expected result; however, he made no comment about it. Those principles (calls/answers or challenges/responses and actions/results) are the basics of piloting discipline and of CRM.

Six second later, the controller repeated the instructed heading of 270°. The F/O reads back the instruction correctly. The captain asked again for the heading indicating that he was still lost in the direction he was supposed to go, despite the fact that it had been received and confirmed more than once and displayed on the instruments in front of him.

2.2.5 Event 5: 1st Stall

At 00:39:59 the captain was heard saying in Amharic *"what is that"*, just before the activation of the stick shaker (from 00:40:01 to 00:40:28). That call was repeated twice during the stall. He was also heard saying *"speed*" as the stick shaker was coming on. His voice indicated a significant stress level. It is not possible to know what he was precisely referring to; referring to *"bank angle"* is unlikely because those alarms were previously heard; referring to stick shaker would indicate that he did not identify the stall warning which would be surprising for a 737 qualified pilot; referring to the strange displays related to airspeed and/or the aircraft vertical and lateral attitudes on the PFD would indicate a loss of situational awareness; referring to an external factor such as weather would also indicate a loss of situational awareness, since the weather was displayed on the PF's screen. Therefore, it is more likely that he was referring to the global situation indicating that he didn't understand why the situation was degrading in such a way.

He then called 5 times *"go around"*; starting from the moment he pushed the throttle. The TO/GA switches on the thrust levers were pushed, with no change in the FD modes since the TO/GA mode was already engaged. The F/O said in a cool voice "*Roger Go around"* confirming that this mode was active. This action was in line with the initial approach to stall recovery procedure in force at the time of the accident and could have contributed in aggravating the situation by increasing the AOA, had the thrust been at a lower power setting[21]. However, neither the thrust was reduced since take-off to produce such an effect nor the pilot followed the laid down approach to stall recovery procedure in force at the time of the accident. The increase in the AOA was the direct result of the aircraft being out of trim and the pilot failure to adjust the attitude by pushing on the control column. As a matter of fact, the pitch eventually reduced through the nose-down stabilizer trim input made by the speed trim system for a period of 7" to compensate for the decreasing airspeed. That implies most likely that the flight crew did not realize what was exactly going on at that time, when the aircraft attitude was very high, the speed decreasing at a fast rate, the aircraft loosing altitude and the stick shaker active, while at the same time hearing more *"bank angle"* calls. Events were outpacing the crew.

Additionally another "*bank angle*" series was heard a few seconds later, while the stick shaker was still active. This excessive bank angle to the left was a consequence of the stall situation (AOA was around 20° at 00:40:02 and then reached 30° at 00:40:14) where aileron were less efficient. The throttle were pushed full forward for a short instant then pulled back a little for a few seconds and then pushed again violently enough to be heard on the CVR. This can be interpreted as a hesitation of the captain on what action to take.

[21] That procedure was changed later on and the new procedure calls for smoothly applying nose down prior to advance thrust as needed Refer to Appendix X for the old and the revised approach to stall recovery procedure.

The auto-throttle was then disconnected, most probably via the auto-throttle disconnect switch. In fact, there are several ways for the auto-throttle to disconnect; not just with the switch. However, this switch is directly recorded on the DFDR and was shown active at the same time that the auto-throttle disconnected. Furthermore, it is typical for crews to press this switch twice, once to disconnect the auto-throttle and the second time to cancel the auto-throttle disconnect light; that was the case in the accident flight.

During that time period, the aircraft attitude was pitching towards 38.5° up and the speed was abnormally dropping through 154 Kts towards the minimum 118 Kts reached during the stall. The captain had difficulties maintaining pitch because the aircraft was trimmed to a low speed resulting in a tendency to pitch up. Once his focus was on correcting the "upset" resulting from the excessive bank angles, his attention was diverted from maintaining the correct pitch attitude of the out of trim aircraft.

Technically, and as per the definition of "upset" in the ET QRH, the aircraft required recovery action from stall prior to upset recovery action. The upset is defined in the ET QRH as a situation where the aircraft is *"unintentionally exceeding the following conditions:*

- *Pitch attitude greater than 25 degrees nose up, or*
- *Pitch attitude greater than 10 degrees nose down, or*
- *Bank angle greater than 45 degrees, or*
- *Within above parameters but flying at airspeeds inappropriate for the conditions"*

During the period discussed in this event, 3 out of these conditions were met: the aircraft pitch reached values greater than 25° nose up, the bank angle reached values greater than 45° and the airspeed was inappropriate for the conditions. In such a case, the QRH calls for the following pilot action: *"If the airplane is stalled, recovery from the stall must be accomplished first by applying and maintaining nose down elevator until stall recovery is complete and stick shaker activation ceases."* What really happened is completely opposite to that![22]

In fact, at the beginning of the stall, as the speed was dropping below the last pilot commanded trimmed speed, the aircraft speed trim system commanded, as per design, a trim down input relieving some of the pressure from the control column. The pilot reacted by significantly pulling the control column back and bringing the wheel to the right, while putting some pressure on the right rudder pedal. Those actions did not completely match what was expected as a reaction to a stall, the ET QRH calls for the pilot to apply and maintain *"nose down elevator",* which was not initially done by the captain. However, that nose down elevator was applied later on during the stall, which eventually helped the aircraft to recover from the stall 27" after the activation of the stick shaker. Was that a training issue or a lack of situational awareness issue? That point is further discussed in section 2.5 of this report.

Throughout that event, apart from the *"roger go around"* confirmation on the thrust setting, no other comment was heard from the F/O; however, when he replied in a fast manner "*roger, roger"* to the ATC instructions of turning towards heading 270°, his calm tone of voice had changed, which most probably indicated a certain amount of stress that was not identified in his previous transmissions. This indicates that he was aware that the situation was not normal. In fact, throughout the flight, the F/O seems to be responding properly to all instructions from the

[22] While the DFDR records only stick shaker, the DFDR data concerning speed, AOA and altitude indicate that the airplane was in full aerodynamic stall at this time.

captain and the ATC, he was selecting on the MCP and calling all the headings and flight levels instructed by the ATC, so why didn't he raise any concern to the captain when he felt that the flight was deviating so far from normal? The ET standard deviation calls SOP requires the PM to call any "inappropriate" pitch deviation, any bank beyond 30° and any speed deviation of +15 Kts or – 5 Kts, all of these conditions had been encountered and exceeded by far, many times till that phase, without any challenge from the F/O. Why didn't the F/O call any of these deviations? This question will be addressed in the Human Factors part of this analysis.

2.2.6 Event 6: The captain requesting help from the F/O

Towards the end of the stall, as the aircraft pitched down towards zero, a left wheel input was made on the order of 50° along with a right rudder input of 5°. These opposing inputs resulted in a condition known as "cross-control" and resulted in no significant bank angle changes over the next 20".

At the same time, as the speed started to increase beyond 195 Kts, the speed trim commanded a nose up trim input increasing the pitch trim from 8.2 to 9.3 units at 00:40:37, resulting in a further increase in the aircraft pitch up tendency. The crew did not take any action to re-trim the aircraft to the desired speed, so, once the nose down pressure was released on the control column, the aircraft pitch started to increase again and became close to 30° up, well above the FD indication that the captain hadn't followed. The direct result of the pitch increase was a speed decrease. This was noticed by the F/O who applied for the first time the standard deviation calls SOP and called in English at time 00:40:48 "*the speed is dropping"*, as it was decreasing below 200 Kts. At the same time the flight crew released the right rudder input while the left wheel input was maintained.

The captain reaction to the F/O call was a confirmation in Amharic *"speed is going down"*. That confirmation by the captain was immediately followed by him with a request in Amharic *"OK, try to do something"*. Once more, that call indicates that he most probably needed help to control the situation without being able to specify what type of help he was requesting. No reaction from the F/O was recorded till 7" later when he re-affirmed his deviation call *"speed"*.

2.2.7 Event 7: Approach to the second stall

As the flight crew released the right rudder input and maintained the left wheel input, the aircraft rolled to the left beyond 35° triggering at 00:40:52 and 00:40:54 two *"bank angle"* alarms. The cross control situation that was induced by the crew action during stall recovery prevented the roll command from being effective and possibly lead the captain to add more left wheel, so when the captain brought the rudder back to neutral the roll authority was back and the aircraft rolled excessively to the left. The captain reaction at 00:40:57 was to induce a right control wheel input and a right rudder input; however, the stick shaker activated again at that same time and the crew's priority became, most likely, to solve the decreasing speed and increasing pitch problems previously mentioned. 2" later, a full left wheel was commanded while the right rudder input was maintained, resulting again in a "cross-control" situation as the aircraft was entering its second stall. The captain was probably overloaded with solving the escalating situation.

2.2.8 Event 8: 2nd Stall

The second stall started as the aircraft was approaching 9,000 feet; at 00:40:57 the stick shaker

activated again and remained on for 26". The aircraft re-entered a stall situation (AOA reached its maximum values of around 26° at 00:41:09). Contrary to any stall recovery procedure, the control column was initially kept backward and gradually increased over the next 17". The control wheel was commanded to the left with right rudder input which didn't permit to improve the situation. Roll reached more than 90° to the left. The aircraft pitched down, the speed started to increase at a high rate and the vertical acceleration dramatically increased.

In the midst of all what was happening, the aircraft was still turning to the left towards the mountains. This alarmed the ATC controller who repeated for the fourth time his instruction to the aircraft to turn right heading 270° warning them that they were turning towards the mountain. This time, no reply was recorded; however, a sound of an open mike was recorded on both the aircraft CVR and the ATC transcript for a period of 3". This indicates that someone (probably the F/O) was trying to read back the clearance or transmit another message but couldn't do that, probably due to the fact that he was overwhelmed by what was going on which had left him speechless.

Simulation performed during the investigation process showed that it was possible to recover from this second stall with significant nose down input. However, the crew of ET409 was not in the same psychological situation than the investigator during the simulation. But this nevertheless shows that with adequate maneuvers the situation during this event, as well as the situation in all previously analyzed events, was recoverable through the application of the approach to stall recovery procedure in force at that time[23].

2.2.9 Event 9: Spiral dive

As the aircraft continued stalling, the aircraft roll to the left continued leading the aircraft into a spiral dive with the bank angle reaching a value of 118.5° left and a pitch attitude of 48° nose down. At 00:41:15 a right control wheel input was recorded with a right rudder pedal input, which could have been an attempt by the crew to level the wings. Simulation performed during the investigation process showed that, even at that stage, it was possible to recover from the upset and save the aircraft without exceeding any structural limitations. However, retarding the throttles all the way to idle and the manual use of the electric trim switch would have been essential.

Two seconds later, at 00:41:17, as the bank angle was decreasing to a value of 45° left, the crew induced a left control wheel input again and brought the rudder back to neutral then to the left. The aircraft was still stalling at 00:41:20 and the bank angle was 60° left when the crew rolled right again, still applying left rudder! The control column was kept between neutral and aft throughout that event, the input on the control wheel was shifting between right and left as well as the input on the rudder pedals, often leading to a "cross control" situation that was aggravating the situation.

It is difficult to understand the captain's logic to make all these input changes. He may have had difficulties to read the PFD as very unusual high banks and low pitch were encountered. He could have also felt some unusual heavy G loads which could have disoriented him. Those changes in flight control inputs and maintaining the thrust at go-around didn't allow the captain to recover from stall situation or from the pitch down attitude, but indicates that he was still struggling to save the situation. They surely indicate a high level of stress the crew was facing

[23] Refer to Appendix K, M-Cab session report

and a loss of situational awareness of what was really happening, apart from their awareness that they were facing an abnormal situation.

2.2.10 Event 10: The stick shaker stops!

As the aircraft was approaching the few last seconds before the end of the recording, the pitch attitude decreased to between 35° and 75° nose down and the speed increased rapidly through 283 Kts, the stick shaker stopped. The aircraft was passing 5110 ft. The Flight Crew was applying right wheel input with left rudder input while pushing the control column forward. While this is a clear indication of a loss of situational awareness, it shows that the Flight Crew was still physically conscious at that advanced stage of the flight, despite the G loads encountered due to the aircraft maneuvers.

The over-speed clacker was heard on the CVR 3" before the end of the recording. The aircraft continued in its uncontrolled dive towards the sea till it impacted the water. The last recorded altitude was 1291' and the last recorded G load was 4.412, well beyond the maximum structural limitation of the aircraft.

Even at that advanced stage when the aircraft was passing 3,000', the simulation showed that with appropriate action, the aircraft was recoverable and prevented from impacting the water, but with some G load, in excess of the +2.5 G for which the aircraft is certified.

2.2.11 Event 11: A "ball of fire"

Eye witness accounts including an ATC controller and a crew flying in the vicinity of the aircraft reported seeing an "orange light" or "an orange explosion" or "a ball of fire" or "a ball that lasted 2-3" " at the time and towards the location the aircraft crashed into the sea.

No sign of any explosion or fire were detected on the wreckage, whether recovered or under water. No sign consistent with fire or explosion were detected during the autopsies carried on some of the bodies. Furthermore, neither the CVR or DFDR patterns reflect signs of an explosion or suggest an aircraft break-up as a result of such an explosion. The only loud noise recorded on the CVR was consistent with the calculated time the main aircraft body impacted the water surface.

The cloud base in the area of the crash at that time was 2,000', the aircraft was diving at a speed of 407 Kts increasing, this means that the time required to travel the 2,000' is less than 3". With the aircraft lights "on and that speed this could have appeared as an orange explosion, a ball of fire, and most certainly as a ball that lasted 2-3" as described by the Malev crew in his testimony.

The presence of thunderstorm activities in that area could have also created such an impression; especially that they produce loud noises similar to the noise produced by explosions and that they were present and active around the area of the crash. In fact, the Malev crew report clearly states what the crew saw in the following terms: *"a ball which lasted for 2-3" and which I considered to be a lightning due to the thunderstorm activity at the area."*

Did the aircraft break-down because of G forces just before impact, resulting in the end of DFDR and ATC Radar recording at 1291'? This will be discussed in section 2.4.5 of this report. Nevertheless, such a break-up wouldn't have produced an explosion, especially that the aircraft

was less than 2" from impacting the water; time at which the CVR stopped recording with a loud interrupted noise.

2.3 Flight Operations

In the flight operations section we shall analyze systemic issues related to the airline, the ATC, the weather, communication between the ATC and the flight, the Airport and the navigational aids available.

2.3.1 Airline Systemic Issues

In this section we examine the airline systemic issues that could have helped prevent such an occurrence or helped detect precursors to it. It examines crew qualification and pairing, procedures, training and safety.

2.3.1.1 Crew Qualifications and pairing

The ET 409 crew experience was within the minimum criteria stipulated in the ET Procedures in the following terms: *"Captain who has less than 300 hours and F/O who has less than 100 hours on type shall not be rostered together.*[24]*"*

The ET 409 crew met those requirements since the Captain had 188 hours and the F/O had 350 hours on type; therefore they could legally be paired together. That level of experience, although within the required approved standard, did not constitute a comfortable margin that would allow the crew to have enough confidence in the operation of the aircraft under demanding conditions, especially when we consider that the captain's experience on the B737-700/800 was acquired in the 51 days preceding the accident, which might have affected the purpose for setting that experience level.

2.3.1.2 Ethiopian Airline operational procedures

The operational procedures of Ethiopian Airlines were reviewed by the IC and were found adequate. They are in line with the Boeing procedures for that type of aircraft and have been verified during the IOSA audit. They do cover for situations like the ones encountered by the aircraft, in particular weather avoidance, recovery from stall and upset recovery. It also includes procedures to call for deviations and for the use of autopilot above the minimum engagement altitude of 400 ft.

The M-Cab simulation proved that the proper application of these procedures would have had saved the aircraft at every stage of the flight. The last part of the spiral dive is well beyond situations encountered by commercial operations. Therefore, no particular procedure is expected to be developed for it. However, applying the appropriate recovery techniques during any previous phase of that flight would have certainly avoided the aircraft reaching such a situation.

However, procedures requiring the PM to challenge the PF are restricted to calling and re-calling deviations when not corrected. When the captain is PM, the procedures clearly stipulate that he can further interfere by re-assigning himself as PF. However, no clear written procedure gives the F/O that right, except in the case of incapacitation. Is the pilot incapacitation procedure

[24] Refer to Appendix H

published in the emergency section of the FOPM enough? When the incapacitation is complete, yes; when the incapacitation is subtle, it is debatable. This will also be further discussed in section 2.5 of this report.

2.3.1.3 Training in Ethiopian Airline

Ethiopian Airlines training program was reviewed by the IC and discussed with various responsible training pilots, including the ones who trained the crew. The program is a well developed one and includes the CRM part in both pilot training and evaluation. Both pilots were trained in accordance to that program and got qualified through passing all the required stages of training.

Despite those facts and although the captain and the F/O were qualified according to the relevant regulations and training program, the accident happened. It happened because of the combination of a failure in basic piloting skills for the captain, and of a CRM failure from the F/O to take sufficient initiatives and be more assertive in helping his captain or identifying a possible case of subtle incapacitation. The issue of CRM and subtle incapacitation are addressed in more details and depth in section 2.5 of this report.

Nevertheless, one can wonder why Ethiopian Airline, a major IOSA registered airline with a training department, sound procedures, safety program, good reputation and long history, was unable to detect, in ab-initio training, recurrent training or graduating training that these two pilots, combined together, were possibly to fail. The strict adherence to SOP and regulation is not sufficient to prevent such accidents.

Another matter is the stall recovery training. The captain was rated as "good" in these exercises during his transition to 737-700/800. However, if he was able to recover from the first stall where the stick shaker lasted for 27", he was also unable to avoid the second one and to recover from it, or to recover from the unusual nose low attitude and excessive bank that resulted from the second stall. Despite the fact that the approach to stall recovery procedure was changed after the accident, had the crew applied the procedure in force at that time, they could have recovered, as demonstrated during the M-Cab sessions. As a matter of fact, the difference between the old and the new approach to stall procedures are essentially in the necessity to lower the nose prior to apply thrust in order to avoid difficulties in reducing the AOA resulting from the pitch up tendency as a result of thrust increase. In the case of the accident flight, the thrust was still at take-off setting; however, the aircraft was not trimmed properly and had a nose up tendency as a result of this miss-trim.

The captain had joined ET more than 20 years prior to the accident. He flew on spraying aircraft for 9 years prior to move to passengers' aircraft. These spraying aircraft require flying and handling skills, which is what we miss in the accident flight.

He was transferred to many other types of commercial aircraft, including turboprops, jet aircraft and jet aircraft with glass cockpit. He spent around 6 years on glass cockpit Boeing 757/767 prior to get his command on F-50 and eventually on B 737-700/800. According to records presented by ET and interviews carried with the ET training personnel, his track history was good apart from a final simulator check that he had to repeat during transition to B 737 - 700/800. Only once during his training a comment is written on "concentration". Was that indicative of any precursor? Could we consider it as a systemic issue? That question is very much debatable and not sufficiently backed to be considered as such, especially that it was only

mentioned once!

2.3.1.4 Ethiopian airline safety policy

Ethiopian Airlines has a safety policy and program that complies with IOSA standards, therefore with ICAO and industry best practices. That program includes a FOQA program and a confidential reporting system. A safety officer is appointed and is independent from Flight Operations; he reports to VP Flight Safety and Quality.

Information relayed to the IC by ET safety and operational personnel revealed that there was no previous indication that trends leading to this scenario were identified. The fact remains the accident happened! Were there any precursors that would have alarmed the safety department about F/O assertiveness? The Flight Safety Officer, who is a captain, had heard the CVR tape as a technical advisor to the Ethiopian Accredited Representative. He knew the F/O and had flown with him, he described the F/O in the following words: *"he seemed like a senior FO on his callouts and performance in flight, he says what he needs to say, he was not the quiet type and I was surprised on the CVR."*

That effect of surprise should be further evaluated and addressed by the airline when reviewing its safety program in order to prevent such reoccurrences.

2.3.2 ATC

ET 409 was handled by 3 ATC services: ATC Ground for initial departure clearance, push-back and taxi, ATC Tower for take-off clearance and initial climb, and ATC Control (Area) for the remaining part of the flight. According to records provided by the BRHIA Navigation Section, all ATC controllers that dealt with the accident aircraft were properly licensed in according to LARs.

Appropriate manuals and procedures have also been verified by the IC and found adequate. They contain detailed normal and emergency procedures. The ATC personnel schedule was also verified and is compatible with the LARs and work laws in Lebanon. The AIP of the aerodrome describes the departure procedures out of BRHIA as well as the arrival procedures. During the night of the accident, the ATC was handling both departing and arriving flights while having to deal with the weather avoidance issues, which are primarily the responsibility of the flight crew .

In his endeavor to help ET 409 avoid weather, the Tower controller amended the clearance to the aircraft from a LATED 1 D departure to a right turn direct Chekka as he was clearing the flight for take-off. Had the aircraft followed the initial standard departure it would have had to climb to 5,000' prior to turn right to Chekka, which would have taken it 5-7 miles SW of the field. An active CB was identified close to the airport towards the SW. Following the LATEB 1D SID route would have lead the flight right into that CB[25].

However, he Tower controller called by phone the Area controller to advise him about the new instruction to ET 409. The Area controller, who was handling at the time two arrivals from the North, advised the Tower to amend the clearance to a heading of 300° or 315°, which the Tower controller did prior to transfer ET 409 to the Area controller. That constituted 2 changes in less

[25] For information on LATEB 1 D departure refer to Appendix K. For information on the weather, refer to Appendix B and to the Etihad Captain's report in Appendix U

than a minute, but did not seem to affect at that stage ET 409 who acknowledged reception of both clearances and acted accordingly.

Normal ATC SOP calls for the Tower controller to verify with the Area prior to amend the departure clearance. According to the Tower controller, this SOP was not followed in order not to delay the take-off clearance given to ET 409. However, this had no effect on the communication exchange with the flight, since the new heading was immediately well received and acknowledged by the flight crew. Nevertheless, the ATC personnel should act in accordance with the laid down SOP.

For the remainder part of the flight and the action following the disappearance from the radar screen of ET 409, the controller appeared to be monitoring the flight closely and getting in contact with it confirming the same instruction to turn onto a heading of 270° in order to steer it away from both weather and arriving traffic route. Nevertheless, these repetitive instructions were ineffective in making the overloaded flight crew respond to the instruction to turn into the 270° heading.

Once the aircraft disappeared and no answer to ATC calls came back, the controller initiated the emergency response procedure.

The communication part between the ATC and ET 409 is further analyzed in section 2.3.4 of this report.

2.3.3 Weather

The reported weather on the night of the accident was cloudy, rainy and the sky around the airport was filled with isolated imbedded CB ranging between 2,000' and 26,000'. Similar weather is not uncommon in that area during that period of the year. BRHIA seldom close because of weather, and when it does it would be for a very short period of heavy rain associated with strong cross-wind, or with CBs over the field. Both these conditions were not present that night at the time of the accident and the airport continued uninterrupted operations throughout that night.

However, this type of weather and the presence of isolated active CBs produce noise and lights similar to those produced by large explosions. Furthermore, for aircraft flying in the vicinity, they add to the stress level caused by added IMC conditions, whereby the land lights and features disappear behind the clouds and are replaced by intermittent stormy lights originating from active CBs. Airline pilots are trained to avoid flying into such weather, and the ET procedure for weather avoidance is clear in his instruction to flight crew to avoid flights into areas with known or forecast thunderstorms. It also calls for pilots *"not to take-off during heavy thunderstorm activity at the departure airfield.*[26]*"*

Nevertheless, the thunderstorms around BRHIA were isolated and could have been avoided by abiding to the headings provided by the ATC, or by selecting other headings and advising the ATC accordingly, as advised by the controller. That part is also further discussed in the following section 2.4.

[26] Refer to ET Adverse Weather Operation Policy in Appendix G

2.3.4 Communications

The communication between the crew and between the crew and the ATC sounded very normal till the end of the 2nd event, when the aircraft turned beyond the 315° heading to which it was cleared and the ATC thought they were turning towards CAK VOR. Till then, the standard call outs and the communication between the ATC and the flight were perfectly understood and complied with by both pilots.

A proper analysis of the communication between the aircraft and ATC would reveal that once the ACC got in contact with the flight, he suggested heading 270°. The aircraft was now more abeam the field to the west, away from the CB that was to the SW. A couple of more CBs were identified NW and NE of the field, so the controller wanted the flight to navigate clear of them, while at the same time avoiding conflict with arriving traffic, who had to pass through the clear from weather corridor to the North of the field prior to establish on the localizer of the arrival runway 16[27].

The Area controller was even trying to be more helpful and suggested to ET 409, "*due to weather to follow heading 270° to be in the clear for fifteen miles twenty miles then go to Chekka, and it is up to you just give me the heading"***.** Thus, the controller suggested first an avoidance heading to the crew and then left it up to them to choose any other heading they felt comfortable with to avoid weather, as long as they advised him of that heading, since the responsibility for weather avoidance rests with the Flight Crew and their aircraft radar is definitely more accurate than the ATC radar in identifying weather and assessing the associated risks. Figure 15 in that report reproduces the snapshot of the radar picture displayed in front of the controller at the beginning of that transmission.

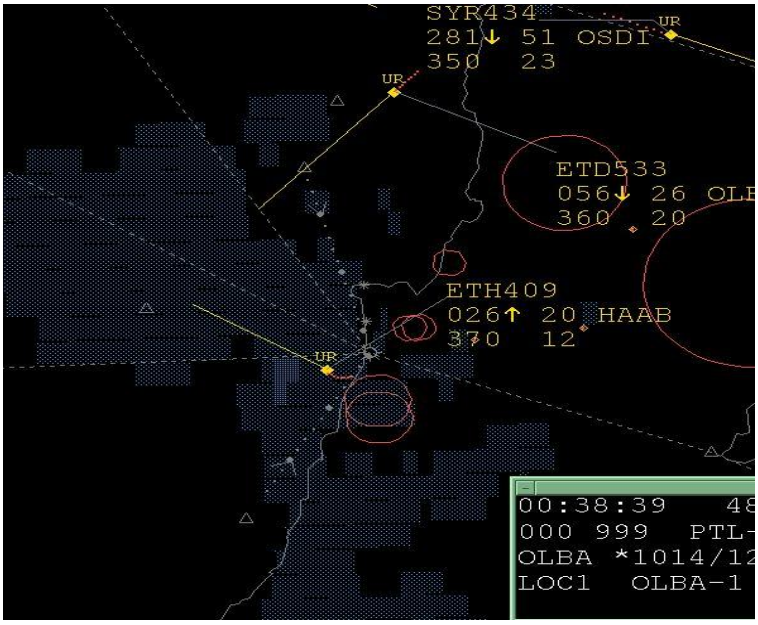

Figure 15: Radar Snapshot at 00:38:39

However, at that same time, the captain was having problems handling the aircraft, he turned beyond the selected/cleared heading despite the FD command and overbanked triggering *"bank*

[27] For more information on BRHIA layout refer to Appendix C

angle" warnings. That situation might have been preoccupying the crew, and the controller offer most likely added to their workload, since they were concentrating on more serious issues and focusing their attention on what was going on at an aircraft handling level. This could explain why the crew initially misread the heading as 210°. Nevertheless, that situation couldn't have been known to the controller.

Therefore the ATC controller who thought that the aircraft, which was now more than 45° right of the cleared to heading, had misunderstood the Tower amended clearance to fly heading 315° v/s fly direct Chekka. So he immediately issued a clearance to turn left heading 270°, which was acknowledged by the crew. Figure 16 below reproduces the snapshot of the radar picture displayed in front of the controller when the aircraft reached a heading of 003°. The captain was heard on the CVR reading back in the cockpit the correct heading and the F/O was recorded setting it on the MCP and confirming his action as per the SOP call-out.

Figure 16: Radar Snapshot at 00:38:59

Beyond that point, the ATC controller was unaware of the problems the crew had to control the aircraft, especially that no particular call indicating such difficulties was received, and all the clearances issued to the crew were read back in a calm and relaxed voice, with the exception of the last non-standard "roger, roger" call back transmitted by the F/O one minute prior to the crash and the open microphone sound he got as a reply to the last instruction the flight crew could have heard around 20" prior to the crash.

The controller, unaware of the problems the crew were facing, was unable to understand why the flight was not maintaining the cleared to heading, or why it was flying south and away from both the cleared to heading and the flight plan track, directly towards the weather and later on towards the mountain. All what he could do was call the flight, repeat his instructions and warn them, towards the end, that they were approaching the mountains.

CVR records confirm that both pilot received and confirmed the instructions from the ATC. The F/O always selected the new headings and level on the MCP as per SOP; however, the captain had difficulties following these instructions and the F/O never challenged him.

2.3.5 Airport & Aids to Navigation

BRHIA is located on the western Lebanese sea shore line to the South of the city of Beirut. The area surrounding the airport is composed of the Mediterranean Sea to the West, the city of Beirut to the North and the mountains of Lebanon to the East. These mountains reach a height of more than 3,000' less than 5 NM East of the field.

Due to this constraint, no departure or approach is allowed from the East. Furthermore, due to the presence of a military restricted area as of 15 NM South of BRHIA, no approach to Beirut is allowed from that area. This leaves a window of opportunity for arriving and departing traffic between a westerly heading and a bearing of 016° between BRHIA and Chekka VOR on the Northern Lebanese sea shore line. All departing and arriving traffic should be channeled through that area.

The airport is well equipped with approach facilities and other navigational aids. The equipment includes both Primary and Secondary radars. The airport is owned by the State and operated by the Lebanese Civil Aviation Authority (DGCA). Records provided by the Authority for the night of the accident revealed that the Primary and Secondary radars were checked and verified for accuracy. All systems were tested normal. All other navigation aids were reported to be working normally as shown by the records of these navigational aids for the night of the accident.

2.4 Aircraft

2.4.1 Aircraft Maintenance

The aircraft possessed a valid Certificate of Airworthiness, and had been maintained in accordance with the relevant regulations. The airplane had taken off from Beirut without any known technical problems.

A few months after the accident, the FAA issued an AD not related to that accident requiring a periodic on-going inspection of the bearing retention for a secure swage on all Boeing NG airplanes. Therefore, the IC decided to send the trim tab mechanism to the NTSB for analysis, especially that inboard attach bearing of the left side tab mechanism was found with all of the bearing balls missing. Refer to Figure 17 below.

Figure 17: Left Inner Attachment Bearing

The reason behind issuing the AD was two reports of unusual airframe vibration involving Boeing 737 NG airplanes. Despite airframe vibration, neither airplane suffered from "loss of integrity" to their flight control systems; both airplanes continued safe flight and landings. Post flight examination of both airplanes revealed that the elevator tab mechanism on one side had become completely detached (both inboard and outboard lugs) from its mountings on the front spar of the elevator. Analysis attributed these fractures to the loss of the attach point bearing retention and subsequent fracture of the attach tab. However, the DFDR of the two airplanes that diverted as a result of the vibration oscillation triggering the issue of the AD showed significant oscillatory movement of the elevator following its final fracture.

Because loss of the bearing balls would have had a similar effect as loss of the bearing retention (i.e. – significant play in the joint), the left tab mechanism from the accident airplane was subject to the detailed examination, since it was found that the bearing had lost all the balls, but the other side of that mechanism remained intact and neither side had become detached. That metallurgical examination conducted at the Boeing facilities revealed that the Inboard Lug Assembly on the accident airplane was damaged prior to the accident but there were no problems with the swaged sleeves[28].

Furthermore, the subject accident airplane did not reveal fractures on the tab mechanism attach points. In those circumstances, the intact side will retain the structural load path of the mechanism and it will continue to function normally without the vibration issue noted in the case of two airplanes mentioned above, which were at the origin of the issue of that AD.

Furthermore, review of the DFDR data from the subject accident airplane notes no anomalous oscillatory movement in the elevator control surface position during the accident flight or any of the recorded previous flights. The aerodynamic analysis of that data noted that the elevator always responded to the flight crew commanded inputs during the accident flight.

In addition, the EQA examination found that the outboard attach bearing on the left mechanism was damaged by the forces of impact and therefore was intact during the accident flight. The bearing retention was also inspected per the above mentioned FAA AD (all 4 attach bearings for both mechanisms); none was found with any looseness.

As such, the above data indicates that the damage noted to the inboard attach point bearing was not consistent with the previous events of the two airplanes at the origin of the AD where there was disengagement from the elevator front spar. It is worth mentioning that on these two occurrences of airframe vibration, despite the damages which were beyond the one identified on the accident airplane, the two airplanes landed safely.

Therefore, the damage identified to the left trim tab of the accident plane was different from the previous two cases and did not contribute to the accident sequence.

2.4.2 Aircraft Performance

The DFDR data shows that the aircraft performed as per design and in response to the input commanded by the flight crew.

[28] For full information on that analysis refer to Appendix O of this report.

2.4.3 Mass & Balance

The weight and balance form for the event flight was provided by ET and listed a gross takeoff weight of 70,443 kg (155,300 lb). This is consistent with the gross weight that was recorded on the DFDR.

The engine N1 that was applied during takeoff was consistent with a 22k de-rate thrust setting[29]. With a 22k de-rate thrust setting, a weight of 70,443 kg (155,300 lb), and a center of gravity of 18%, the Airplane Flight Manual (AFM) for ET-ANB defines the recommended takeoff stabilizer as approximately 6.9 units. The event weight and balance form listed the stabilizer setting as 5.26 units[30]. This is 1.64 units in the airplane nose-down direction beyond that recommended in the AFM.

In addition, the stabilizer that was recorded on the DFDR was approximately 5.94 units at the start of the takeoff, which is still within the certified range for take-off (green-band range), but nearly 1 unit in the airplane nose down direction that recommended by the AFM.

The DFDR data also shows a continuous pull on the control column in order to maintain the airplane climb attitude commanded by the DFDR. This confirms the fact that the set trim, although within the limitation of the aircraft, was in the nose down direction and was inappropriate for the take-off conditions.

Similar situations of limited miscalculation do occur for various reasons during normal operations; however, basic flying skills require the pilot to maintain his aircraft in trimmed situation at all times. In that case, to trim "up" in order to relieve the load on the control column. Why didn't that happen? We shall discuss that in section 2.5 of this report.

2.4.4 Aircraft Instrumentation

No particular problem with the aircraft instrumentation was reported on the accident aircraft prior to the flight or on the DFDR. As per the design of these instrumentations, the investigator who flew the M-Cab was not a B 737 certified pilot and found no difficulties in reading the aircraft instruments or following the FD command.

2.4.5 Aircraft Systems

All the recorded data retrieved from the DFDR revealed that there was no specific issue related to the aircraft that could have contributed to the crash. Both the DFDR and CVR data did not record during flight any interference or sound associated with a lightning strike. An examination of the recovered wreckage, including interior components from the forward, mid and aft section of the airplane, including a large section of the stabilizer, and a review of the underwater videos of the remaining wreckage, revealed no indication of any sort of visual evidence associated with such a strike.

A black soot near the APU exhaust was identified by the Airworthiness team and was sent for further analysis and evaluation by the NTSB. Despite the fact that nothing in the DFDR warrant

[29] While the "Notes for the CG Limits" mentioned on the ET 409 Balance Chart (refer to Appendix V) only shows ratings of 24K, 26K and 27K, Appendix 2 of the Airplane Flight Manual (AFM-D631A001.8AS4) applicable to the accident plane includes provisions for the 22K trust rating.

[30] Refer to Appendix V for a copy of the Load-Sheet and the Weight & Balance Form

the theory of system failure leading to explosion, interference as a result of a lightning strike, or another sort of unlawful interference that could have produced traces consistent with high temperature or fire, the IC wanted to rule out that theory and sent a piece of the aircraft wreckage where the black soot was identified.

The analysis of that piece, along with autopsies of recovered bodies, confirmed without doubt that the aircraft was not subjected to heat or explosion. The fact that the DFDR readings end with the aircraft passing 1291 ft does not imply necessarily that the aircraft broke down at that moment, despite the fact that it could have started experiencing some loss of structural integrity due to the fact that the recorded airspeed at that altitude exceeded the certified dive velocity (Vd) of 400 Kts while the G load was well above the certified +2.5 G; under these circumstances, a loss of structural integrity would be possible. Nevertheless, both the speed and rate of descent at that stage were excessive and the calculated impact time was less than 2" away, time at which the CVR stopped recording with a big bang noise, most likely resulting from the aircraft impact with the water.

2.5 Human Factors

The accident airplane possessed a valid Certificate of Airworthiness, and had been maintained in accordance with the relevant regulations.

The airplane had taken off from Beirut without any known technical problems, flown by properly licensed and qualified crew. The documents received by the Flight Crew prior to departure, including weather information, were in accordance with the relevant requirements. The ATC controller were properly following up the accident flight and offering the necessary instructions, suggestions and reminder calls. The aircraft continuously responded to the crew input and all its systems reacted as per design, including the speed trim command and the warning/alarm systems.

The captain had been flying for more than 21 years. Although new on the B 737-800 type, all his experience was on aircraft that required manual/electrical trim. He had been on jet aircraft as a F/O for nearly 8 years and as Captain for 51 days. So, he was familiar with that type of flying and he knew that rudder on this type of aircraft is not normally used to fly, unless there was an engine failure or a cross-wind take-off or landing. This raises a series of questions: Why didn't the PF trim that aircraft properly? Why, out of 4' 17" of flight, that aircraft was in trim for less than 40"? Why was the PF using the elevator in a manner inconsistent with the FD command and sometimes giving opposite inputs between the elevator and the electrical trim; trimming up while pushing down[31]? Why was the PF using the rudder and ailerons in a manner inducing "cross control" situations and inconsistent with the FD demands and the recovery procedures he had practiced during training? What had happened to the pilot's basic flying skills and what was the reason for such degraded performance?

[31] In fact, the B737 type aircraft is equipped with a cutout function which will stop the electric trim if the column moves in the opposite direction, beyond the neutral range. This neutral range is defined such as the electric trim in the opposite direction (nose up in this case) will cutout when the control column is deflected in a nose down direction of between 2.5 to 3.9 degrees. A review of the DFDR data shows a control column deflection of 2.0 degrees in the nose down direction during the stabilizer nose up command electric command. As such, consistent with its design, the column deflection on the accident flight did not activate the stabilizer trim cutout switch at that time.

The F/O had been identified by his trainers and his peers as a good one; see one the best. He had been known to be assertive and was trained as such throughout most of his training program. His voice sounded very calm and confident on the CVR and during radio transmissions on the ATC transcript. The F/O received the ATC instructions, confirmed them to the captain and set them on the MCP.

He must have also heard all the *"bank angle*" warnings, and the 2 stick shakers. So why didn't he, as PM, challenge the captain throughout the 4' 17" flight time, as required by the ET SOP? Why didn't he try to take over control of the aircraft and save it as required by the ET procedures?

Why didn't the crew apply the procedures specified in the ET QRH and other operational manuals and recover from the stall as the aircraft was approaching it? Why did the crew allow the aircraft to enter into a spiral dive? These are the questions we shall try to find answer to during this analysis.

We have established during the analysis of the DFDR data and the examination of the aircraft wreckage that the aircraft was airworthy and responding properly to the crew input. We have also established that this was the captain's first flight into BRHIA, the flight was operated at night with isolated CBs around the airport affecting the standard departure route. The captain had 188 hours experience on type accumulated in 51 days and the F/O a total airline and type experience of 355 hours.

We should keep all these elements in mind while we examine both physiological and psychological factors that might have affected the crew. We shall also examine how these factors became more critical when combined with other external factors and how they led to the crew degraded performance. We shall then discuss and analyze some CRM issues.

2.5.1 Physiological factors affecting the crew

Both pilots seem to have enjoyed a healthy life and no particular reported medical problems had been reported. No total incapacitation occurred leading to the accident, since both pilots were heard talking till a few seconds prior to the end. The flight crew inputs on the controls were also recorded on the DFDR till the end of recording. That is definitely a sign of a strong physical body.

However, on the date of the accident, the crew was heard discussing with a ground staff the components of the meal they had in Beirut during their lay-over and were heard stating, although in a joking manner, that they suspect the food they ate contained "weed" and that they couldn't sleep. That comment could have been a banal one if the accident didn't occur.

Could indigestion as a result of a heavy meal cause subtle incapacitation? Gastronomical disorders have been identified as major contributors to incapacitation. Physiological and psychological factors have also been identified as causal factors for subtle incapacitation. In fact, the FOPM clearly defines the causes of such an incapacitation as being "*minor brain seizures, low blood sugar (hypoglycemia), other medical disorders or preoccupation with personal problems."* It also stipulates that *"since the crew member concerned may not be aware*

of, or capable of rationally evaluating his situation, this type of incapacitation is very dangerous"[32].

In fact subtle incapacitation is about a slow degradation of performance in a crew member. It is more dangerous when it occurs to the captain, due to the cockpit authority gradient. The pilot would look and sound as if he was conscious; however, his performance would have degraded. Symptoms of subtle incapacitation include: *"Skills or judgment may be lost with little or no outward sign; the victim may not respond to stimulus, may make illogical decisions, or may appear to be manipulating controls in an ineffective or hazardous manner; failure to respond normally to two consecutive challenges or one significant warning should trigger action. Symptoms may be evident only in moments of high stress or workload*[33]*".*

Most of these symptoms were present in the case of the captain: Turning beyond pre-selected and acknowledged headings, not following the FD, flying the aircraft out of trim, failure to call for the after take-off checklist or for anti-icing "ON" when penetrating heavy rain in probably icing temperature, failure to engage and confirm the engagement of the auto-pilot, late to recognize the stall, failure to properly apply the stall recovery procedures, manipulating the controls in an ineffective and hazardous manner, failure to respond to series of warning, failure to react to ATC repeated instructions and failure to follow the procedures the PF was freshly trained to follow, considering that he was released on type 51 days prior to the accident.

The fact remains that all of this occurred in moments of high stress and workload: departure late at night from a new airport surrounded by high terrain on one side and weather on the other (1st time the captain flies out of BRHIA), having to cope with a new modern aircraft (51 days since release), having had a heavy meal that didn't allow him proper sleep, having a junior F/O on the right seat and having to cope with ATC instructions, which at times required him to come back with his decision following an ATC suggestion.

While these high stress and workload factors shouldn't have caused by themselves the degraded performance recorded by the flight, they surely contributed to raise the stress level of the captain which, in turn, could have added to spatial disorientation and loss of situational awareness and developed into a case of, or similar to, subtle incapacitation. Such incapacitation have been identified by experts as being the result of sleep loss, fatigue, emotional stress, blood chemistry imbalances, or as a result of some drugs or alcohol.

According to interviews with his NoK and colleagues, the captain did not drink and did not suffer any emotional stress. He enjoyed a good health and was only taking medication for hair fungus. However, he had accumulated more than 188 hours of flying on a new type of aircraft in 51 days, often flying at different hours of the day. While that amount is still within the legal limits, it certainly could have generated some successive periods of acute fatigue[34], due to the combination of mental activity required to fly a new aircraft and the excessive physical activity associated with the tight schedule. That could have eventually developed into a chronic fatigue[35]. That chronic fatigue linked with the sleep loss resulting from the heavy meal and the

[32] Refer to the ET FOPM extracts in Appendix
[33] Refer to Transport Canada document TP 11629 – Pilot Incapacitation www.tc.gc.ca
[34] Acute fatigue is defined in the ICAO Manual of Aircraft Accident and Incident Investigation (Doc 9756), v. IV, as *"The result of excessive physical and/or mental activity during a short period. A temporary condition that may be reversed by adequate rest."*
[35] The same manual mentioned in the previous reference defines chronic fatigue as *"The result of long exposure to successive periods of acute fatigue, over many days or weeks, without adequate rest periods for recovery."*

other external contributing factors discussed above could have most likely joined together and contributed to this situation, whereby symptoms of subtle incapacitation to the captain are identified; bearing in mind that the captain was the PF on that flight, this could explain some of the actions, reactions and inactions witnessed on the aircraft controls through the DFDR data.

However, despite the fact that most of the facts linked with the symptoms of subtle incapacitation are identified through the DFDR and CVR data, the absence of autopsy to the pilots' bodies/remains, as a result of their impact with the water surface at high speed, does not allow us to physically confirm the case of subtle incapacitation due to physiological reasons. Nevertheless, dismissing that possibility would certainly make it very difficult to explain the pilot mishandling and mismanagement of the flight, in view of his long experience, training received and time spent with the airline.

2.5.2 Psychological factors affecting the crew

While the case for the captain's subtle incapacitation could be supported by factual evidence of related symptoms from the DFDR and CVR, regardless of the real reason for that subtle incapacitation; the passiveness of the F/O throughout the flight raises a lot of concerns. The F/O has been described by one of his training pilots in the following terms: *"he seemed like a senior FO on his callouts and performance in flight, he says what he needs to say, he was not the quiet type."* What made him so quiet on that particular day?

The F/O had more than 300 hours on type and was acknowledged by his superiors as well as by his peers as one of the best F/O. His radio transmissions, comments on the CVR and tone of voice showed that he was conscious of what was going on and performing his normal duties in a proper manner. However, he never took an initiative and he did not perform his expected duties whenever things deviated from normal: failing to remind the captain when he did not ask for the after take-off checklist, calling deviations from ATC instructions or aircraft profiles, challenge the captain when he was not controlling the aircraft as a PF should have been doing and avoiding to take control of the aircraft when he felt that the captain was completely out of the loop.

In fact, twice the captain seems to have felt that he was not in good shape or unaware of what was exactly happening, so he requested assistance from his F/O. That came as the aircraft was entering its 2nd stall when the F/O called in English *"the speed is dropping"* and the captain replied in Amharic *"speed is going down… OK, try to do something"*. A few seconds later and following 2 "*bank angle*" aural warnings he told his F/O *"hold this thing"*. These calls indicate a situation of cognitive saturation by the captain, where the information processed was exceeding his span of attention. That is another indication of subtle incapacitation when the subject is an experienced pilot who must have faced similar workload throughout his career.

However, even when asked by the captain, the F/O failed to provide the assistance required. Did he feel that it was too late to intervene at that stage? Did he wonder what type of help was required of him? Was he reluctant to "unnecessarily" interfere as a PM in the PF duties? Was he afraid of making mistakes? Was he shy of asking the captain questions that might look "irrelevant"? Did he consider that since the experienced captain couldn't control the aircraft, he wouldn't be able to?

To properly analyze the F/O passiveness we must consider that, despite the fact that ET encourages during training the F/O to take over in case of subtle incapacitation, that

incapacitation was identified by the training pilots interviewed as failure to respond more than once to standard calls. The incapacitation procedures laid down in the ET FPOM emergency section lists 5 symptoms of incapacitation, mainly *"incoherent speech, strange behavior, irregular breathing, pale facial expression and jerky motions that is either delayed or too rapid"*. It clearly specifies that *"if any of these are present, incapacitation must be suspected and action taken to check the state of the crewmember."* We shall analyze the flight information in light with the above prior to analyze the F/O passiveness.

While nothing in the recorded data we have allows us to confirm that the captain suffered from irregular breathing or pale facial expression, the recorded data points to some strange flying behavior associated with some uncoordinated, delayed or too rapid inputs on the control column, wheel and surprisingly enough, rudder! While the captain's speech cannot be clearly classified as incoherent, his tone of voice throughout his recorded conversations, once the aircraft started its take-off roll and till the crash in-flight, in addition to the need for him to re-confirm the clearances received in an interrogative way, implies that he was under some stress and was not properly aware of the prevailing situation affecting his flight.

However, asking the F/O during flight to identify all these issues would be very demanding, regardless of his experience. Nevertheless, he could have surely noticed the unusual indications on the FD, the unusual movements of the control wheel and column, the unusual speed and the captain's non abidance by the ATC instructions. He surely heard the captain's request for his assistance, which were recorded twice on the CVR. He also must have heard the multiple *"bank angle"* aural warnings and the two prolonged stick shakers. However, the CVR does not record any call or comment in that respect! If that is the case, his reluctance to intervene and take over control of the aircraft wouldn't be surprising.

In fact, all these require standard deviation calls by the PM, according to the ET SOP. Only twice did the F/O call *"speed*"! When he did, the captain immediately requested help, but the F/O failed to provide such help. This raises the following question: Was the F/O suffering some channelized attention with his full attention focused on one stimulus (accomplishing his normal PM duties) to the exclusion of all others? He surely accomplished those duties properly through the communication with the ATC, announcing normal changes and other standard call outs and setting the required information on the MCP. However, he did not remind the captain about the after take-off checklist and definitely failed to properly process the flight situation information and perform the standards deviation calls which were of a higher importance during the events that the flight went through.

With the level of experience he had, would it be demanding to ask the F/O to intervene and take over from the captain, who had been in the company for more than 20 years, when one of his training instructors had written in his file that he shouldn't *"interfere with PF duties unnecessarily" and* discouraging him from asking *"irrelevant questions"* or repeating *"minor mistakes"*? In fact, although that remark came in a training context and was mentioned once early in his training prior to start his FFS sessions and that the F/O training performance were highly quoted, especially in the field of CRM; such remark most likely affected his subconscious mind and could have contributed to his reluctance to intervene.

2.5.3 Individual human performance and CRM

The accident scenario indicates that the captain had progressively lost the control of the situation, starting with roll control problem to which were added heading control problems, then

pitch control problem until the final loss of control. The basic instrument flying performance of the captain on that day was questionable. It seems that he was at this time unable to alternatively pay attention to the basic parameters starting with attitude displayed on the PFD and ND indications.

This insufficient performance could originate from a mix of low experience on type, high workloads, chronic fatigue, distraction by multiple ATC messages while concentrating on manually flying in bad weather, spatial disorientation at night and low situational awareness in a fast changing environment, all combining together to increase the workload and stress level to a high degree and create a situation of high anxiety with symptoms similar to those of a subtle incapacitation, which was not recognized by the F/O, even after two late requests for help by the captain.

While the flight behavior indicates that spatial disorientation was an issue, since the pilot faced difficulties in maintaining the aircraft vertical, lateral and horizontal attitudes; that spatial disorientation evolved into a situational awareness issue, since his ability to keep track of the aircraft indications (namely on the PFD and ND) was degraded, and his ability to prioritize significant environmental, navigational and aircraft related events was impaired.

If situation awareness refers to one's ability to accurately perceive what is going on in the cockpit and outside the aircraft, it further extends to the planning of several solutions for any emergency situation which could occur in the immediate future. The Flight Crew was unable to properly process the information from sense inputs, instruments, and other sources to form an accurate picture of what was happening. Did that loss of situational awareness come as a result of a subtle incapacitation by the captain and failure of recognizing it by the F/O, or was it a result of a combination of events, both external to the flight and inherent to the Flight Crew, that led to a situation of high workload and stress?

In fact, there is no direct indication in the captain’s training record examined by investigators that he already had either occasional or recurrent serious difficulties in basic flying. However his repeated failure to focus on the main priorities of controlling the aircraft attitude and trajectory during the 4’ 17” flight raises the question on his ability to divide his attention in a structured manner as it is taught (or should be) in initial pilot schools. Would that been possible after 21 years of flying? His actions indicated beyond doubts that his situational awareness was impaired. So, why didn’t the F/O intervene as required by his company SOP?

CRM principles are designed in such a way that if a pilot has difficulties, he could find support from the other pilot. The CVR does not indicate any significant help spontaneously offered by the F/O to his captain, even when requested to do so; exception to that is the F/O performance of his routine duties. Even when the captain did not call for the after take-off checklist, the F/O did not remind him of that important part of the SOP!

While this is true for short term flying, questions can also be raised on how the crew took the weather condition into account; there is no evidence in the CVR of any discussion about the departure strategy before take-off, or about tactical choices during the flight to avoid weather, despite the fact that the Tower controller had given them the opportunity to exercise their tactical choice in avoiding the weather, as long as they inform him of the heading they wish to follow. No comment is made on what is depicted by weather radar, even when sounds of heavy rain are heard on the CVR. No request for engine anti-ice is recorded despite the fact that they most likely flew in icy conditions.

While the captain's actions are consistent with the symptoms of loss of situational awareness that could indicate some form of subtle incapacitation, the F/O failure to challenge the captain or take over control could be found in his reluctance to act in a manner that might generate some remarks similar to the one mentioned once in his training file[36], especially with the experience gradient that existed between him and the captain and despite the training program and documentation that should have given him the administrative support for such an action. That experience gradient could also explain why he did not take over control of the aircraft, even when requested to help: if the experienced captain cannot handle it, will I be able to?

2.6 Survivability: S&R Operations

Due to the impact forces with the water at such high vertical and horizontal speeds and the G loads at the end, the accident was not survivable.

The S&R operations were launched immediately by the Lebanese government using all the resources available and all the help provided by friendly nation's ships and aircraft stationed in the region. The S&R was led by the Lebanese Army due to logistical reasons and in order to provide a good protection of the accident site.

In view of the existing resources, the level of crisis management planning and preparedness to face such a catastrophe and the prevailing weather, we can consider that the effectiveness of these operations was good and the organization was acceptable. However, this wouldn't have been possible without the help and assistance of friendly nations help and civilian contracted services. Furthermore the interagency coordination was spontaneous and not in response to a pre-planned and exercised plan.
Therefore, the Lebanese government should consider establishing a crisis management plan in order to face such situations and either equip some entity with the required resources to face such crises, or to establish a contract with a S&R agency to complement the DGCA contract with the BEA. The lack of precise data on the sea bed surface within the Lebanese territorial water should also be addressed.

The separation of the CSMU from the main CVR chassis can only be attributed to the forces of the aircraft impact with the water surface. Signs of such an impact have been identified on all the aircraft parts that were retrieved from the sea or pictured/videotaped in the sea bed.

The efforts of the navy divers, who were operating with limited equipment and under difficult meteorological conditions and psychological pressure, were essential in the protection, search and retrieval of the human remains, aircraft recorders and parts.

[36] Even if that remark was mentioned once during his training, such remarks could negatively affect pilots till they acquire enough experience to allow them to link such remarks to their training context.

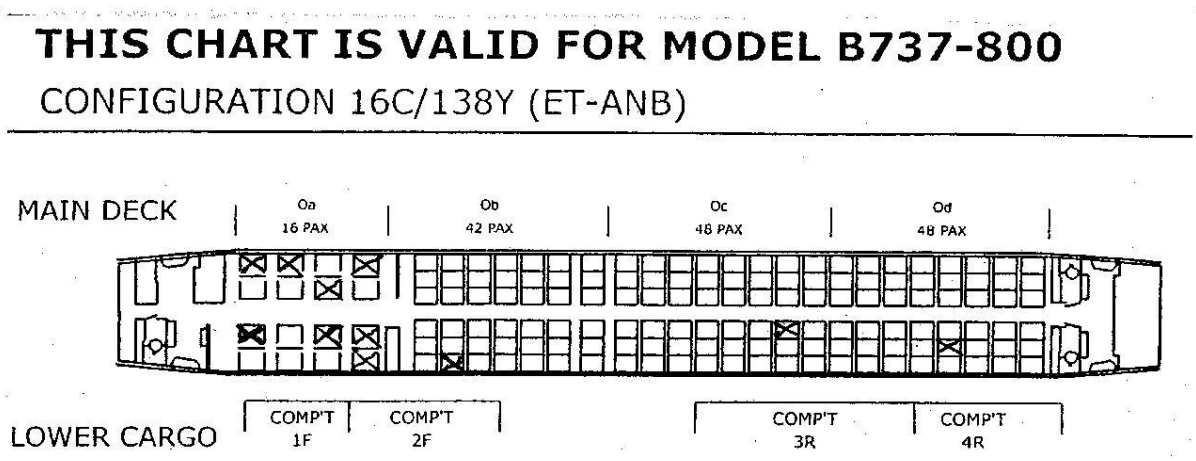

Figure 18: Airplane Map

N.B. ***Seats marked with an X are the seats were of the passengers whose bodies were recovered on day 1. Two out of these passengers were children under 5 years of age.***

3. Conclusions

3.1 Findings

3.1.1 The Aircraft

1- The aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures.

2- The aircraft was airworthy when dispatched for the flight.

3- The aircraft had been properly loaded to a TOW of 70,443 Kg with a C of G of 18% at the gross take-off weight.

4- The Weight & Balance form listed the stabilizer setting as 5.26 units. The DFDR recorded a setting of 5.94 units at the beginning of the take-off roll. The AFM recommended setting for the aircraft take-off conditions was 6.9 units. Therefore, the stabilizer position during take-off was more airplane nose down, although still within the certified range for take-off (Green Range).

5- The aircraft flew in an out of trim situation for most of the time, while all systems were functioning properly.

6- The aircraft behavior was the result of its response to the pilot's input throughout the flight.

7- There was no evidence of any defect or malfunction in the aircraft that could have contributed to the accident.

8- The aircraft was structurally intact till the last couple of seconds prior to the accident. However, the aircraft could have began to experience loss of structural integrity when passing 1290 feet during the final dive (2" before impact) due to the excessive speed and loads. However, the wreckage lay-out and CVR recording supports that it's main body was destroyed by impact forces with the water.

9- No signs of fire or explosion was detected in the aircraft wreckage.

10- The design of the aircraft's primary flight instruments and radio navigation instruments are adequate for the situational awareness of the crew at a time of high workload.

3.1.2 The Flight Crew

1- The flight crew were properly licensed and qualified for the flight in accordance with existing regulations.

2- The Flight Crew was in compliance with the flight and duty time limitation regulations.

3- The flight crew possessed the proper medical certification and had the opportunity to have the appropriate rest to operate that flight.

4- This was the captain's first flight into Beirut.

5- The crew expressed some concerns as a result of the meal they had during the lay-over in Beirut and that it could have affected the quality of their sleep prior to operate the flight.

6- The captain's actions, statements and degraded performance during that period were consistent with the effects of spatial disorientation and loss of situational awareness that could have been the result of a subtle incapacitation, although there was insufficient evidence to determine the reasons of that incapacitation.

7- The F/O failure to abide by all the airline SOPs and intervene with the captain throughout most of the events of the flight, even when called to do so, contributed to the flight crew degraded performance.

3.1.3 Flight Operations

1- The flight was dispatched in accordance to the company Operations Manual.

2- The Flight crew carried out normal radio communications with the relevant ATC till the last phases of the flight when the aircraft was approaching the spiral dive.

3- The aircraft anti-icing system was not used despite the fact that the aircraft most probably flew in icing conditions; however, the performance analysis conducted based on the DFDR data indicates that icing was not a factor in the accident.

4- The crew did not discuss or perform any tactical action to deviate from CB clouds present in the area around the airport whenever required during the flight.

5- The aircraft did not follow any assigned heading provided by the ATC, despite the fact the crew was acknowledging the headings and the F/O was selecting them on the MCP.

6- The aircraft went twice into stall situations for prolonged times (27" & 26") and there was sufficient altitude available to recover from stall each time.

7- The aircraft flew many times in a "cross lateral control" situations induced by the pilot actions on the control wheel and rudder pedals.

8- During the final phase of the flight the aircraft went into an uncontrolled spiral dive induced by the pilot inconsistent inputs on the aircraft flight controls.

9- There was no distress calls received from the aircraft during flight.

10- The ATC controllers provided proper instructions and follow-up to the flight.

11- The weather on the night of the accident was a contributor in increasing the workload on both the controllers and the Flight Crew.

12- The aircraft did fly in heavy rain and icing conditions, but it did not encounter any severe turbulence or lightning strike.

3.1.4 The Operator

1- The SOP of the operator did contain a statement encouraging the PM to take over from the PF in cases of incapacitation.

2- The operator is IOSA certified with a safety program in place.

3- The SOP for the PM to monitor the PF and call any deviation was not properly implemented and was not effective in preventing the continued degradation in the captain's performance during that flight.

4- The CRM training provided by the operator was not effective in promoting F/O's assertiveness and leadership.

5- The operator FOQA program did not identify trends that could have lead to such an accident.

3.1.5 ATS & Airport Facilities

1- The Ground, Tower and Area Radar controllers were all licensed, medically fit and correctly rated to provide the service.

2- The number of ATC controllers on duty was in accordance with the regulations.

3- The ATC controller's load was assessed as moderate with minor complexity considering the normal workload, weather and traffic prevailing in Beirut during that part of the year.

4- The coordination between the Tower and Area controller was not in line with the ATC SOP, although this had no particular bearing on the accident.

5- The ATC controller requested ET 409 repetitively to turn to a heading of 270 in order to avoid weather, traffic and mountains.

6- The ATC controllers provided prompt and efficient assistance to the Flight Crew, that assistance was not effective.

7- Despite the fact that the ATC did not receive any distress call, the ATC effective radar monitoring resulted in an effective response from ATC to the accident.

8- All airport equipment, radars, navigational facilities and lighting were operating normally at the time of the accident.

3.1.6 Flight Recorders

1- The aircraft was equipped with a DFDR and a CVR.

2- The DFDR was recuperated from the sea and provided all the required information recorded on it.

3- The CVR detached from its chassis and had to be retrieved from the sea bed through thorough under-water hand search by the Lebanese Navy Divers.

4- One out of the 24 CVR's memory chips (U16) was unreadable and prevented getting the full audio CAM track, creating a gap of 10" of missing recording on the CAM twice during the flight.

5- The quality of the audio information recorded was good. All information was transcribed.

6- Both DFDR and CVR data were instrumental in revealing the factual information related to that flight.

7- An ATC Radar recording was also verified and information on it was found consistent with the DFDR data.

8- An ATC communication transcript was also developed and found consistent with the CVR data.

3.1.7 Medical

1- As a result of the impact, there was no possibility to carry an autopsy on the flight crew.

2- The inability to carry such an autopsy deprived the investigation from a factual tool that could reveal evidence of incapacitation or other physiological factors that might have affected the flight crew performance.

3- No medical history of the flight crew and presented to the investigation indicate any sign of physiological or psychological disturbance.

4- Post-mortem examination and autopsies of some bodies that were recovered in acceptable conditions revealed no signs consistent with fire or explosion.

5- All 90 persons on board were identified through DNA matching.

3.1.8 Survivability

1- The accident was not survivable due to the magnitude of the acceleration forces and the impact with the water surface.

2- The occupants succumbed to the effects of the impact with the surface of the water.

3.1.9 Search & Rescue Operations

1- The S&R operations were effective and timely.

2- Despite the lack in appropriate equipment, the devotion of the Lebanese Army personnel and divers was instrumental in the success of the S&R operations.

3- The foreign assistance provided by friendly forces stationed in the region was instrumental in the success of the S&R operations.

4- The devotion of the Lebanese Army command and personnel and the foreign assistance compensated for the weak crisis management planning and interagency coordination.

3.1.10 Safety Oversight

1- The ECAA oversight of the operator's procedures and operations was adequate.

3.2 Causes

3.2.1 Probable Causes

1- The flight crew's mismanagement of the aircraft's speed, altitude, headings and attitude through inconsistent flight control inputs resulting in a loss of control.

2- The flight crew failure to abide by CRM principles of mutual support and calling deviations hindered any timely intervention and correction.

3.2.2 Contributing Factors

1- The manipulation of the flight controls by the flight crew in an ineffective manner resulted in the aircraft undesired behavior and increased the level of stress of the pilots.

2- The aircraft being out of trim for most of the flight directly increased the workload on the pilot and made his control of the aircraft more demanding.

3- The prevailing weather conditions at night most probably resulted in spatial disorientation to the flight crew and lead to loss of situational awareness.

4- The relative inexperience of the Flight Crew on type combined with their unfamiliarity with the airport contributed, most likely, to increase the Flight Crew workload and stress.

5- The consecutive flying (188 hours in 51 days) on a new type with the absolute minimum rest could have likely resulted in a chronic fatigue affecting the captain's performance.

6- The heavy meal discussed by the crew prior to take-off has affected their quality of sleep prior to that flight.

7- The aircraft 11 bank angle aural warnings, 2 stalls and final spiral dive contributed in the increase of the crew workload and stress level.

8- Symptoms similar to those of a subtle incapacitation have been identified and could have resulted from and/or explain most of the causes mentioned above. However, there is no factual evidence to confirm without any doubt such a cause.

9- The F/O reluctance to intervene did not help in confirming a case of captain's subtle incapacitation and/or to take over control of the aircraft as stipulated in the operator's SOP.

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4. Safety Recommendations

In accordance with Annex 13 to the Chicago Convention, the sole objective of the investigation shall be the prevention of accidents and incidents. Therefore, the following recommendations aim at preventing other accidents from similar causes.

4.1 The Operator

4.1.1 The operator should revise its CRM program in order to stress on the F/O assertiveness and leadership requirements especially in periods of abnormal performance.

4.1.2 The operator should consider its classification of airports where non-technical constraints might affect flight operations and brief their flight crew accordingly.

4.1.3 The operator should re-examine his crew pairing and scheduling policies in order to ensure a less stressful cockpit environment.

4.1.4 The operator should consider establishing write up criteria for pilots training files in order to avoid the adverse effects of any miss-interpretation by the trainees.

4.1.5 The operator should consider developing his safety oversight program in order to detect such potential flight crew performance.

4.2 The ECAA

4.2.1 The ECAA should ensure that the recommendations to the operator have been implemented.

4.2.2 The ECAA should re-examine the regulations concerning crew pairing policies.

4.3 ICAO

The Investigation recommends that ICAO re-examines the international requirements for the identification, training and reporting of subtle incapacitations symptoms and cases.

4.4 Lebanon

4.4.1 The Investigation recommends that the Lebanese Government establishes requirements to ensure that responses to such accidents are made systematically without reliance on foreign ad hoc assistance.

4.4.2 The Investigation recommends that the Lebanese DGCA re-evaluate the working conditions of the ATC personnel.

4.4.3 The Investigation recommends that the Lebanese government considers establishing administrative and logistic support for such investigations.

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List of Appendices

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Appendix A: ET Air Operator Certificate (AOC)

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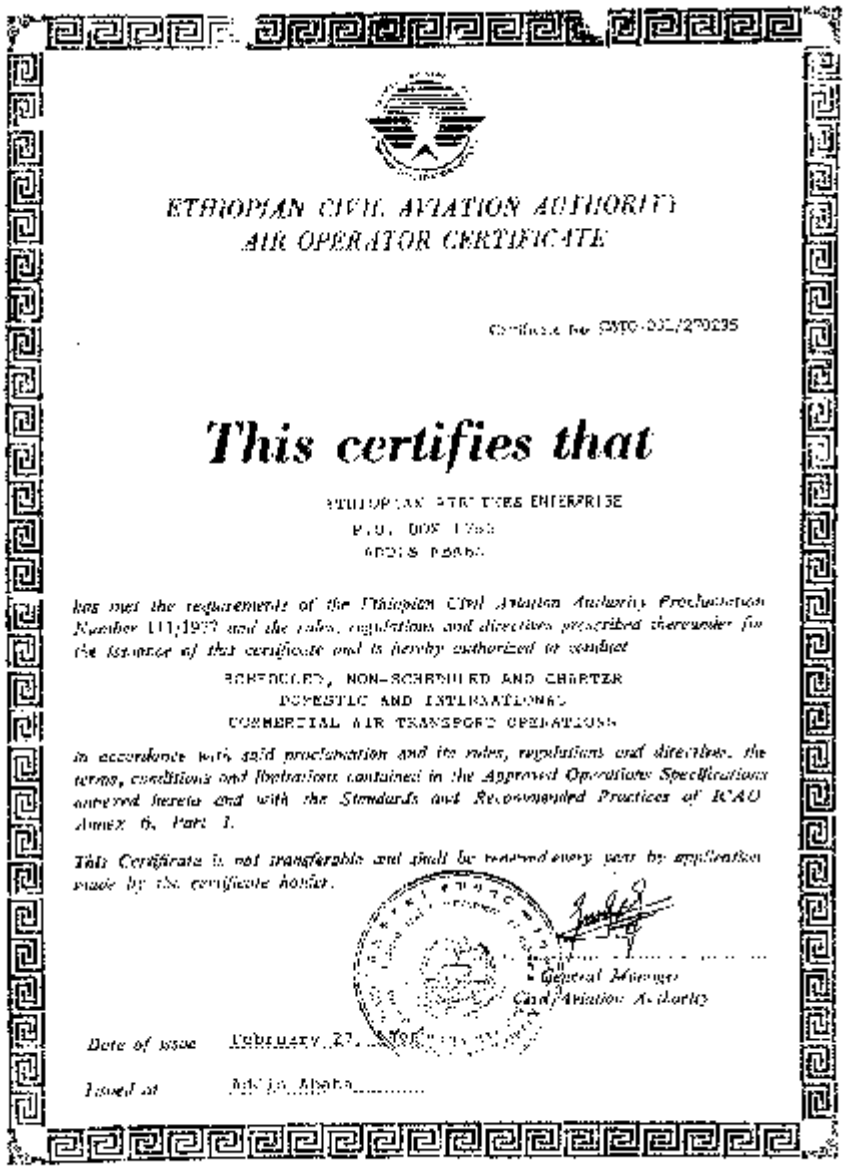

ETHIOPIAN CIVIL AVIATION AUTHORITY
AIR OPERATOR CERTIFICATE

Certificate No. [illegible]

This certifies that

ETHIOPIAN AIRLINES ENTERPRISE
P.O. BOX [illegible]
ADDIS ABABA

has met the requirements of the Ethiopian Civil Aviation Authority Proclamation Number 141/1997 and the rules, regulations and directives prescribed thereunder for the issuance of this certificate and is hereby authorized to conduct

SCHEDULED, NON-SCHEDULED AND CHARTER
DOMESTIC AND INTERNATIONAL
COMMERCIAL AIR TRANSPORT OPERATIONS

in accordance with said proclamation and its rules, regulations and directives, the terms, conditions and limitations contained in the Approved Operations Specifications annexed hereto and with the Standards and Recommended Practices of ICAO Annex 6, Part 1.

This Certificate is not transferable and shall be renewed every year by application made by the certificate holder.

[illegible]
General Manager
Civil Aviation Authority

Date of issue February 27, [illegible]

Issued at Addis Ababa

PAGE 1 OF 2

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Appendix B: Meteorological Documents

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SIGMET (126.0 MHz)

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From telecomunication Dept.

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Aviation Digital Data Service (ADDS)

Output produced by METARs form (0440 UTC 25 January 2010)
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OLBA 240800Z 14004KT 090V170 8000 FEW020CB BKN026 16/08 Q1014 NOSIG
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OLBA 240300Z 16006KT 120V200 8000 BKN030 VV025 13/10 Q1016 NOSIG
OLBA 240200Z VRB03KT 8000 BKN030 16/07 Q1015 NOSIG
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OLBA 240000Z 16006KT CAVOK 15/09 Q1016 NOSIG
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     BECMG 2605/2607 33008KT 9999 FEW028
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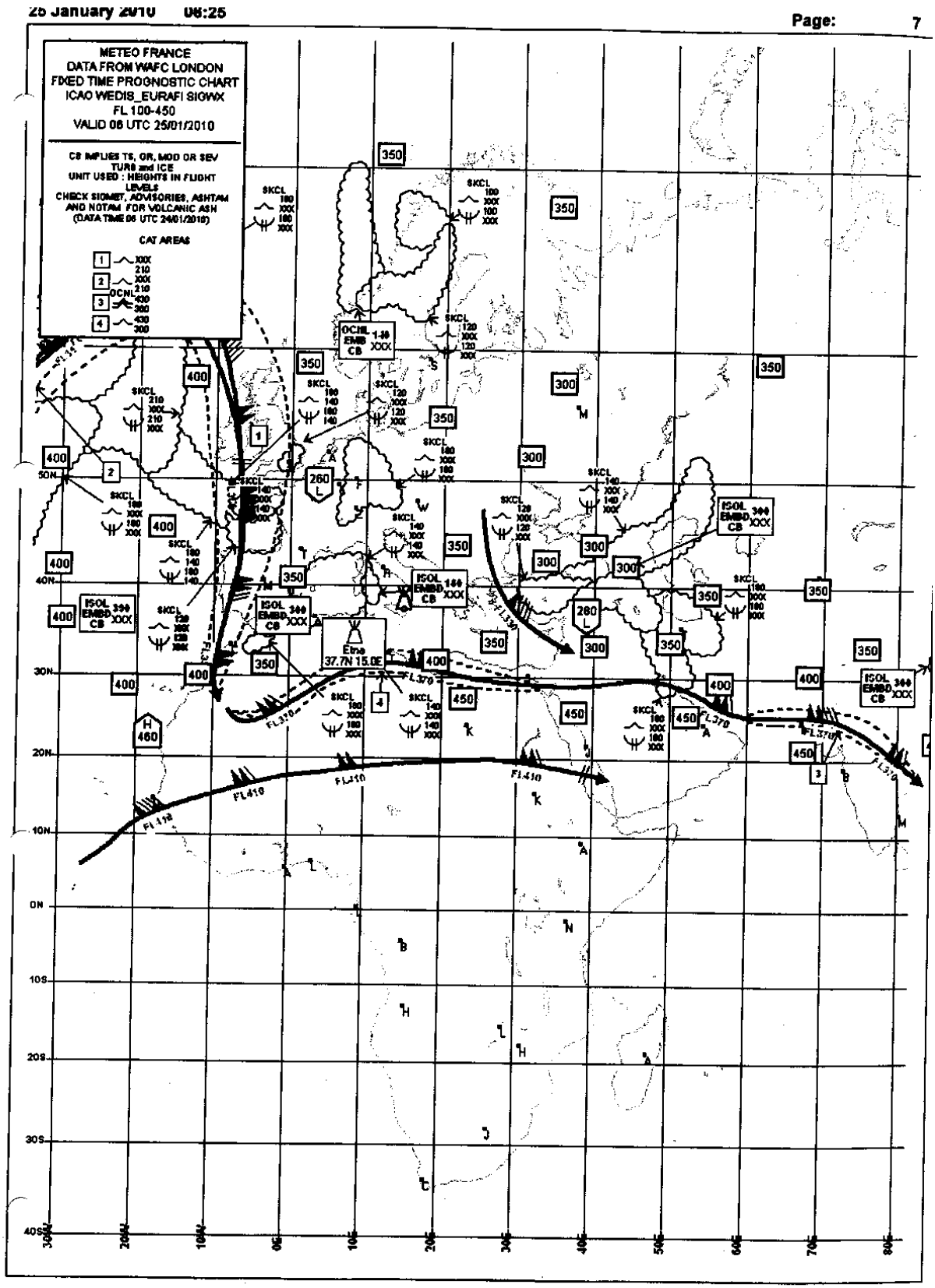
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FIXED TIME PROGNOSTIC CHART
ICAO WEDIS_EURAFI SIGWX
FL 100-450
VALID 06 UTC 25/01/2010
CB IMPLIES TS, OR, MOD OR SEV TURB and ICE
UNIT USED : HEIGHTS IN FLIGHT LEVELS
CHECK SIGMET, ADVISORIES, ASHTAM AND NOTAM FOR VOLCANIC ASH
(DATA TIME 06 UTC 24/01/2010)
CAT AREAS
Etna
37.7N 15.0E
FL370
FL410
FL430
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40N
30N
20N
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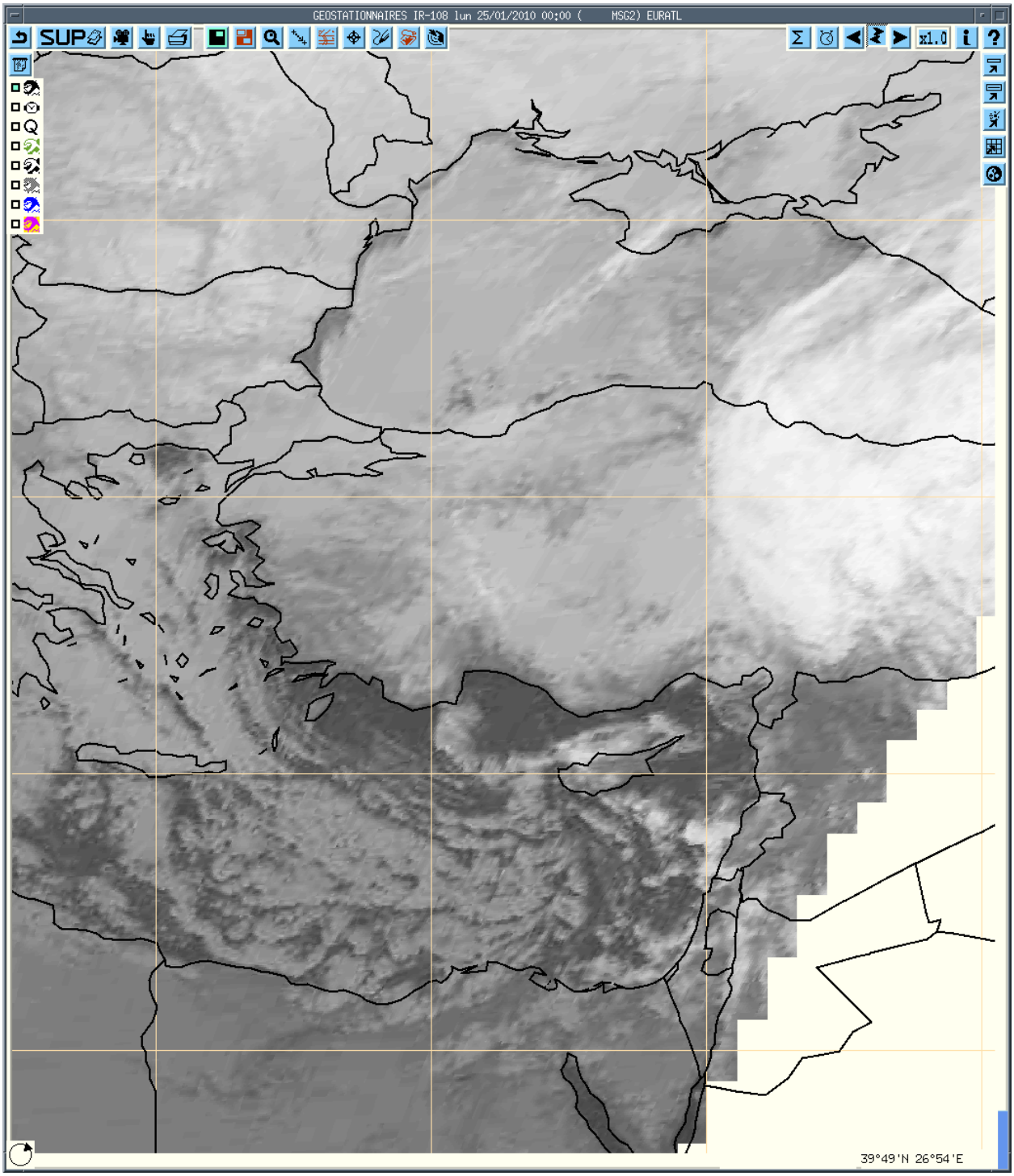
0N
10S
20S
30S
40S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SUP
x1.0
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Intentionally

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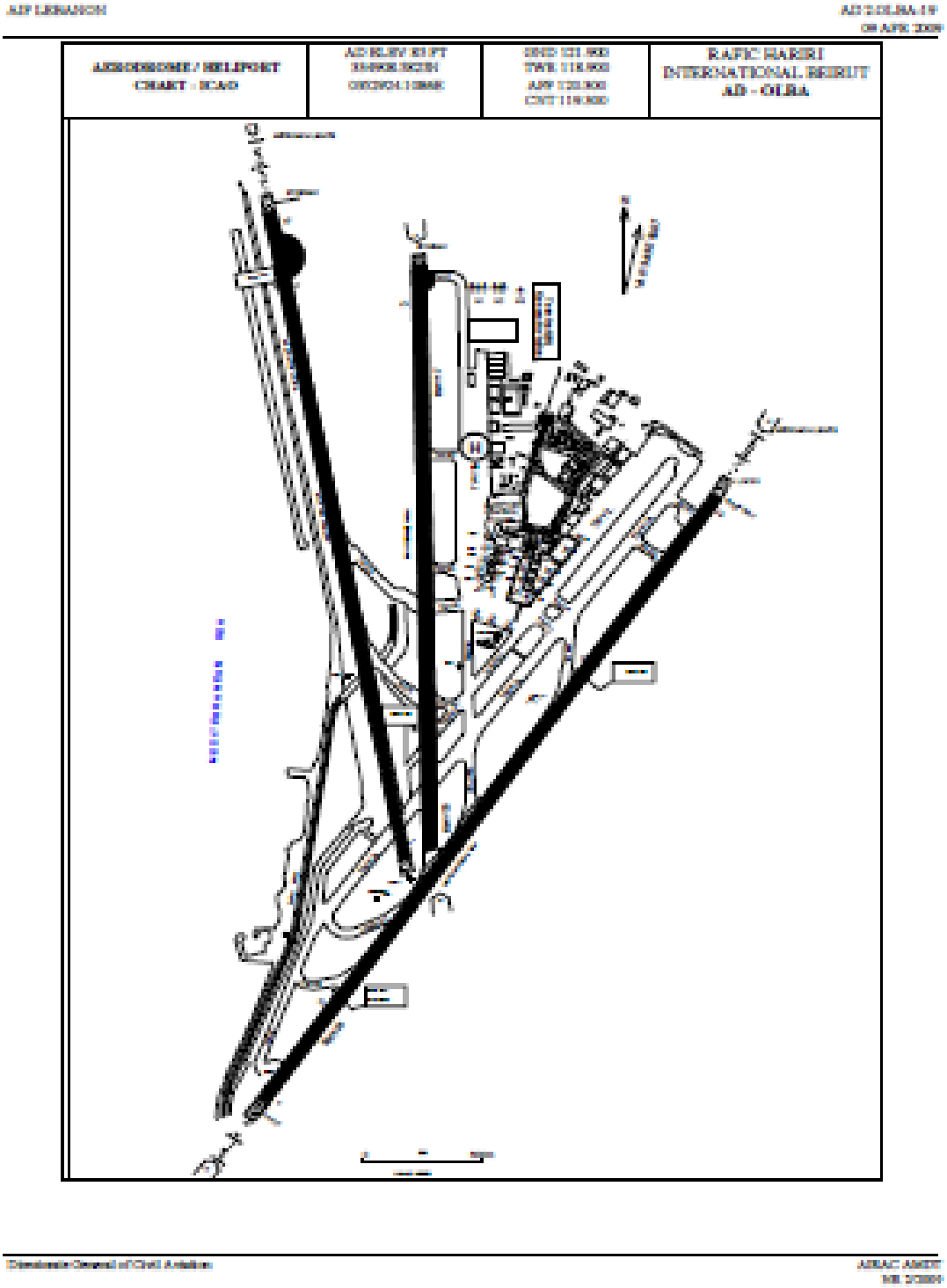
Appendix C: BRHIA Lay-out Map



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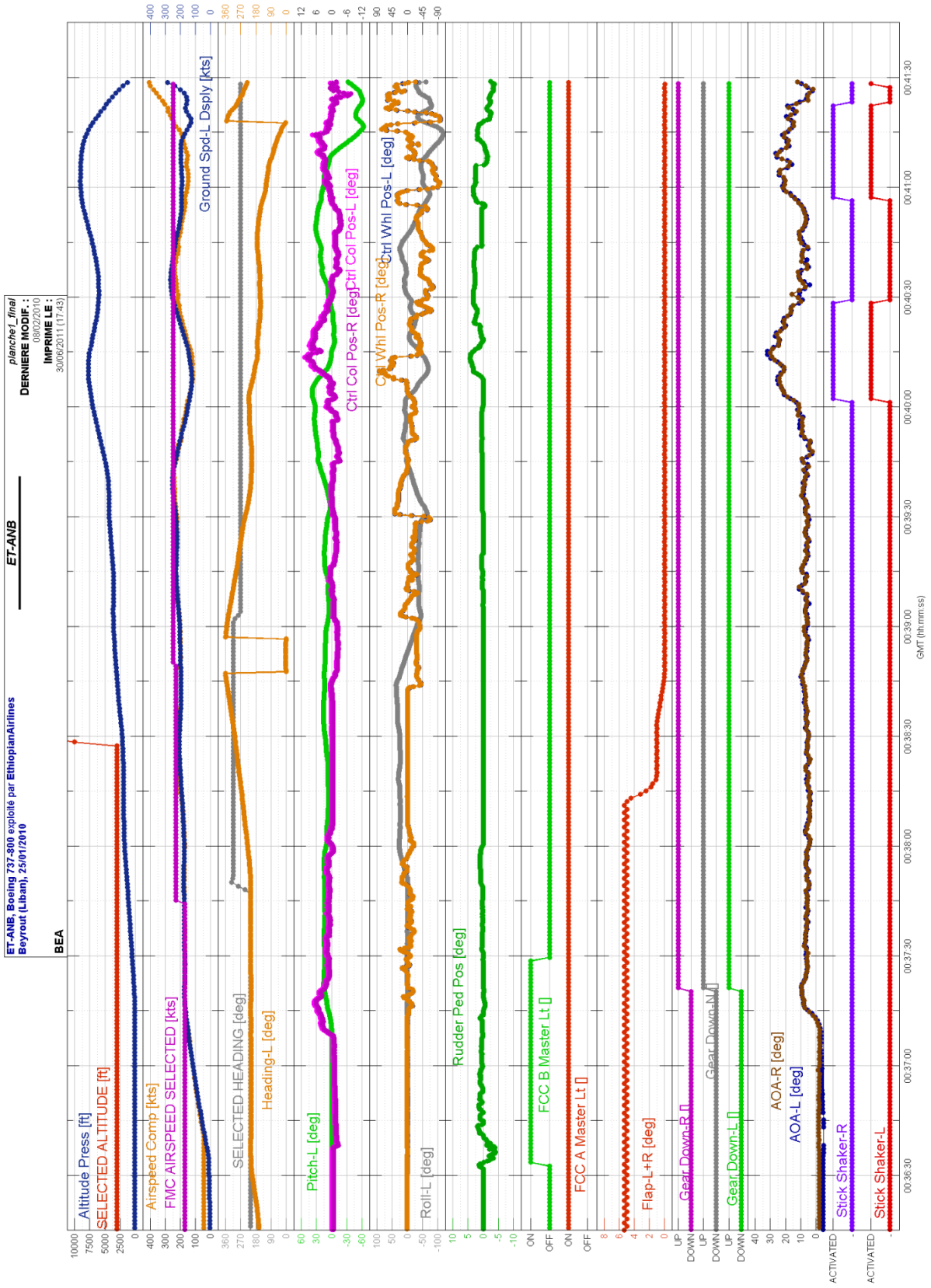
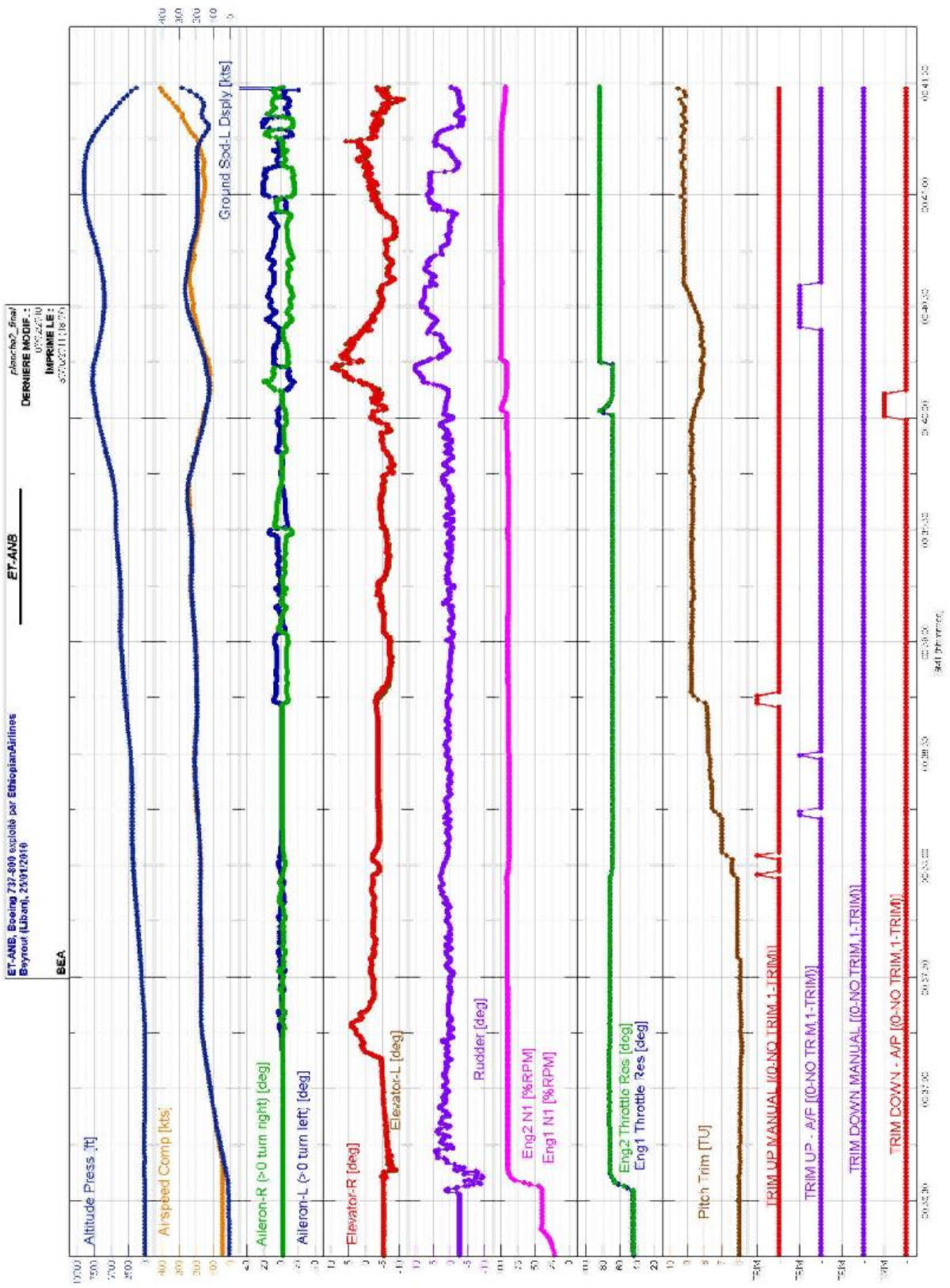
Appendix D: BEA DFDR Data Curves




ET-ANB, Boeing 737-800 exploité par EthiopianAirlines
Beyrouet (Liban), 25/01/2010
BEA
ET-ANB
planche2_final
DERNIERE MODIF. :
IMPRIME LE :
Altitude Press [ft]
Airspeed Comp [kts]
Ground Sod-L Dsply [kts]
Aileron-R (>0 turn right) [deg]
Aileron-L (>0 turn left) [deg]
Elevator-R [deg]
Elevator-L [deg]
Rudder [deg]
Eng2 N1 [%RPM]
Eng1 N1 [%RPM]
Eng2 Throttle Res [deg]
Eng1 Throttle Res [deg]
Pitch Trim [TU]
TRIM UP MANUAL [(0-NO TRIM,1-TRIM)]
TRIM UP - A/P [(0-NO TRIM,1-TRIM)]
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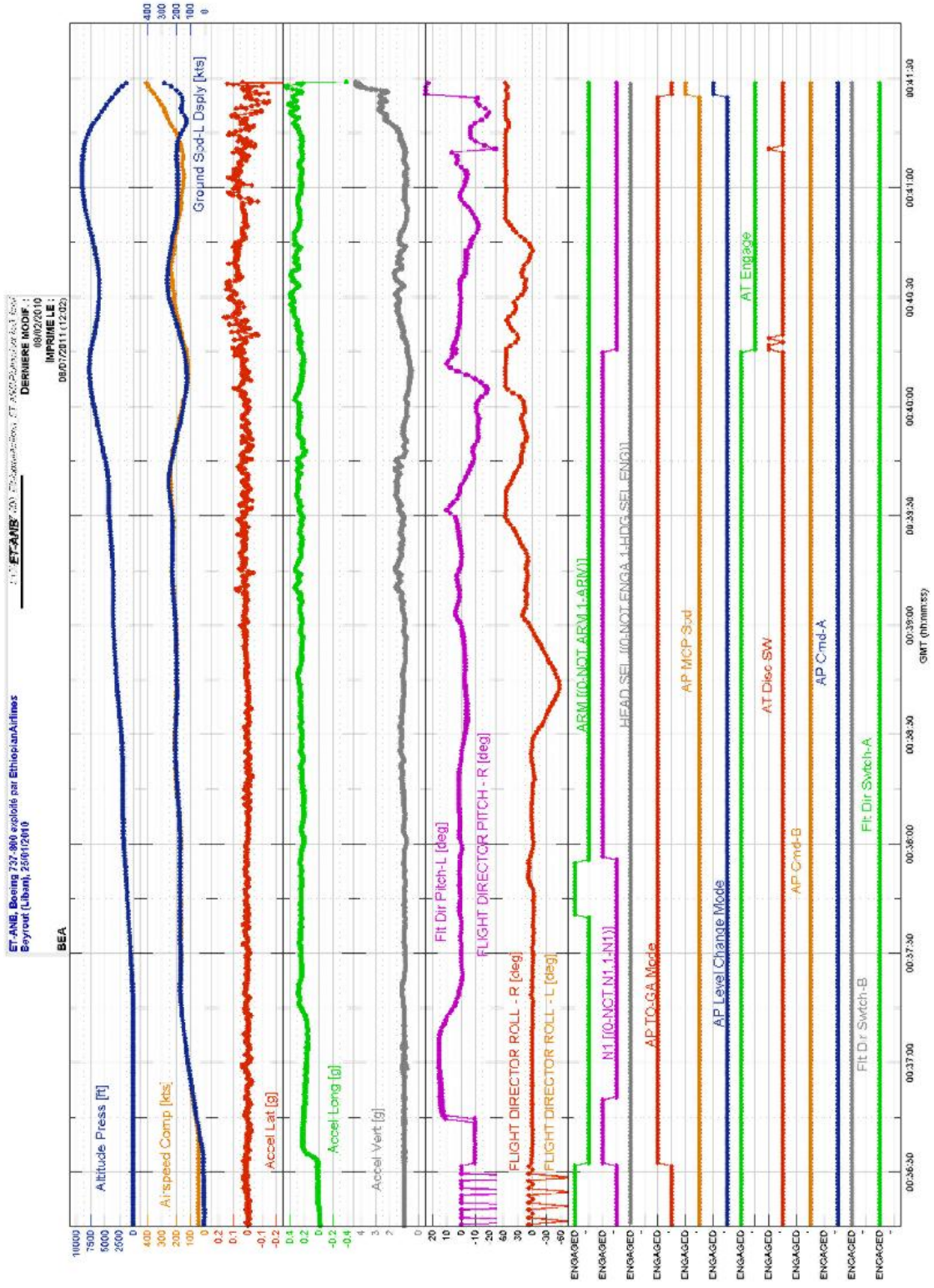
TRIM DOWN - A/P [(0-NO TRIM,1-TRIM)]


ET-ANB, Boeing 737-800 exploité par EthiopianAirlines
Beyrouth (Liban), 25/01/2010
ET-ANB
DERNIERE MODIF. :
08/02/2010
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BEA
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Airspeed Comp [kts]
Ground Sod-L Dsply [kts]
Accel Lat [g]
Accel Long [g]
Accel Vert [g]
Flt Dir Pitch-L [deg]
FLIGHT DIRECTOR PITCH - R [deg]
FLIGHT DIRECTOR ROLL - R [deg]
FLIGHT DIRECTOR ROLL - L [deg]
ARM [(0-NOT ARM,1-ARM)]
N1 [(0-NOT N1,1-N1)]
HEAD SEL [(0-NOT ENGA,1-HDG SEL ENG)]
AP TO-GA Mode
AP MCP Sod
AP Level Change Mode
AT Engage
AT Disc SW
AP Cmd-B
AP Cmd-A
Flt Dir Switch-B
Flt Dir Switch-A
ENGAGED
00:36:30
00:37:00
00:37:30
00:38:00
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00:39:30
00:40:00
00:40:30
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GMT (hh:mm:ss)

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Appendix E: Description of S&R Operations

The following are extracts from the Search & Rescue Report Presented by the Commander in Chief of the Army to the Lebanese Government. It comprises an introduction and a description of daily S&R operations.

All times are Local Time (GMT +2)

Introduction:

On 25/01/2010, around 0245 AM, the commander in chief of the BRHIA Security Forces called the director of operations informing him that an Ethiopian plane crashed into the sea abeam Khaldeh. Immediately, the alert of the Army Command Operations room was raised and all the commanders informed in order. Orders were issued to the Naval Forces, the Air Force, the Navy Special Sea Diving Unit and all other units present in the area and on adjacent sea shores to interfere and participate in the Search & Rescue operations giving the absolute priority to look for surviving persons and then to ensure that all retrieved aircraft parts are collected at the Beirut Naval Base.

The military police was tasked to account for the bodies and carry the legal procedure in delivering those bodies to the Internal Security Forces (police). The units were directed towards the area where some aircraft parts and bodies were found floating and a survey of the sea bed was initiated in the potential areas where the aircraft might have crashed.

To accomplish that task, specialized civilian and military ships belonging to the United States of America and other Naval Forces attached to the UNIFIL were requested to assist, which they did. The following list represents all the states participating in these efforts:

1- Lebanon:

   a. The Army
      - Army Joint Staff Command
      - Directorate of operations
      - Air Force
      - Naval Force
      - Special Sea Divers Unit
      - Military Medical unit
      - Military police
      - Brigades 3, 7 , 8 & 9
      - Special Interference Unit 2 ,4 , & 5
      - Special forces
   b. The Directorate General of the Internal Security Forces
   c. The Directorate General of Civil defense
   d. The Lebanese Red Cross
   e. The Beirut Fire Brigade

2- Foreign Forces:

a. The UNIFIL Naval Force represented by the following States: Germany, Italy, Turkey, Greece.
b. The US Navy via the following Ships USS Ramage &USNS Grapple.
c. Two Civilian specialized Ships: The Ocean Alert & the Odyssey Explorer.
d. A British Helicopter.
e. Divers from the US Navy specialized in under water search.
f. A French aircraft and a team of French experts.

I- <u>On 25/01/2010</u>

At 0255 orders were issued to the Naval Forces to set sail of all available ships and units towards the crash area of the Ethiopian plane in order to participate in the search and rescue operations. Groups of special sea divers were placed on board the ships & units. At the same time the Naval Operations Room of the UNIFIL was advised and asked officially to participate in the S&R operations while contact was establish with the BRHIA ATC in order to precisely determine the calculated area where the aircraft had crashed.

As a result of the above, all readily available Navy ships & units set sail at 0335, parts of the aircraft and bodies were identified and retrieved as of 0545. AT 0615, Air Force helicopters and a helicopter from the Italian Command Ships ITS Zefiro participated in these efforts. Bodies and parts were retrieved from the sea in the location identified in Attachment B.

At 0740, the first foreign ship joined the S&R effort, which was the German ship "Mosel", which is part of the UNIFIL.

At 1037 the total number of ships participating in the S&R efforts was 9; 6 belonging to the Lebanese Naval Forces, 2 German and the USS Ramage.

At 2000, an official request was sent to the UNIFIL in order to assist in surveying and searching the sea bed in the crash calculated area in order to determine the location of the aircraft wreckage & black boxes (DFDR & CVR).

The Army Intelligence Unit initiated its own research and identified a white area in the sea opposite the coast of Naameh.

II- <u>26/01/2010</u>

The civilian ship Ocean Alert arrived at 0700 & joined the S&R operations.

A meeting was also held at 0700 at the Naval Base Commander's office. The meeting was chaired by the Deputy Chief of Staff for Operations and attended by all the forces & parties participating in the S&R operations. The goal of the meeting was to set a work plan for the Naval Forces, the Air Forces, the Ocean Alert, the USS Ramage destroyer and the Units belonging to the UNIFIL.

As a result of the meeting the following work plan was set:

1- The areas of operations for the participating ships were determined as per

Attachment I.

2- The Lebanese Navy units shall secure &protect the working area while continuing its mission of searching for retrieving bodies & parts from the aircraft.

3-Appointing a coordination officer from the Lebanese Navy to be placed on board each foreign ship in order to coordinate and supervise the S&R operations carried by each ship.

4-Focus on surveying the sea bed as per the work areas specified in figure A. The area was divided between the following ships that possess such survey capabilities: The USS Ramage, the Ocean Alert and the German mine sweeper Laboe.

III- 27/01/2010

The S&R survey operations continued with the additional help of naval units from the following States joining in: Italy, Germany, Turkey & Greece.

The Navy special sea divers unit initiated many dives close to the sea shore.

At 1100 a meeting was held at the Beirut Naval base chaired by the Deputy Chief of Staff for Operations and in the presence of the IIC & representatives from the Civil Defence, the Ministry of Health, the Lebanese Red Cross, the UNIFIL Naval command, the Director of Information in the army command, the commander of the Lebanese Naval Forces, the commander of the Lebanese Air Force, the commander of the Military Police the D/commander of the Naval for operations, the commander of the special divers Unit, the commander of the Naval Forces for Operations, the commander of the Special Divers Unit, the commanders of the Naval Bases, the commander of the Fire Brigade, officers from directorates of Intelligence, a representative for the Ocean Alert and a representative for the USS Ramage destroyer.

The attendees were briefed of the following:

-The progress of the Naval S&R operations and the work plan.

-The IIC and other members from the IC briefed the participants on the procedures techniques that should be followed in handling the bodies and the aircraft parts in order to preserve all the factual information and evidence required by the IC to reveal the real causes of the accident.

Later on that day, a delegation from the Army Supreme Command led by the Deputy Chief of Staff for Operations visited all the ships participating in the S&R operations in order to assess the operations, particularly in the efforts aiming at surveying the sea bed .The delegation was briefed by the commander of the USS Ramage that they were unable to detect signals from the black boxes with the equipment in their possession, which is designed and calibrated to mainly detect sub-marines. The Deputy Chief of Staff requested the USS Ramage commander to obtain the appropriate equipment. The USS commander ordered some technical adjustment to the Sonar unit on board in order to allow it to detect the 37.5 KHz frequency.

At 2330 on that day, the USS Ramage picked a signal from the aircraft while it was 14 km west of Khaldeh.

In view of that important development, the Ocean Alert was directed to survey the sea bed in

the area where the ÙSS Ramage picked up the signal. The survey operations lasted for 30 hrs and, as a result, some architectural shapes where identified in the sea bed at a depth of 1400 meters.

The decision was then taken to contact the representative of the Ocean Alert in order to initiate the sail of the Ocean Explorer ship from the UK to Lebanon, a sail that might last for 10 days, in order to profit from the capabilities of that ship which is specialized in retrieving big pieces of wreckage from the Ocean beds.

Till then, the Air Forces helicopters and aircraft were pursuing their survey missions and had achieved the following missions:

- A UH-H1(single engine), 21 missions totalling 40 hrs
- A Sikorsky, 11 missions totalling 20 hrs
- A Cessna 150 equipped with an Infra Red camera, 3 missions totalling 4 hours

IV- From 28/1 till 29/1/2010

Focus on the survey of the area 14 Km from Khaldeh continued. The sea bed in that area was surveyed in coordination with the USS Ramage and the Ocean Alert. Till then, the signal from the black boxes had been picked only once.

During the night o 29/1/2010, a team of two experts from the BEA joined the search efforts. They were equipped with the proper tools to detect the signal transmitted by the DFDR and the CVR.

V- 30/1/2010

A coordination meeting was held at the Beirut Naval Base under the chairmanship of the Deputy Chief of Staff for Operations. All the parties involved in the S&R operations and the IC attended that meeting. The latest information from the Ocean Alert ship about the sea bed area where the signal was picked up by the USS Ramage was shared with participants. It showed some sonar pictures revealing shapes that are not consistent with the geology of sea bed (refer to Attachment III).

The 2 French BEA experts attended that meeting and they received all the available information. They were then carried with their boat on board the Landing Ship Transport (LST) "Damour" and were dropped in the area that was dedicated to the USS Ramage in order to confirm signal received from the black boxes. That trial failed due to thigh sea waves and the deteriorating weather which forced the 2 experts to abandon their mission. At the same time, the Ocean Alert ship returned to shore and docked at Beirut port in order to up-lift some supplies while she was awaiting the improvement of the weather.

VI- 31/1/2010

At 1210 the Ocean Alert ship set sail from Beirut port in order to continue the survey of the area 14 Km west of Khaldeh. The French team where reviewing the signals recorded on 30/1/2010 in order to detect any signal from the DFDR or the CVR that might have been picked up.

In the evening, the US Ramage departed the Lebanese National Waters.

VII- 1/2/2010

The weather improved and the French team sailed again to the area where the signal was picked up by the USS Ramage 14 Km west of Khaldeh. The Ocean Alert ship went to survey the area opposite to Naameh, identified by the Army Intelligence. The sea divers continued their operations near the sea shores.

A coordination meeting was also held for the S&R team in the presence of members from the IC. During that meeting, the Directorate of Intelligence presented the information they had while the IIC presented the flight path as extracted from the ATC Radar data. At the end of that meeting, the IIC stressed on the importance of searching in the area where the signal was picked by the USS Ramage, since that search was warranted by a concrete fact, which is the signal from the black boxes. However, that did not preclude the necessity to search in the calculated area for the crash, since that area was calculated based on Radar recorded data and plots and it concur with the information gathered by the Army Intelligence.

During that meeting, the Deputy Chief of Staff requested from the French military attaché in Lebanon to assist with the S&R efforts. He also requested from the US military attaché to assist in the retrieval of the wreckage from the deep sea bed because of the long period (10 days) that the Odyssey Explorer ship will take to reach Lebanon.

As a result of that meeting, the Ocean Alert was requested to continue its survey of the area where the signal was picked up, while the Army Command would continue the search in the calculated area of the crash.

VIII- 2/2/2010

At 1210, the Special Divers Unit picked a floating body in the area of calculated crash 4 km SW of the airport. Immediately, the Lebanese Navy ship "Sour" sailed towards that area with the 2 French BEA experts on board.

At 2030 the French experts succeeded in picking up a signal from the black boxes. A unit of 4 French divers joined the BEA team while the Americans advised that the ship USNS Grapple, specialized in sea dive and rescue operations from deep seas, will arrive to Lebanon on 6/2/2010.

IX- 3/2/2010

The S&R operations continued. At 0900 the Special Divers Unit picked a floating body and identified another body trapped under the aircraft wing 37 meters under the water opposite the coast of Naameh (4 Km SW of BRHIA). However, due to deteriorating weather conditions, the search mission was interrupted while the Ocean Alert ship docked at Beirut Port at 0725 because of bad weather and in order to repair the ROV that was damaged during operations. It stayed there till 0910 on 5/2/2010 when it was re-supplied with logistics, the ROV was fixed and the weather improved.

X- 4/2/2010

The S&R operations stopped as a result of bad weather and storms affecting the sea conditions. That time was used to evaluate what was accomplished so far and review the plan for the future operations.

A presentation on diving techniques and recovering parts from deep seas by a US advisory team was delivered to the IC and the parties participating in the S&R operations. Later on, information gathered from the Ocean Alert was presented.

The IC decided to establish an operations room at the Beirut Naval Base in order to supervise more closely the S&R operations and a team of French experts was placed on board the Ocean Alert ship in order to confirm the signals received from the black boxes and take underwater pictures to allow retrieving them.

On the same date, the Lebanese Navy LST "Damour" was equipped with a cooling container provided through the efforts of the Directorate of Intelligence from the Port of Beirut. The purpose was to prepare "Damour" to be a reception center for the retrieved bodies or parts thereof. The Military Police, the Criminal Evidence Department, the Military Medical Department and the Directorate General of Civil Defence where advised to send their representative on board "Damour" in order to handle and treat the retrieved bodies and conduct the necessary legal procedures prior to the delivery of these bodies to the Ministry of Health.

In addition to the above, the Army Command requested from the presidency of the government to avail the ship "Cana", which belongs to the National Scientific Research Center, and allow the Navy to use that ship and take advantage of the equipment on board, which includes a ROV, in order to further survey the area where the wreckage has been found.

XI- 5/2/2010

The Ocean Alert ship sailed from the Port of Beirut in order to survey of the sea bed where the signals had been picked up by the French experts (4 Km off the coast of Naameh).

The Ocean Alert was able to provide pictures of architectural shapes present at a depth of 45 meters in an area that extends for 150 meters and occupies a surface of 500 square meters.

Based on that information, a group of the Special Sea Divers Unit and supporting boats sailed from the Family Beach in Khaldeh, which was used as an advanced operational center to launch the diving operations, in order to ensure the logistical support to the divers participating in the S&R.

XII- 6/2/2010

The specialized ship Ocean Alert video-taped the potential area of location of the black boxes to confirm the sonar pictures taken on 5/2/2010.

The result was a confirmation that the wreckage belonged to the Ethiopian airplane. At the same time, the USNS Grapple had arrived to participate in the S&R and immediately joined the operations. A coordination officer was appointed on board that ship throughout the period it participated in the S&R, which extended till 10/2/2010 when it sailed away.

Upon its arrival, the USNS Grapple helped retrieve the stabilizer tail section of the airplane, which allowed the retrieval of the DFDR which was buried underneath that section. The retrieval operation was supervised by the Deputy Chief of Staff, the Director of Operations, the Commander of the Naval Forces the Assistant Commander of the Navy for Operations and the Commander of the Special Sea Divers Unit. A coordination meeting was held during which the USNS Grapple was considered as a support vessel to retrieve the large parts of the aircraft in case the IC requested that. He USNS Commander declared that the ship capabilities were placed under the Lebanese Army towards the use of US divers and the medical evacuation of the Lebanese divers in case of health related incidents.

XIII- 7/2/2010

The diving operations were launched through the Special Sea Divers who were able to locate the DFDR, retrieved it and delivered it to the IIC at 1230 through the Deputy Chief of Staff.

The search continued to retrieve the bodies and parts thereof from the same area.

XIV- From 8/2 till 10/10/2010

The search operations continued by the Naval Forces and the Special Sea Divers who were able to retrieve the chassis of the CVR on 10/2/2010. The CVR itself was detached and missing.

In the evening, the door of the LST "Damour" was broken as a result of the strong sea waves during support operations of the sea divers. The USNS Grapple left the Lebanese National Waters.

XV- From 11/2 till 16/2/2010

The diving, search and retrieval of human bodies and parts operations continued. The Naval Forces and the Special Sea Diving Unit continued their search for the CVR. The CVR was found at 1000 on the 16th January and delivered by the Director of Operations in the Army to the Deputy IIC Captain Mohammed Aziz.

At the same time, the Odyssey Explorer joined the operations of identifying the parts from the aircraft in order to determine the exact spots where the diving operations should continue in order to retrieve the human remains and any other parts which could be required by the IC.

XVI- From 17/2 till 19/2/2010

The specialized ship Odyssey Explorer video-taped the wreckage and whatever remained

from the human remains and belongings of the passengers and crew. 63 points were identified and the special sea divers in coordination with the Lebanese Navy carried retrieval operations targeting the human remains in that area.

XVII- From 20/2 till 22/2/2010

The retrieval operations continued by the special sea divers based on the video-taped information. These operations were interrupted from time to time due to bad weather conditions.

All aircraft parts have been identified, recorded and placed under navy custody at the Beirut Naval Base in order to preserve the evidence and to make them available to the IC whenever required.

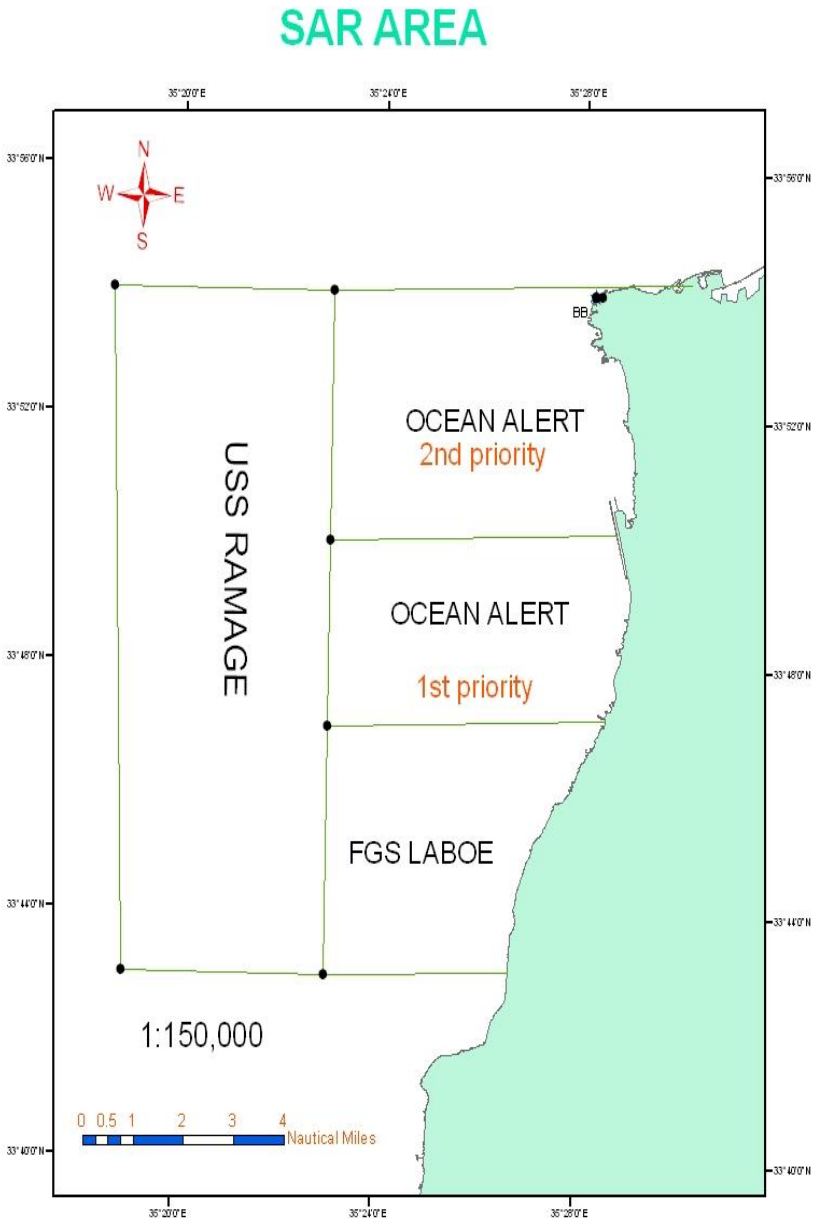
Conclusion:

In conclusion, we can say that the S&R operations were successful and accomplished in record time compared to similar S&R operations (25 days). That is mainly due to the devotion of the participants, especially the special sea divers, despite the bad weather, the high sea waves and the lack of proper radio coordination equipment between the various forces participating in the S&R operations.

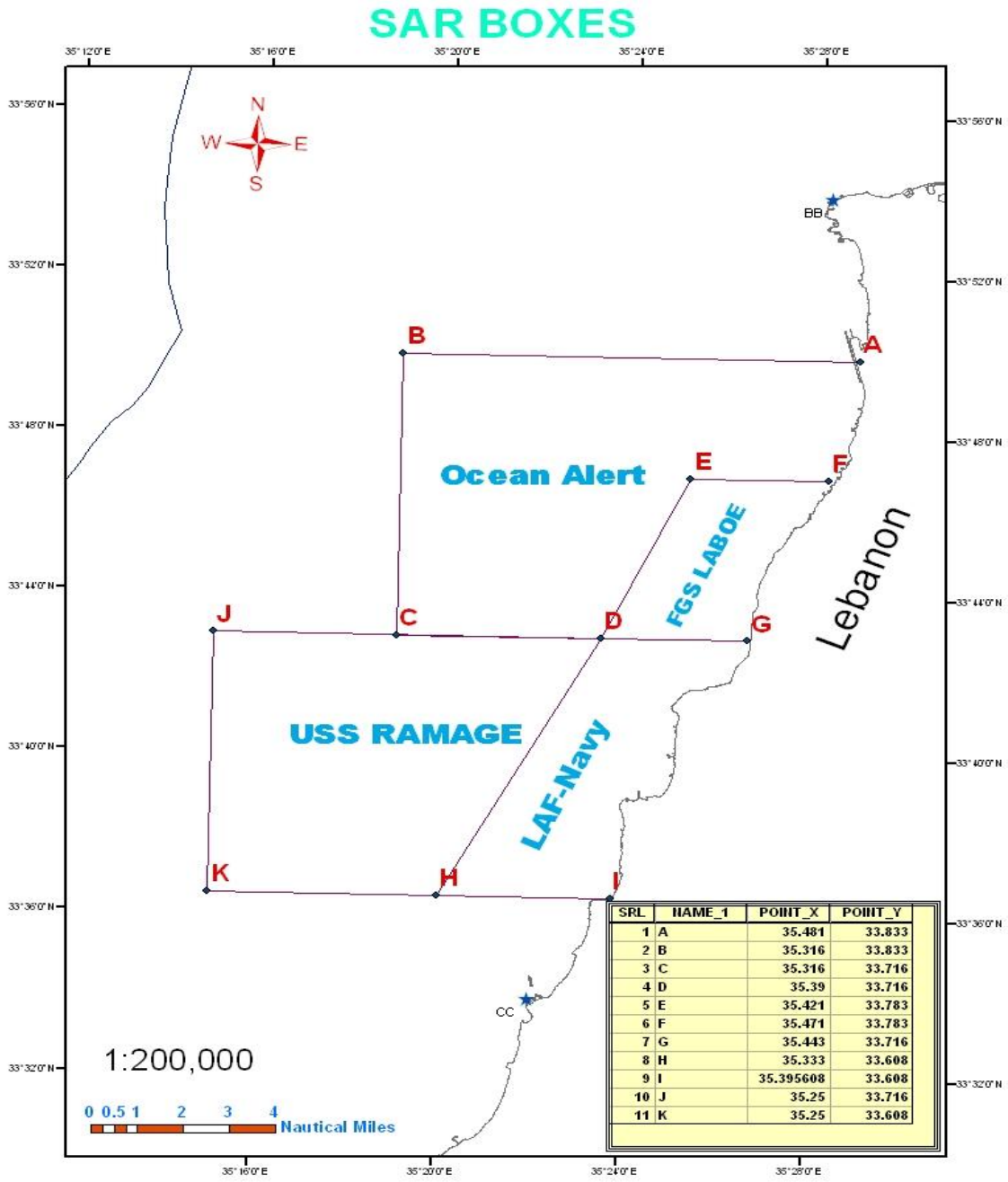
The assistance presented by the various foreign forces was also instrumental in achieving these results. So was the innovation demonstrated by the Army who managed to come with practical solutions to the lack of equipment.

Finally, the controversy created by the signal picked by the USS Ramage was the result of the presence of a sea valley between the point where that signal was picked up and the point which was identified later by the French experts and where the wreckage was found. That allowed the sonar equipment on the USS Ramage to pick a signal which was 10 Km away through an adjusted sonar equipment (refer to Attachment IV).

Attachment I: Division of S&R Work 26 & 27/1/2010



26/1/2010



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1	A	35.481	33.833
2	B	35.316	33.833
3	C	35.316	33.716
4	D	35.39	33.716
5	E	35.421	33.783
6	F	35.471	33.783
7	G	35.443	33.716
8	H	35.333	33.608
9	I	35.395608	33.608
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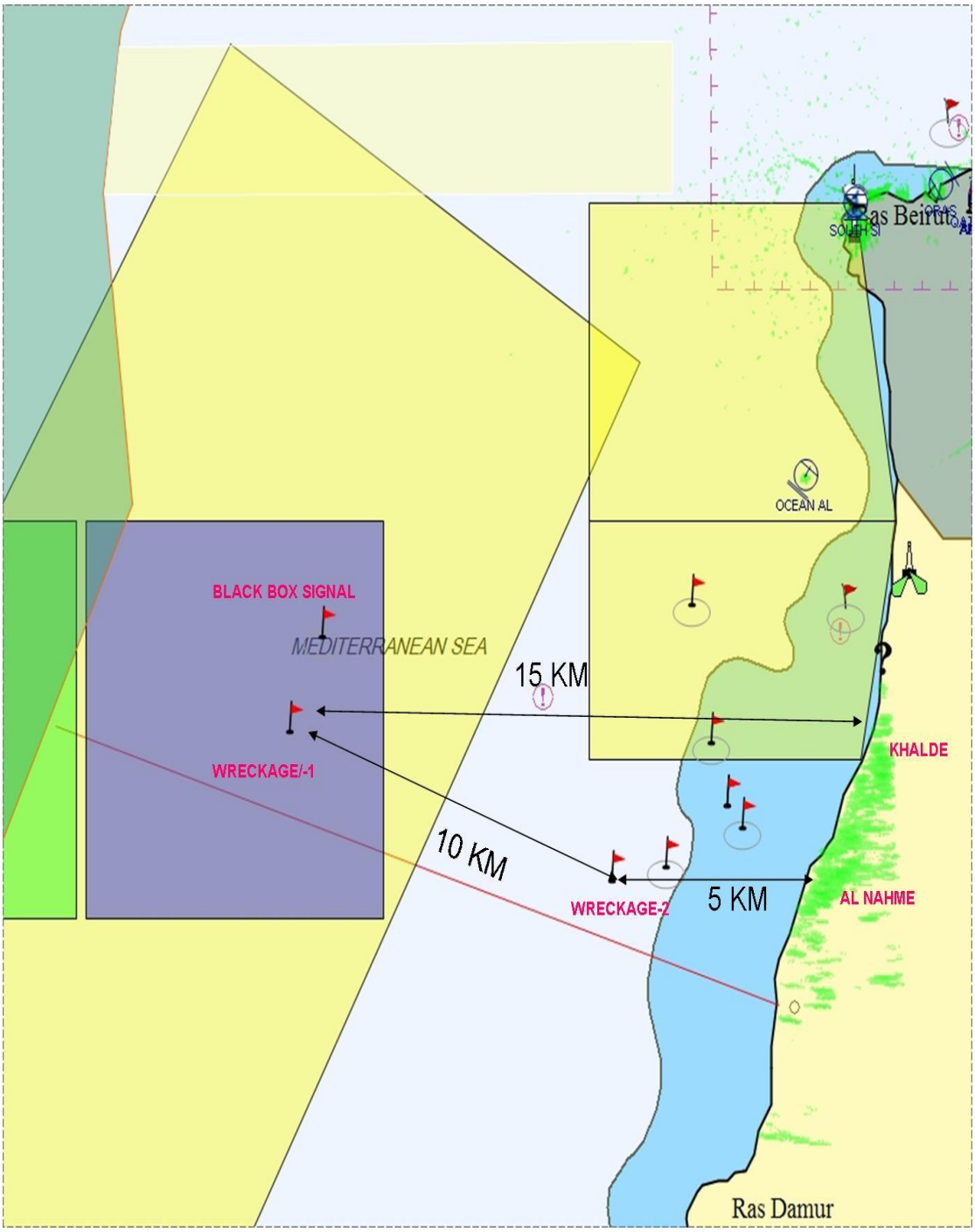
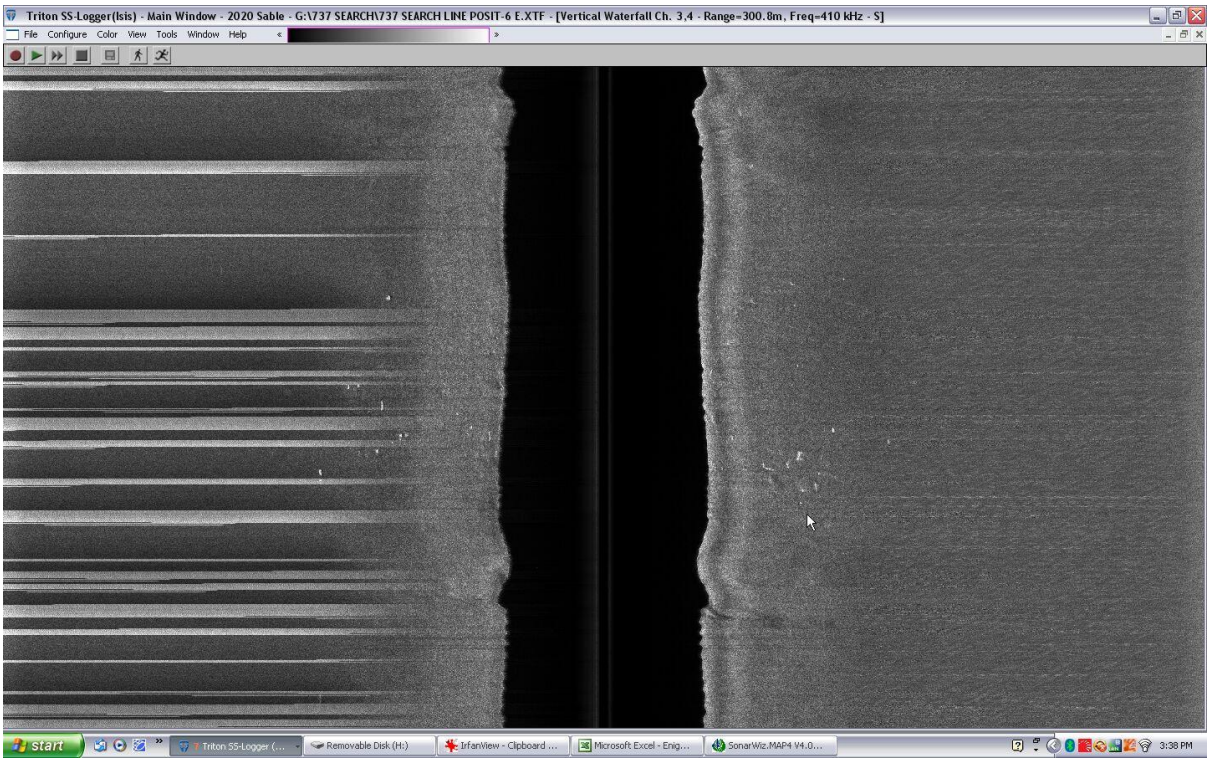
11	K	35.25	33.608

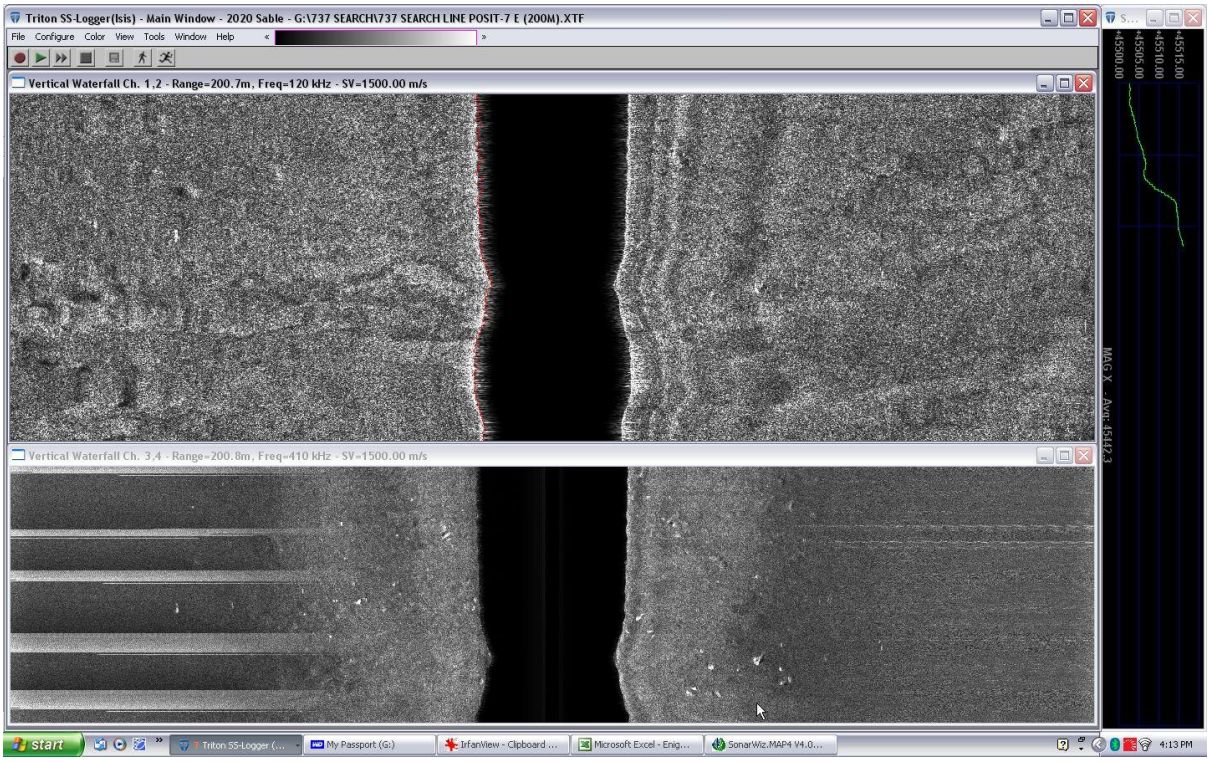
27/1/2010

Attachment II: Location of Bodies Retrieved Prior to Pinger Signal Reception

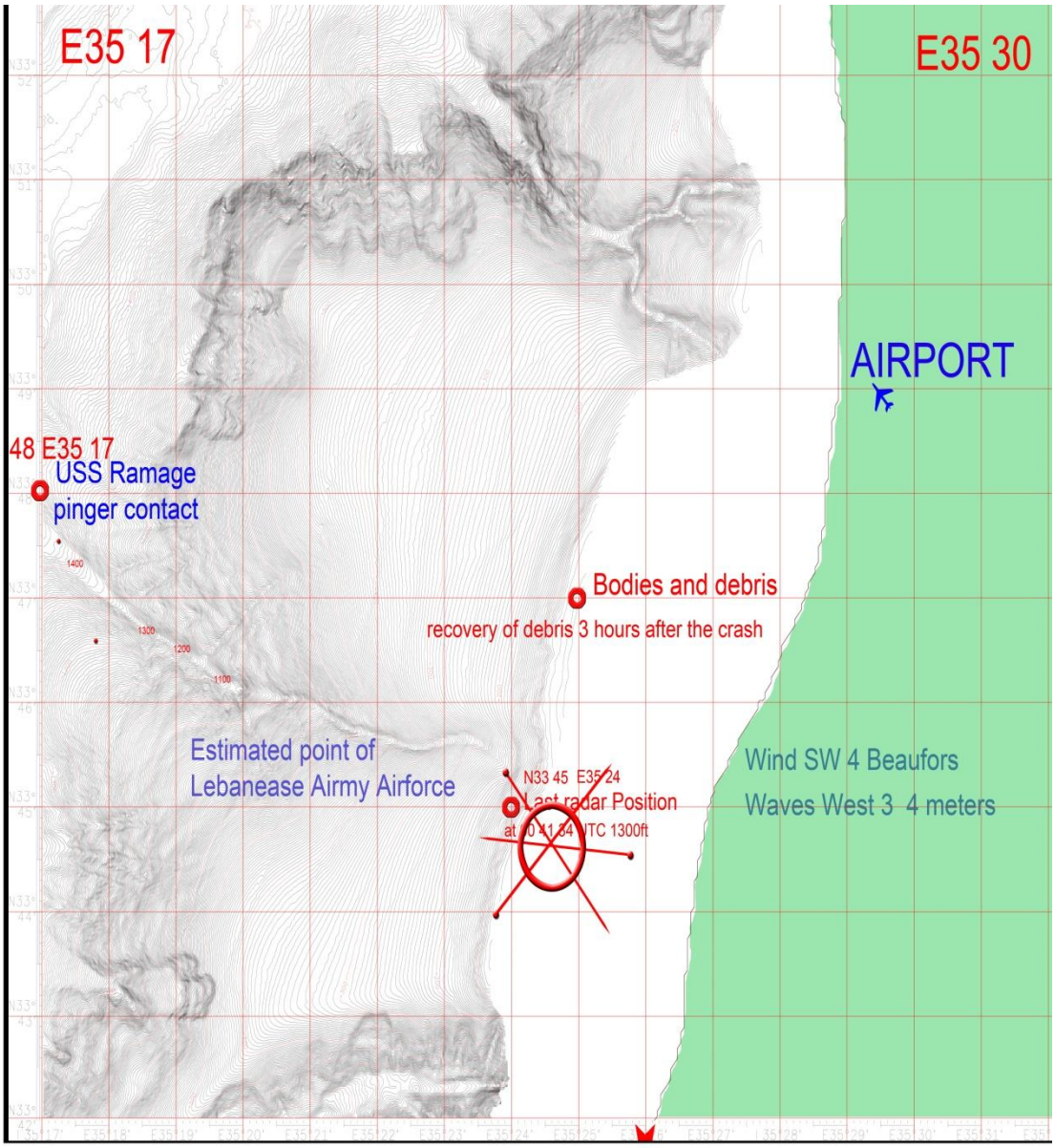


Attachment III: Sonar Pictures of Area 14 KM from Khaldeh





Attachment IV: Location nn of DFDR v/s Pinger Signal received by the USS Ramage



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Appendix F: ET Incapacitation Procedure

below are intended to alert ATC and military radar facilities that assistance is required.

With receiver only operating, the pilot flying shall monitor 121.5 MHZ and fly a right-hand, triangular pattern with one-minute legs and 120-degree turns at 1.5°/second. At least two patterns should be flown before resuming course. A radar controller observing such a pattern shall respond on 121.5 MHZ.

With transmitter and receiver inoperative, the pilot flying shall fly a left-hand triangular pattern as described above. A radar controller observing such a pattern shall dispatch an escort if possible. If at night or in IMC, the landing lights should be turned ON to aid the escort aircraft. When contact is established the pilot should follow the escort. (See Interception Signals in CHAPTER 4.7)

3.9 INCAPACITATION – EMERGENCY

3.9.1 DEFINITION

Incapacitation of a crewmember is defined as any condition that effects the health of a crewmember during the performance of duties assigned to him which renders him incapable of performing the assigned duties.

The definition includes either total or partial incapacitation which does not allow the fulfillment of duties in the "normal" way.

3.9.1.1 GENERAL

In flight pilot incapacitation is a significant safety hazard and has caused many accidents.

Incapacities have occurred more frequently than other emergencies in all age groups and during all phases of flight. There are many forms of incapacitation ranging from obvious sudden death to a lingering and difficult to detect partial loss of functions.

3.9.1.2 TYPES OF INCAPACITATION

a. Obvious incapacitation: means total functional failure and loss of capabilities. Generally, this can be easily detectable and can be a prolonged condition. Among the possible causes are heart disorders, severe brain disorders, severe internal bleeding etc.

b. Subtle incapacitation: this may be considered a more significant safety hazard, because it is difficult to detect and the effects can range from partial loss of function to complete unconsciousness.

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Appendix G: ET Procedures for use of on-board Weather Radar

1.15 ENTERING THE RUNWAY

CAPTAIN	FIRST OFFICER
Approaching line up position, call BEFORE TAKEOFF Procedure. *Weather radar/Terrain and set range to 40 NM.	Put ON white anti-collision light and *weather radar/Terrain and set range to 40 NM.
Call for BEFORE TAKEOFF checklist.	Read BEFORE TAKEOFF checklist. Obtain T/O clearance when instructed by the Captain.
When T/O clearance is obtained, command to put ON the remaining Landing Lights and check TFC displayed.	Put on the remaining Landing Lights, and transponder. Check TFC is displayed.
Complete BEFORE TAKEOFF checklist.	

* PM sets on Terrain and PF on WXR.

1.16 TAKEOFF

As part of the final flight deck preparation, review the TAKEOFF REF page to ensure the entries are correct. Ensure V_2 is set on the MCP. The map display on the ND, map range and LEGS page sequence shall be consistent with the departure procedure. A rolling takeoff is recommended.

1.16.1 CAPTAIN AS PF

CAPTAIN	FIRST OFFICER
Check the runway and T/O path is clear	
Smoothly advance the Thrust Levers to approximately 40% N1 and check indications are stabilized and symmetrical.	Check indications are stabilized and symmetrical.
Push TO/GA and follow the Thrust Levers movement towards target N1.	Monitor annunciation and call out "N1, TO/GA engaged." Monitor the forward movement of the Thrust Levers and adjust takeoff thrust prior to 60 Kts. Then callout "T/O THRUST IS SET."
Scan engine instruments and call out abnormal indications.	
Respond by saying, "CHECKED."	Call: - Speed increasing. - 80 kts. - Throttle Hold when THR HLD is annunciated.
Both hands on the control wheel.	Call out "V_1" if there is no Auto callout.
At V_R rotate to approx 15° pitch attitude. After liftoff, follow F/D commands. Establish positive rate of climb.	At V_R call out "ROTATE" Monitor airspeed and vertical speed.

Do the BEFORE TAXI checklist. F/O

Before Takeoff Procedure [AD 2002-19-52 and AD 2002-24-51]

Engine warm up requirement:

- verify an increase in engine oil temperature before takeoff.

Engine warm up recommendations:

- run the engines for at least 2 minutes
- use a thrust setting normally used for taxi operations.

Pilot Flying	Pilot Monitoring
	Check the center tank fuel quantity. Both center tank fuel pump switches must be OFF for takeoff if center tank fuel is less than 2300 kilograms. Do not accomplish the CONFIG non-normal checklist with less than 2300 kilograms in the center tank prior to takeoff.
	Notify the cabin crew to prepare for takeoff. Verify that the cabin is secure.
The pilot who will do the takeoff updates changes to the takeoff briefing as needed.	
Set the weather radar display as needed. Set the terrain display as needed.	
Call "BEFORE TAKEOFF CHECKLIST."	Do the BEFORE TAKEOFF checklist.

Before Takeoff Procedure [Alternate Method of Compliance (AMOC) to AD 2002-24-51]

Engine warm up requirement:

- verify an increase in engine oil temperature before takeoff.

Wind shear, with or without turbulence, alters the lift force acting on an aircraft, resulting in a significant sinking or rising motion. It is thus categorized as:

- Increased performance shear caused by increasing headwind or decreasing tailwind component or vertical updrafts.
- Decreased performance shear caused by decreasing headwind or increasing tailwind component or vertical downdrafts.

2.14.1 ADVERSE WEATHER OPERATION POLICY

Flights through areas with known or forecast thunderstorms, severe turbulence or wind shear should be avoided whenever possible due to various hazards involved, e.g. hail, lightning strikes, gusts, up and downdrafts with subsequent altitude or attitude changes and high "g" loads, etc.
Do not take off during heavy thunderstorm activity at the departure airfield. Delay the approach or divert to an alternate airfield rather than penetrate a severe thunderstorm in the approach area.
Strong winds may reach a magnitude where ground handling and operation, including taxi, will become unsafe or even impossible.
If **surface** mean wind speeds of **60 kt** or above are reported, takeoff or landing is not authorized and the airfield must be considered closed.
Mutual information on development and position of thunderstorms between pilots and ATC, as well as a careful weather watch is of great importance for the early and adequate avoidance of severe weather areas.

Use all available weather and wind shear detection systems, both in the aircraft and ground-based. Use all ATC and Pilot reports.

- Pilots are encouraged to improve their own standards of judgment based on visual cues. They should also be aware of the extreme limitations of weather radar in producing a reliable picture regarding the existence, location and intensity of wind shear. Radar and wind shear detection systems fitted to aircraft can only paint weather and moisture, whereas wind shear may occur some considerable distance from any such visible weather.
- At some airfields low level wind shear alert systems attempt to provide warning in the event of horizontal changes in wind direction and velocity exceeding certain values, and rapid surface pressure changes, which help to detect cold front passages and thunderstorm gust fronts.
- In the case of wind shear along the approach path, Pilot reports still represent the main source of information.

With strong shears, aircraft can experience large fluctuations of airspeed and lift in very short periods.

Pilots should be cautious whenever wind shear can be expected.
Immediate corrective action, in accordance with FCOM procedures, to avoid high sink rates close to the ground is of vital importance.

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Appendix H: ET Procedures for Flight Crew Pairing

1.11.3 LANDING AUTHORITY – SEAT SHARE POLICY

Subject to the limitations described below, Captains are expected to allow First Officers to carry out a reasonable proportion of the flying provided the captain considers that conditions are suitable.

In deciding how much flying to give to a first officer, a captain should bear in mind that it is one of his professional responsibilities to help his first officer improve his knowledge, experience and ability and maintain his recency of experience; but on no account should a captain give a first officer any flying beyond his capabilities, beyond his professional responsibilities or the stage of training which he has attained.

It is the responsibility of each pilot to ensure that his/her recency of experience requirement is fulfilled. If a pilot has not had this requirement satisfied he should report to his respective chief pilot and/or the scheduling ahead of time so the appropriate measure can be taken. Normal control for this requirement will be fulfilled when both scheduling and pilots track recency of experience by at least one landing per 30 days or a calendar month.

Any captain and/or first officer deliberately infringing on these instructions may be considered to be guilty of disobedience or conduct prejudicial to the interests of the company.

The captain is authorized to allow a first officer to carry out takeoffs and landings when the captain has accumulated **300 hours** command time on type.

A captain may allow a student captain to make takeoffs and landings from the left seat provided he himself is qualified to do so, on the type.

If the first officer has less than **100 hours** on the type, and the Captain is not an appropriately qualified check/instructor pilot, the Captain must make all takeoffs and landings in the following situations:

- At special airports (category C)
- During low visibility (CAT II) operations
- Strong cross winds
- Emergency or abnormal situations

The Captain shall handle all low visibility takeoffs and landings and rejected takeoffs.

Inexperienced flight crews (Captain who has less than 300 hours and F/O who has less than 100 hours on type) shall not be scheduled together.

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Appendix I: ATC Voice Recording Transcript

OFFICIAL TRANSCRIPT

ETHIOPIAN AIRLINES FLIGHT 409, ETH-409
BOEING 737-800, ET-ANB, S/N 29935
BEIRUT, LEBANON
JANUARY 25, 2010

LEGEND

GND……..... HARIRI GROUND 121.9
TWR…… …… …….. TOWER 118.9
CTL…….. ……. BIERUT CONTROL 119.3
ETHIOPIAN FLIGHT 409……. ETH409
ETIHAD FLIGHT 533…… ETD533
MALEV FLIGHT 240…… .MAH240
OLYMPIC FLIGHT 463…… NOA463
****……. UNINTELLIGABLE CONVERSATION
CTL AND TWR…… PHONE CONVERSATON BETWEEN HARIRI TOWER AND HARIRI RADAR CONTROL

START OF OFFICAL TRANSCRIPT: ALL TIMES UTC

STARTING COMMUNICATION WITH HARIRI GROUND FREQUENCY 121.9 MHZ		
00:25:04	ETH409	GROUND ETHIOPIAN 409 GOOD MORNING
00:25:14	GND	ETHIOPIAN GOOD MORNING GO AHEAD
00:25:19	ETH409	ETHIOPIAN 409 GATE 6 DESTINATION ADDIS LEVEL 350 REQUESTING START AND PUSH
00:25:24	GND	PUSH BACK AND START APPROVED FOR RUNWAY 21
00:25:29	ETH409	**(START UP)PUSH PACK APPROVED FOR RUNWAY 21 ETHIOPIAN 409
00:30:14	ETH409	GROUND ETHIOPIAN 409 REQUESTING TAXI CLEARANCE
00:30:24	GND	ETHIOPIAN 409 TAXI LIMA ALPHA HOTEL HOLDING POINT RUNWAY 21 COPY ATC
00:30:29	ETH409	LIMA ALPHA HOTEL HOLDING POINT RUNWAY 21 GO AHEAD ATC PLEASE
00:30:34	GND	ATC CLEARS ETHIOPIAN 409 TO DESTINATION VIA LATEB ONE DELTA DEPARTURE FLIGHT PLAN ROUTE CLIMB THREE THOUSAND FEET SQWACK TWO FIVE SIX ONE
00:30:49	ETH409	CLEARED TO DESTINATION VIA LATEB ONE DELTA DEPARTURE VIA FLIGHT PLAN ROUTE TO CLIMB INITIALLY THREE THOUSAND FEET SQUAKING TWO FIVE SIX ONE
00:30:59	GND	READ BACK CORRECT REQUEST REGISTRATION
00:31:04	ETH409	REGISTRATION ECHO TANGO ALPHA NOVEMBER BRAVO
00:31:09	GND	CONFIRM NOVEMBER BRAVO

00:31:14	ETH409	AFFIRM
00:31:16	GND	ROGER AND I CONFIRM SQUAWK TWO FIVE SIX ONE
00:31:19	ETH409	TWO FIVE SIX ONE ROGER
00:31:23	GND	READ BACK CORRECT TOWER EIGHTEEN NINER GOOD DAY
00:31:24	ETH409	EIGHTEEN NINER GOOD DAY
CHANGING TO HARIRI TOWER FREQUENCY 118.9MHZ		
00:31:52	ETH409	TOWER GOOD MORNING ETHIOPIAN 409 TAXING ON LIMA
00:31:54	TWR	GOOD MORNING LINE UP TWO ONE ETHIOPIAN 409 REPORT READY FOR DEPARTURE
00:31:59	ETH409	CLEARED TO LINE UP TWO ONE CALL YOU READY FOR DEPARTURE
00:34:09	TWR	GOOD MORNING OLYMPIC 463 CLEARED TO LAND ONE SIX WIND CALM
0034:11	NOA463	CLEARED TO LAND RUNWAY ONE SIX OLYMPIC 463
00:34:13	TWR TO CTL (PHONE CALL)	(SOUND OF BUZZER TONE CALL) CONTROLLER ANSWERS THE CALL
00:34:14	CTL TO TOWER (PHONE CALL)	هلء بحكي معك هلء بحكي I WILL TALK TO YOU LATER I WILL TALK
00:34:16	TWR TO CTL (PHONE CALL)	ليك الأولمبيك DIRECT CHEKA HEY OLYMPIC DIRECT CHEKA
00:34:18	CTL TO TWR (PHONE CALL)	يللا باي BYE
00:35:29	ETH409	ETHIOPIAN 409 READY FOR DEPARTURE
00:35:36	TWR	ETHIOPIAN 409 WIND NEARLY CALM CLEARED TAKE OFF TWO ONE IMMEDIATE RIGHT TURN TO CHEKA
00:35:44	ETH409	CLEARED FOR TAKE OFF RUNWAY TWO ONE IMMEDIATE RIGHT TURN TO CHEKA ETHIOPIAN 409
00:35:47	TWR	CORRECT
00:36:09	TWR	OLYMPIC 463 KILO CROSS ONE SEVEN AND GROUND ONE TWO ONE NINE BYE BYE
00:36:13	NOA463	ONE TWO ONE NINE KILO GOLF OLYMPIC FOUR SIX THREE
00:38:11	TWR TO CTL (PHONE CALL)	ألو HELLO
00:37:04	CTL TO TWR (PHONE CALL)	الأثيوبي شو طالع WHERE IS ETHIOPI GOING
00:37:06	TWR TO CTL (PHONE CALL)	DIRECT هلء برمو رجاع .... أديه بعطبه INITIALLY DIRECT…. NOW YOU TURN HIM LATER. WHAT SHALL I GIVE HIM INITIALLY
00:37:09	CTL TO TWR (PHONE CALL)	كيف كيف DIRECT شو رايح WHAT..WHAT DIRECT WHERE IS HE GOING

00:37:13	TWR TO CTL (PHONE CALL)	كان على أساس طلب DIRECT CHEKA أديه بعطيه HEADING INITIALLY HE ASKED DIRECT CHEKA WHAT HEADING SHALL I GIVE HIM
00:37:18	CLT TO TWR (PHONE CALL)	أيه WHAT
00:37:20	TWR TO CTL (PHONE CALL)	أديه بعطيه HEADING WHAT HEADING SHALL I GIVE HIM
00:37:22	CTL TO TWR (PHONE CALL)	عطيه THREE ONE FIVE أو HEADING THREE ZERO ZERO GIVE HIM HEADING THREE ZERO ZERO OR THREE ONE FIVE
00:37:24	TWR TO CTL (PHONE CALL)	أيه لح أعطيه بس عمئلك هو كان طالب DIRECT CHEKA بعطيه THREE ZERO ZERO YES I WILL GIVE HIM BUT I'M TELLING YOU HE WAS ASKING DIRECT CHEKA SHALL I GIVE HIM THREE ZERO ZERO
00:37:28	CTL TO TWR (PHONE CALL)	أيه أيه YES YES
00:37:29	TWR TO CTL (PHONE CALL)	أوكي OK
00:37:34	TWR	ETHIOPIAN 409
00:37:36		UNKNOWN MIKE CLICK
00:37:39	TWR	CHECK TURN RIGHT INITIALLY HEADING THREE ONE FIVE
00:37:44	ETH409	ONE FIVE ROGER
00:38:04	TWR	ETHIOPIAN 409 CONTROL NINETEEN THREE MASALAMA
00:39:09	ETH409	NINETEEN THREE MASALAMA
CHANGING TO BEIRUT CTL FREQUENCY 119.3MHZ		
00:37:38	CTL	MALEV 240 DESCEND SEVEN THOUSAND FEET
00:37:40	MAH240	DESCENDING SEVEN THOUSAND FEET MALEV 240
00:38:17	ETH409	CONTROL ETHIOPIAN 409 CROSSING TWO THOUSAND FEET
00:38:21	CTL	ETHIOPIAN 409 GOOD MORNING CLIMB FLIGHT LEVEL TWO NINER ZERO
00:38:26	ETH409	FLIGHT LEVEL TWO NINE ZERO ETHIOPIAN 409
00:38:35	CTL	SIR I SUGGEST FOR YOU DUE TO WEATHER TO FOLLOW HEADING TWO SEVEN ZERO TO BE IN THE CLEAR FOR FIFTEEN MILES TWENTY MILES THEN TO GO TO CHEKA AND ITS UP TO YOU JUST GIVE ME THE HEADING
00:38:50	ETH409	CONFIRM HEADING TWO ONE ZERO
00:38:52	CTL	ETHIOPIAN 409 SIR NEGATIVE TO PROCEED DIRECT CHEKA SIR TURN LEFT FLY HEADING TWO SEVEN ZERO
00:39:01	ETH409	LEFT HEADING TWO SEVEN ZERO
00:39:06	ETD533	ETIHAD533 CONFIRM WE ARE NOW CLEARED FOR THE APPROACH TO ZALKA
00:39:10	CTL	ETIHAD533 CONTINUE PRESENT HEADING SIR TURN LEFT HEADING TWO ZERO ZERO ETIHAD533
00:39:18	ETD533	**ETIHAD533
00:39:24	MAH240	MALEV 240 CLOSING TO THE LOCALIZER *

00:39:28	CTL	MALEV 240 PROCEED TO ZALKA
00:39:30	MAH240	CONTINUE TO ZALKA MALEV 240
00:39:45	CTL	ETHIOPIAN 409 FOLLOW HEADING TWO SEVEN ZERO TURN RIGHT HEADING TWO SEVEN ZERO
00:39:51	ETH409	HEADING TWO SEVEN ZERO ROGER
00:40:20	CTL	ETHIOPIAN 409 FOLLOW HEADING TWO SEVEN ZERO SIR FOLLOW HEADING TWO SEVEN ZERO TURN RIGHT HEADING TWO SEVEN ZERO NOW
00:40:28	ETH409	ROGER ROGER (SOUND OF OPEN MIKE)
00:40:32	ETD533	ETIHAD533 WE NEED TO CONTINUE THROUGH THE CENTER LINE DUE TO THUNDERSTORM SITTING THERE AND I'LL TELL YOU WHEN I CAN TURN BACK
00:40:40	CTL	ETIHAD533 ROGER
00:40:50	MAH240	MALEV 240 REQUEST HEADING ONE THREE ZERO TO AVOID WEATHER
00:40:55	CTL	MALEV 240 APPROVED
00:40:57	MAH240	THANK YOU AND READY FOR FURTHER DESCENT
00:41:01	CTL	MALEV 240 DESCEND FIVE THOUSAND FEET
00:41:03	MAH240	FIVE THOUSAND FEET MALEV 240
00:41:04	CTL	ETHIOPIAN 409 ETHIOPIAN 409 YOU'RE GOING TO THE MOUNTAIN TURN RIGHT NOW HEADING TWO SEVEN ZERO
00:41:11		(SOUND OF OPEN MIKE 3 SECONDS)
00:41:27	CTL	ETHIOPIAN 409 ABLE TO PROCEED TO CHEKA NOW
00:41:43	ETD533	ETIHAD533 NOW JUST ESTABLISHED NINE MILES THANK YOU
00:41:48	CTL	ETIHAD533 CONTINUE ILS APPROACH RUNWAY ONE SIX CONTAC TOWER ONE ONE EIGHT DECIMAL NINE
00:41:52	ETD533	ONE ONE EIGHT DECIMAL NINE THANK YOU SIR GOOD NIGHT
00:41:56	MAH240	BEIRUT MALEV 240 PLEASE CONFIRM THE ACTUAL WEATHER ON THE AIRPORT
00:42:08	CTL	MALEV 2 ETHIOPIAN 409 BEIRUT ETHIOPIAN 409 BEIRUT
00:42:27	CTL	MALEV 240 CONTINUE WITH BEIRUT CONTROL BEIRUT APPROACH ONE TWO ZERO THREE
00:42:30	MAH240	ONE TWO ZERO THREE BYE BYE MALEV TWO FOUR ZERO
00:42:32	CTL	ETHIOPIAN 409 BEIRUT
00:42:41	CTL	ETHIOPIAN 409 BEIRUT
00:42:56	CTL	ETHIOPIAN 409 BEIRUT
00:43:04	CTL	ETHIOPIAN 409 AT FREQUENCY ONE TWO ONE FIVE BEIRUT
00:43:26	CTL	ETHIOPIAN 409 BEIRUT
00:43:36	CTL	ETHIOPIAN 409 BEIRUT
00:43:55	CTL	ETHIOPIAN 409 BEIRUT
00:44:03	CTL	ETHIOPIAN 409
00:44:44	CTL	ETHIOPIAN 409 BEIRUT CONTROL IF YOU ARE HEARING ME PROCEED TO ZALKA HOLDING PATTERN ORBIT OVER ZALKA
00:45:10	CTL	ETHIOPIAN 409 BEIRUT
00:46:04	ETD533	BEIRUT APPROACH ETIHAD 533 GO AROUND
00:46:10	CTL	ETIHAD 533 BEIRUT FOLLOW HEADING TWO

00:46:16	ETD533	HEADING TWO THREE ZERO CONFIRM
00:46:19	CTL	FOLLOW HEADING TWO SEVEN ZERO CLIMB FIVE THOUSAND FEET
00:46:20	ETD533	TWO SEVEN ZERO FIVE THOUSAND
00:46:26	CTL	AND ETIHAD 533 FOR YOUR INFORMATION WE ARE LOSTING AN AIRCRAFT ETHIOPIAN ETHIOPIAN AND WE DO'NT KNOW HIS LEVEL OR WHAT'S HAPPENED TO HIM AND WE DON'T KNOW HIS POSITION
00:46:37	ETD533	COPIED ETIHAD 533
00:46:51	CTL	ETIHAD533 CONTACT APPROACH ONE TWO ZERO THREE
00:47:00	ETD533	BEIRUT ETIHAD FIVE THREE THREE NOW WE ARE TURNING… END OF TRANSCRIPT

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Appendix J: CVR Data Transcript

C V R T R A N S C R I P T

FOREWORD

The following is the transcript of the elements which were understood from the work on the CVR recording. This transcript contains conversations between crew members, radiotelephonic messages and various noises corresponding, for example, to the movement of selectors or to alarms.

The reader's attention is drawn to the fact that the recording and transcript of a CVR are only a partial reflection of events and of the atmosphere in a cockpit. Consequently, the utmost care is required in the interpretation of this document.

The voices of crew members are heard via the different channels of the CVR. They are placed in separate columns for reasons of clarity. Others columns are reserved for; the noises and alarms heard via the CAM; VHF communications with ATC.

GLOSSARY

UTC	Timing synchronized with FDR / ATC communications
SV	Synthetic voice
→	Communications with ATC
( )	Word or group of words in parentheses are doubtful
word	Word or group of words in italic are translated from the Arabic
(*)	Word or group of words not understood

N.B.: *Only one page of the CVR recording of the pre-flight departure phase is included in this appendix, along with the full text of the flight phase. This is in line with the ICAO standards requiring that only records pertinent to the analysis of the accident shall be included in the final report. That page is hand written because it contains Amharic words.*

1

UTC Time	Captain	First Officer	Others	Remarks / Sounds / Translation
24:03:32	የሆቴሉ: እንቅልፍ: የማያስተኛ ነገር: አለው: ብዬ::			THIS ROOM DOESN'T MAKE YOU SLEEPY.
24:03:44	ይለያሉ: እንዴ: ሁለቱ::			DOES this two DIFFER
		አዎ: ይሄ: 350 ነው		YES, this ONE IS 350
24:03:47	እረ ገኘሁ: ይሄ: 370 ነው: [illegible]: ነው::			OH! REALLY THIS ONE IS 370
24:04:03	አንድ: ብቻ: ነው: ያመጣው			DID HE BRING ONLY ONE
24:04:05		አንድ: [illegible]: ነው: ያመጣው		HE BROUGHT ONE COPY
24:04:10	እስቲ: እንዴ: ልየውና: LEVEL ምናምን::			LET ME SEE AND CHECK THE LEVEL
24:04:21		HEAD WIND ነው: ዛሬም ያለን::		TODAY ALSO WE HAVE HEAD WIND
24:04:38	አንዱ: PAGE ሙሉ: ይሄ: ነው			THIS COVERS ONE WHOLE PAGE.
24-04-42		ኧ! RUNWAY 21 ግን: የለውም: 03/17		YEAH, BUT RUNWAY 21 DOESN'T HAVE, 03/17
24-05-13	ወደላይ: አይ: ነው: የምንወጣው: 370			IT WON'T TAKE TIME TO CLIMB 370
24-05-26	እንውጣ እንግዲህ			LET'S GO PLEASE
24-05-38	ገና: ቆይተን: እንጠይቃለን::			WE WILL REQUEST LATER.
24-07-20	ምንድን? ይበላሸው: ነገር: እንጀራ: አለበት: እንዴ? WEED ነገር: አለበት?			WHAT WAS IN THE FOOD WE HAD? WAS THERE WEED IN IT?
24-07-29		(LAUGHING) ምን: አዞረህ: እንዴ		(LAUGHING) DID YOU FELT DIZZY
24-07-32	መተኛት: አልተኛም: እኮ::			OH! I COULDN'T SLEEP.
24-07-34		እኔም: እንቅልፍ ሲያምረኝ: የሚገርምህ: ነገር::		WELL! ME TOO
24-07:36	WEED የሚቀመጥበት የሚሸጠው: እንጀራ: ወስዶ: [illegible]	(LAUGHING)		(LAUGHING)

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
00 h 35 min 36 s			Ethiopian four zero nine wind nearly calm cleared take off two one immediate right turn to Cheka	
35 min 45 s		→ Roger cleared for take-off runway two one immediate right turn to Cheka Ethiopian four zero nine		
35 min 56 s	*(Ethiopian words)*			*Does it mean that three thousand is not valid anymore*
35 min 58 s		*(Ethiopian words)*		*Three thousand is still there*
00 h 36 min 01 s	*(Ethiopian word)*	*(Ethiopian words)*		*ok* *Shall I confirm it to you*
36 min 03 s		Right side is clear		
36 min 05 s	Left side is clear			
36 min 06 s				Sounds similar to selector movement
36 min 19 s	Ok airborne at three six			
36 min 24 s	Transponder ON			
36 min 26 s		Transponder is ON		

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
36 min 28 s	Weather on my side			
36 min 29 s		Roger terrain on my side		
36 min 30 s	Stabilized			
36 min 33 s	*(Ethiopian word)*			*Yes*
36 min 34 s		N one heading select TOGA		
36 min 41 s		Take off thrust set speed increasing		
36 min 44 s	Check			
36 min 46 s				Sound similar to interferences on the radio
36 min 48 s	*(Ethiopian words)*			*Do you see that?*
36 min 49 s		Eighty knots		
36 min 51 s		Throttle hold (*Ethiopian word)*		Ethiopian word for acknowledging
36 min 59 s				Gap in the CAM recording (10 sec) due to the U16 memory not available
00 h 37 min 08 s		Rotate		
37 min 10 s				The CAM is again available
37 min 17 s		Positive rate		
37 min 19 s	Gear up			
37 min 31 s	L NAV heading select rather			
37 min 33 s		Heading		

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
		select (*)		
37 min 35 s		(check)		
37 min 35 s			Ethiopian four zero nine	Sounds similar to trim wheel turning
37 min 39 s		→ Go ahead		
37 min 40 s			*Leyk* turn right initially heading three one five	
37 min 45 s		→ Three one five roger		
37 min 46 s	Heading three one five			
37 min 47 s		Right heading three one five		
37 min 51 s	N one flaps one speed flaps up speed rather			
37 min 55 s		Roger		
37 min 57 s				Sounds similar to trim wheel turning
00 h 38 min 02 s				Sounds similar to trim wheel turning
38 min 03 s		N one flaps up speed		
38 min 07 s			Ethiopian four zero nine control nineteen three Masalama	
38 min 10 s	Flaps one	→ Nineteen three Masalama		
38 min 11 s				Sounds similar

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
				to flaps lever movement
38 min 12 s	Nineteen three			
38 min 13 s				Sounds similar to trim wheel turning
38 min 17 s		→ Control Ethiopian four zero niner crossing two thousand feet		
38 min 22 s			Ethiopian four zero nine good morning climb flight level two niner zero	Sounds similar to trim wheel turning
38 min 26 s		→ Flight level two niner zero Ethiopian Four Zero Nine		
38 min 29 s				Sounds similar to trim wheel turning
38 min 31 s	Flaps up			
38 min 34 s		Roger flaps up		Sounds similar to flaps lever movement
38 min 35 s			Sir I suggest for you due to weather to follow heading two seven zero to be in the clear for fifteen miles twenty miles then to go to Chekka and it is up to you	Sound similar to a horn not compatible with aircraft warning
38 min 41 s				SV: bank angle
38 min 43 s				SV: bank angle
38 min 44 s				Sounds similar to trim wheel turning

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
			just give me the heading	
38 min 48 s	Two one say again?			
38 min 50 s		→ Confirm heading two one zero		
38 min 52 s			Ethiopian four zero nine sir negative to proceed direct Cheka sir turn left now heading two seven zero	
38 min 59 s	Left heading two seven zero?	→ Roger		
00 h 39 min 01 s		→ Left heading two seven zero		SV: bank angle
39 min 03 s				SV: bank angle
39 min 04 s		Two seven zero is set		
39 min 22 s				Sounds similar to heavy rain
39 min 29 s				SV: bank angle
39 min 30 s				SV: bank angle
39 min 40 s	*(Ethiopian words)*			*Ok Engage auto autopilot*
39 min 46 s			→ Ethiopian four zero nine follow heading two seven zero turn right heading two seven zero	
39 min 51 s		→ Right heading two		

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
		seven zero roger		
39 min 54 s	*(Ethiopian words)*			*ok what heading did he say*
39 min 56 s		Two seven zero set		
39 min 59 s	*(Ethiopian words)*			*What is that?*
00 h 40 min 00 s	Speed			
40 min 01 s				Sounds similar to stick shaker starting
40 min 06 s				SV: bank angle
40 min 08 s				SV: bank angle
40 min 09 s	*(Ethiopian words)*			*What is that?*
40 min 13 s	*(Ethiopian words)*			*What is that?* (louder)
40 min 15 s				Sound similar to selector movement
40 min 16 s	Go around			
40 min 17 s	Go around			
40 min 18 s	Go around			
40 min 19 s	Go around			
40 min 19 s		Roger		
40 min 20 s	Go around	Go around	Ethiopian four zero nine follow heading two seven zero sir follow heading two seven zero turn right heading two	

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
			seven zero now	
40 min 28 s				End of sounds similar to stick shaker and start of sounds similar to heavy rain
40 min 28 s		→ Roger roger		Then Push to talk button activated without voice
40 min 47 s				Gap in the CAM recording (10 sec) due to the U16 memory not available
40 min 48 s		The speed is dropping		
40 min 49 s		*(Ethiopian words)*		*Speed is going down*
40 min 50 s	*(Ethiopian words)*			*Ok try to do something*
40 min 52 s				SV: bank angle
40 min 54 s				SV: bank angle
	(Ethiopian words)			*Hold this thing*
40 min 55 s		(speed)		
40 min 57 s				The CAM is again available with sounds similar to stick shaker
00 h 41 min 05 s			Ethiopian four zero nine Ethiopian four zero nine you are going in the mountain turn right now	

UTC Time	Captain	First Officer	ATC	Remarks / Sounds / Translation
			heading two seven zero	
41 min 12 s		→		Push to talk button activated without communication
41 min 15 s	(*)			
41 min 23 s				End of sounds similar to stick shaker
41 min 24 s	*(*)*			
41 min 25 s				Sounds similar to clacker (over speed warning)
41 min 28 s			Ethiopian four zero nine	Loud sounds
41 min 29 s				SV: bank angle
00 h 41 min 30 s				End of recording

Appendix K: M-Cab Session Report

Please double click on this page to open the Appendix

Chief Engineer
Air Safety Investigation
Commercial Airplanes

The Boeing Company
P.O. Box 3707 MC 07-32
Seattle, WA 98124-2207

29 August 2011
6 September 2011 (Revision A)
66-ZB-H200-ASI-18624 Revision A

Mr. Dennis Jones
Accredited Representative
National Transportation Safety Board
490 L'Enfant Plaza SW
Washington, DC 20594

Subject: Aerodynamic Performance Study – Ethiopian Airlines 737-800 ET-ANB Accident in Beirut, Lebanon – 25 January 2010

Reference: Engineering Flight Simulation Session Meeting held 22 & 23 September 2010 in Seattle

Dear Mr. Jones:

As part of the investigation into the subject event, Boeing was provided the Flight Data Recorder (FDR) raw binary data and was requested to conduct a performance study of the accident flight. Specific requests included any influence of the flight path stemming from external atmospheric effects (winds) and the consistency of the behavior of the airplane given the control inputs. In addition, Boeing was requested to conduct a simulation of the flight in the Engineering Flight Simulator.

Please find our analysis of the FDR data as enclosed with this letter. The reference simulator session was held in the Engineering Multi-Purpose Simulator. The investigation was provided a copy of all presentation material along with digital video data of the different scenarios run during the simulation sessions.

The information included with this correspondence is controlled under the US Export Administration Regulations (15 CFR Parts 300-799) and has been categorized as ECCN: 9E991. Information categorized as ECCN 9E991 is acceptable for public release.

Revision A is sent to add mention that the overspeed clacker warning is noted (in addition to the stick shaker) around time 17584 on page 6 of the enclosure and to correct a section call out (from Section 7 to Section 6) on page 14 of the enclosure.

Please feel free to contact us if you have any questions.

Best regards,

<original signed by>

Chief Engineer
Air Safety Investigation

Enclosure: Aerodynamic Performance Study – Ethiopian Airlines 737-800 ET-ANB Accident in Beirut, Lebanon – 25 January 2010

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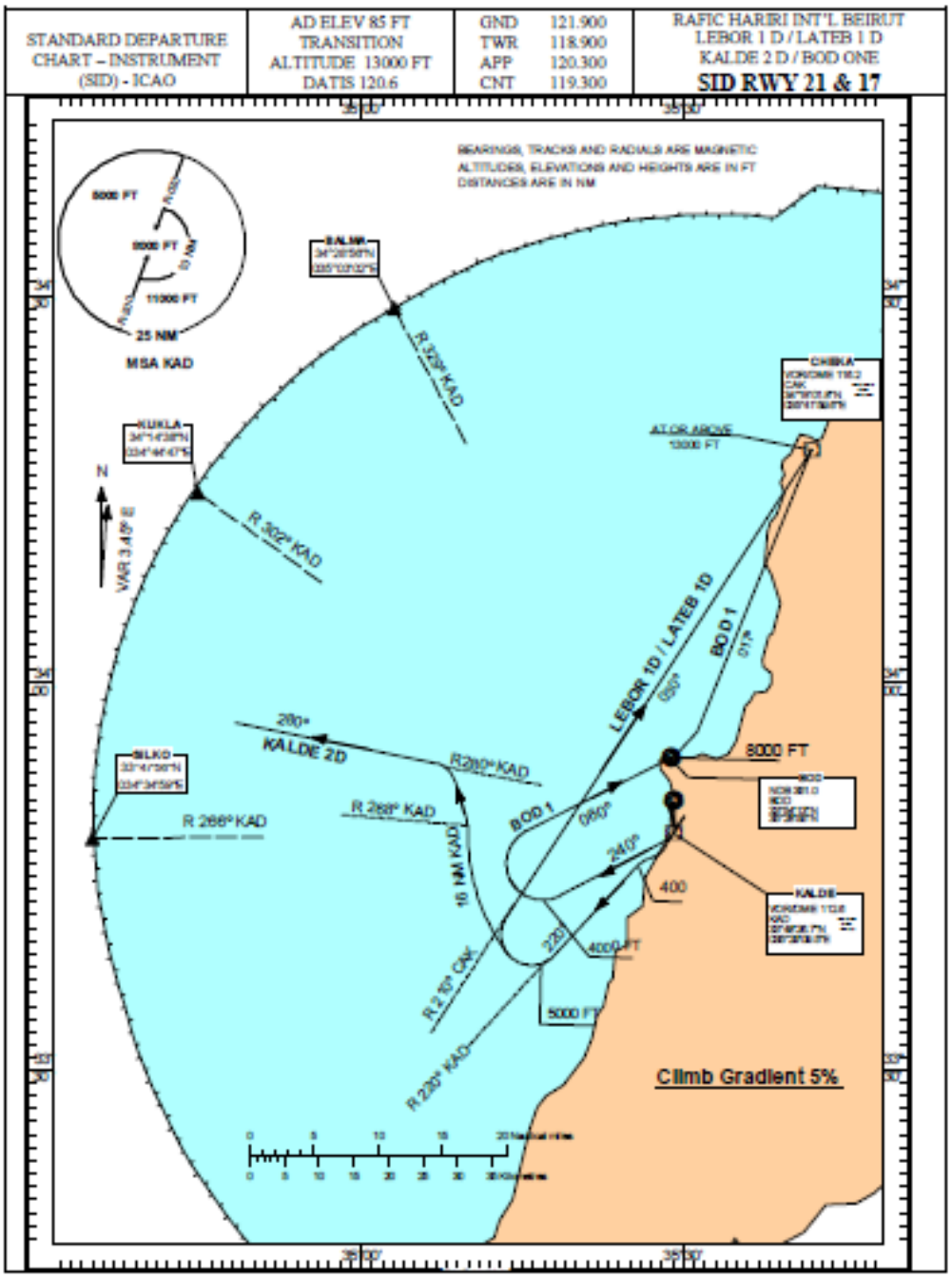
Appendix L: Lateb 1 D SID plate



RAFIC HARIRI INTL BEIRUT
STANDARD DEPARTURES ROUTES – INSTRUMENT (SID) RWY 21 OR (17)

General instructions.

Air traffic gradient 5 % minimum
If Aircraft unable to comply with these SIDs, pilots must advise ATC from start-up request.

Noise abatement:
All take-offs must comply with the configuration and the climb rating in accordance with noise reduction depending on the current operational conditions.
The routes are established for noise abatement reasons. Strict adherence within the limits of aircraft performance is mandatory.

DESIGNATOR	ROUTE	CLIMB INSTRUCTION
LEBOR 1D LEBOR one Delta Departure	At (400 FT) turn right and intercept KAD R220. At 5000 FT turn right to establish on CAK R210 to CAK. After CAK proceed to LEBOR. **Remarks** : Procedure Design gradient is 4.1 %. The critical obstacle 506 FT, is located at 4260m from DER and 1240 m left to axis.	Climb Gradient 5 %. Cross CAK at or above 13000 FT. Cross LEBOR at or above FL 240
KALDE 2D KALDE two Delta Departure	At (400 FT) turn right and intercept KAD R220. At 5000 FT turn right to follow 16 DME KAD arc, at KAD R268 turn left to follow KAD R280 and then join the proper airway when cleared by ATC. **Remarks** : Procedure Design gradient is 4.1 %. The critical obstacle 506 FT, is located at 4260m from DER and 1240 m left to axis.	Climb Gradient 5 %
LATEB 1D LATEB one Delta Departure	At (400 FT) turn right and intercept KAD R220. At 5000 FT turn right establish on CAK R210 to CAK. After CAK proceed to LATEB. **Remarks** : Procedure Design gradient is 4.1 %. The critical obstacle 506 FT, is located at 4260m from DER and 1240 m left to axis.	Climb Gradient 5 %. Cross CAK at or above 13000 FT. Cross LATEB at or above FL 290.
BOD 1 BOD ONE Departure	After take-off turn right heading 240°, when passing 4000 feet AMSL turn RIGHT, intercept 060° bearing to BOD NDB (351 KHZ), then along airway W201 to CAK DVOR/DME (116.2 MHZ), then LEBOR or LATEB	Climb gradient 5% Cross BOD at or above 8000ft Cross CAK at or above 13000 ft Cross LEBOR at or above FL240 Cross LATEB at or above FL290 or as cleared by ATC

Appendix M: Boeing 737-800 Stabilizer Trim Description

Please double click on this page to open the Appendix

Mach Trim System

A Mach trim system provides speed stability at the higher Mach numbers. Mach trim is automatically accomplished above Mach .615 by adjusting the elevators with respect to the stabilizer as speed increases. The FCC's use rudder computer Mach information from the ADIRU to command a Mach trim actuator position. The Mach trim actuator repositions the elevator feel and centering unit which adjusts the control column neutral position.

Stabilizer

The horizontal stabilizer is positioned by a single electric trim motor controlled through either the autopilot switches on the control wheel or autopilot trim. The stabilizer may also be positioned by manually rotating the stabilizer trim wheels.

Stabilizer Trim

Stabilizer trim switches on each control wheel can initiate electric trim motion through the main electric stabilizer trim circuit when the airplane is flown manually. With the autopilot engaged, stabilizer trim is accomplished through the autopilot stabilizer trim circuit. The main electric and autopilot stabilizer trim have two speed modes: high speed with flaps extended and low speed with flaps retracted. The autopilot is engaged, actuation of either pair of stabilizer trim switches automatically disengages the autopilot. The stabilizer trim wheels rotate whenever electric stabilizer trim is actuated.

The STAB TRIM MAIN ELEC cutout switches and the STAB TRIM AUTOPILOT cutout switch, located on the control stand, are provided so that the autopilot or main electric trim inputs can be disconnected from the stabilizer trim motor.

Control column mounted stabilizer trim cutout switches stop operation of the main electric and autopilot trim when the control column movement opposes trim direction. When the STAB TRIM override switch is positioned to OVRD, electric trim can be used regardless of control column position.

Manual stabilizer control is accomplished through cables which allow the pilot to position the stabilizer by rotating the stabilizer trim wheels. The stabilizer is held in position by two independent brake systems. Manual rotation of the trim wheels can be used to override autopilot or main electric trim. The effort required to manually rotate the stabilizer trim wheels may be higher under certain flight conditions. Grasping the stabilizer trim wheels will stop stabilizer motion.

Stabilizer Trim Operation with Forward or Aft CG

In the event the stabilizer is trimmed to the end of the electrical trim limits, additional trim is available through the use of the manual trim wheels. If normal trim is used to position the stabilizer beyond these electrical trim limits, the stabilizer trim switches may be used to return the stabilizer to electrical trim limits.

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Appendix N: ET Standard Deviation Calls

To minimize confusion and enhance professionalism, use standard terminology at all times.

CHECK (ED) / CROSS CHECK (ED)
VERIFY
TUNE
SET
SELECT
ARM
ENGAGE
ON/OFF
LANDING
GO-AROUND
I HAVE CONTROL
YOU HAVE CONTROL
1000' to level off
10,000' AGL ... etc.
Proper adherence to the FCTM standard callouts as specified in Section 1 is an essential element of a well-managed flight deck.

1.29.1 STANDARD DEVIATION CALLS

The PM will call attention to deviations from desired attitude, speed, heading, altitude or track using an appropriate call-out. The limits cannot always be stated in precise terms, but guidelines are given below. PM must be particularly alert to deviations from target airspeed and should certainly draw attention to speed losses if the trend is continuing 5 kts below the correct target speed. PF may also usefully make standard calls as an indication to the PM that he has registered the deviation. However, PM should not take this to mean that the deviation will be corrected, and must make the appropriate call if the deviation continues.

The following is a guide to deviations which would prompt a standard call:

Airspeed	+15 kts/−5 kts	**"SPEED"**
Pitch Attitude	Any inappropriate pitch or 7.5° on touchdown	**"PITCH"**
Roll Attitude	Over 30° Bank	**"BANK ANGLE"**
Glide slope	½ Dot	**"GLIDESLOPE"**
Localizer	½ Dot	**"LOCALISER"**
Vertical Speed	>1000FPM(Precision) >1300FPM(Non-Precision)	**"SINK RATE"**

- If an attitude callout is made, both pilots should immediately cross-check their main attitude displays and if a discrepancy exists, reference should then be made to the Standby Altimeter to determine the correctly functioning display.

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Appendix O: Trim Tab Analysis Report

Please double click on this page to open the Appendix

Chief Engineer
Air Safety Investigation
Commercial Airplanes

The Boeing Company
P.O. Box 3707 MC 07-32
Seattle, WA 98124-2207

11 August 2011
6 September 2011 (Revision A)
66-ZB-H200-ASI-18623, Revision A

Mr. Dennis Jones
Accredited Representative
National Transportation Safety Board
490 L'Enfant Plaza SW
Washington, DC 20594

BOEING

Subject: Equipment Quality Analysis Report – Ethiopian Airlines 737-800 ET-ANB Accident in Beirut, Lebanon – 25 January 2010

References: (a) EQA meeting held in Seattle 21 March 2011
(b) EQA meeting held in Seattle 11 May 2011

Dear Mr. Jones:

As part of the investigation into the subject event, both the left and the right Elevator Trim Tab Mechanisms were removed from the recovered wreckage and examined during the reference (a) and (b) meetings. Boeing has completed the enclosed reports from these examinations.

As a matter of follow-up, one of the observations on the right-hand mechanism is that the inboard mechanism support bearing had been over-rotated as seen in Figure 7 of Enclosure 1. Enclosure 3 shows this installation (Figure 1) and an up-close photo (Figure 2) of the bearing in the as-recovered condition. At the time of recovery, this bearing did not exhibit the over-rotation damage seen in the EQA report indicating that the damage occurred either during mechanism extraction from the wreckage or during shipment to Seattle.

In addition, a motivating factor for examination of the left side tab mechanism is the fact that the inboard attach bearing was found with all of the bearing balls missing. It was subsequently found (see Enclosure 2 Metallurgical Exam) that this condition existed at the time of the accident.

There have been two reports of significant airframe vibration (both resulting in flight diversions) involving 737NG airplanes. Post flight examination of the airplanes showed that both attach points on one tab mechanism fractured. Analysis attributed these fractures to the loss of the attach point bearing retention and subsequent fracture of the attach tab. This issue is currently subject to an FAA Airworthiness Directive which requires a periodic on-wing inspection of the bearing retention for a secure swage. Because loss of the bearing balls would have a similar effect as loss of the bearing retention (i.e. – significant play in the joint), the left tab mechanism from the accident airplane was subject to the detailed exam during the reference b) meeting.

Enclosure 4 shows a fractured mechanism (Figure 1) following one of the above mentioned in-flight diversions involving a 737-800 airplane. Figure 2 shows the FDR data at the time that the mechanism became detached from the elevator front spar. Significant oscillatory movement of the left elevator (approximate 1hz rate) is noted following the final fracture.

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Appendix P: Black Soot Analysis Report

Please double click on this page to open the Appendix

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

month/day/year

MATERIALS LABORATORY FACTUAL REPORT — Report No. 11-082

A. ACCIDENT INFORMATION

Place	:	Beruit, Lebanon
Date	:	January 25, 2010
Vehicle	:	Boeing 737
NTSB No.	:	DCA10RA023
Investigator	:	Dennis Jones NTSB AS-10

B. COMPONENTS EXAMINED

Section of fuselage skin located near the auxiliary power unit (APU), below the APU oil cooler vent opening

C. DETAILS OF THE EXAMINATION

A section of fuselage skin from the APU compartment was submitted to the Materials Laboratory for examination. The section of fuselage was 16 inches (in) long, 2.5 in wide at the narrowest end and 5 in at the widest end. One side of the section was painted with green zinc chromate primer paint as shown in Figure 1. There was no discoloration to the primer paint and the surface was uniformly covered with a light coating of sand or dirt. Zinc chromate primer paint changes color when exposed to heat[1]. Depending on the length of exposure or temperature, the color can range from tan to brown to black. Since there was no change in the color of the paint on the primer side, there was no indication that this section of fuselage was exposed to heat/high temperatures. The opposite side appeared to have been painted with white or grey paint as shown in Figure 2. There was one area where the paint had been rubbed or smeared away but no bare metal was showing through. Other than the smeared area, there appeared to be no damage to the paint on this side. On the surface of the paint, there was a coating that was consistent with soot. The soot appeared to be slightly oily . The uniformity of the soot varied from the middle of the section having a light coating to the coating increasing in concentration around the long edges of the section. Other than darkening/discoloration attributed to the soot, the paint on this side of the section appeared to be the original color.

[1] Kuchta, J.M and Clodfelter, R.G., *Aircraft Mishap Fire Pattern Investigations*, Air Force Aero Propulsion Laboratory, Technical Report AFWAL-TR-85-2057, pg. 94.

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Appendix Q: CVR Chip Recovery Report

Please double click on this page to open the Appendix

Technical document

CVR examination

Date of occurrence:	January 25th, 2010
Place of occurrence:	Off Beirut (Lebanon)

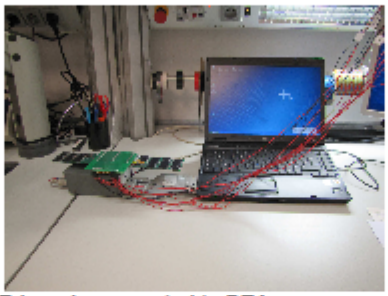
Aircraft type:	Boeing B737-800
Registration number:	ET-ANB
Operator:	Ethiopia (Ethiopian Airlines)
Flight Recorder:	Solid State Cockpit Voice Recorder (SSCVR) • Make and model: Allied Signal 6022 • P/N: 980-6022-001 • S/N: 05449

The CVR board examination was performed based on the agreed test plan referenced "*ET-ANB_CVRactionplan / Date of issue November 2nd 2010*".

WORK PERFORMED:

A direct read out was performed prior starting the examination. The memory boards were connected with the recovery cable to the BEA 6022 CVR chassis used as a playback system. The download was performed using the manufacturer reading device. This readout operation was successful and identical to the download performed on February 17th, 2010.

The CVR boards were connected to the BEA memory reader and each memory chip was individually selected and read out. All the memory chips were correctly read out except U16 (also referred as CE#19 memory chip in Honeywell documentation) which could not be read out at all. The read-out data was saved.



CVR boards connected to BEA memory reader

The assumption based on the visual inspection performed in February 17th, 2010 is confirmed: U16, the memory chip with the crack, is the non-functioning memory chip.

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Appendix R: Trim Activation Table

The following table describes the Trim activation timing, orders and results at different stages of the flight. It has been complied through the DFDR data.

Time	Press Alt [ft]	Air Speed Comp [kts]	TRIM Down A/P [0-NO Trim, 1-Trim]	Trim Down Manual [0-NO Trim, 1-Trim]	Trim UP A/P [0-NO Trim, 1-Trim]	Trim UP Manual [0-NO Trim, 1-Trim]	Pitch Trim [TU]	Mach Trim Comm and [Delta]
0:36:30	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-1.4
0:36:31	87	45	0	0	0	0	5.9	-1.4
0:36:32	87	45	0	0	0	0	5.9	-1.4
0:36:33	87	45	0	0	0	0	5.9	-1.4
0:36:34	88	45	0	0	0	0	5.9	-1.4
0:36:35	91	45	0	0	0	0	5.9	-1.4
0:36:36	92	45	0	0	0	0	5.9	-1.4
0:36:37	93	45	0	0	0	0	6.0	-1.4
0:36:38	94	45	0	0	0	0	5.9	-1.4
0:36:39	94	45	0	0	0	0	5.9	-1.4
0:36:40	94	45	0	0	0	0	5.9	-1.4
0:36:41	92	45	0	0	0	0	5.9	-1.4
0:36:42	92	48	0	0	0	0	5.9	-1.4
0:36:43	93	53	0	0	0	0	5.9	-1.4
0:36:44	94	57	0	0	0	0	5.9	-1.4
0:36:45	93	62	0	0	0	0	5.9	-1.4
0:36:46	94	65	0	0	0	0	5.9	-1.4
0:36:47	94	70	0	0	0	0	5.9	-1.4
0:36:48	94	72	0	0	0	0	5.9	-1.4
0:36:49	93	77	0	0	0	0	5.9	-1.4
0:36:50	93	80	0	0	0	0	5.9	-1.4
0:36:51	93	83	0	0	0	0	5.9	-1.4
0:36:52	92	88	0	0	0	0	5.9	-1.4
0:36:53	91	91	0	0	0	0	5.9	-1.4
0:36:54	90	95	0	0	0	0	5.9	-1.4
0:36:55	91	98	0	0	0	0	5.9	-1.4
0:36:56	90	102	0	0	0	0	5.9	-1.4
0:36:57	90	106	0	0	0	0	5.9	-1.4
0:36:58	87	109	0	0	0	0	5.9	-1.4
0:36:59	87	113	0	0	0	0	5.9	-1.4
0:37:00	87	117	0	0	0	0	5.9	-1.4
0:37:01	85	120	0	0	0	0	5.9	-1.4
0:37:02	84	124	0	0	0	0	5.9	-1.4
0:37:03	83	127	0	0	0	0	5.9	-1.4
0:37:04	83	129	0	0	0	0	5.9	-1.4
0:37:05	83	133	0	0	0	0	5.9	-1.4

0:37:06	81	136	0	0	0	0	5.9	-1.4
0:37:07	81	139	0	0	0	0	5.9	-1.4
0:37:08	79	143	0	0	0	0	5.9	-1.4
0:37:09	78	147	0	0	0	0	5.9	-1.4
0:37:10	75	150	0	0	0	0	5.8	-1.4
0:37:11	72	153	0	0	0	0	5.8	-1.4
0:37:12	70	157	0	0	0	0	5.8	-1.4
0:37:13	67	159	0	0	0	0	5.8	-1.4
0:37:14	65	162	0	0	0	0	5.8	-1.4
0:37:15	68	164	0	0	0	0	5.9	-1.4
0:37:16	73	167	0	0	0	0	5.9	-1.4
0:37:17	79	169	0	0	0	0	5.9	-1.4
0:37:18	86	171	0	0	0	0	5.8	-1.4
0:37:19	107	173	0	0	0	0	5.9	-1.4
0:37:20	131	173	0	0	0	0	5.9	-1.4
0:37:21	156	174	0	0	0	0	5.9	-1.4
0:37:22	185	172	0	0	0	0	5.9	-1.4
0:37:23	224	171	0	0	0	0	5.9	-1.4
0:37:24	269	171	0	0	0	0	5.9	-1.4
0:37:25	312	170	0	0	0	0	5.9	-1.4
0:37:26	353	169	0	0	0	0	5.9	-1.4
0:37:27	398	170	0	0	0	0	5.9	-1.4
0:37:28	439	169	0	0	0	0	5.9	-1.4
0:37:29	475	169	0	0	0	0	5.9	-1.4
0:37:30	517	169	0	0	0	0	5.9	-1.4
0:37:31	547	170	0	0	0	0	5.9	-1.4
0:37:32	584	170	0	0	0	0	5.9	-1.4
0:37:33	624	170	0	0	0	0	5.9	-1.4
0:37:34	657	174	0	0	0	0	5.9	-1.4
0:37:35	695	170	0	0	0	0	5.9	-1.4
0:37:36	736	171	0	0	0	0	6.1	-1.5
0:37:37	779	170	0	0	0	0	6.1	-1.5
0:37:38	819	170	0	0	0	0	6.1	-1.5
0:37:39	859	170	0	0	0	0	6.1	-1.5
0:37:40	899	172	0	0	0	0	6.1	-1.5
0:37:41	936	173	0	0	0	0	6.1	-1.5
0:37:42	978	173	0	0	0	0	6.0	-1.5
0:37:43	1022	172	0	0	0	0	6.1	-1.5
0:37:44	1063	173	0	0	0	0	6.0	-1.5
0:37:45	1104	173	0	0	0	0	6.1	-1.5
0:37:46	1147	173	0	0	0	0	6.1	-1.5
0:37:47	1188	174	0	0	0	0	6.1	-1.5
0:37:48	1228	175	0	0	0	0	6.1	-1.5
0:37:49	1271	174	0	0	0	0	6.1	-1.5
0:37:50	1315	176	0	0	0	0	6.1	-1.5
0:37:51	1356	175	0	0	0	0	6.1	-1.5

0:37:52	1397	175	0	0	0	0	6.1	-1.5	
0:37:53	1442	176	0	0	0	0	6.0	-1.5	
0:37:54	1484	175	0	0	0	0	6.1	-1.5	
0:37:55	1526	174	0	0	0	0	6.1	-1.5	
0:37:56	1572	174	0	0	0	0	6.1	-1.5	
0:37:57	1616	173	0	0	0	0	6.1	-1.5	
0:37:58	1657	173	0	0	0	1	6.3	-1.5	Trim UP Manual
0:37:59	1698	173	0	0	0	0	6.4	-1.5	
0:38:00	1734	172	0	0	0	0	6.4	-1.5	
0:38:01	1765	172	0	0	0	0	6.4	-1.5	
0:38:02	1789	173	0	0	0	0	6.4	-1.6	
0:38:03	1809	174	0	0	0	1	6.7	-1.6	Trim UP Manual
0:38:04	1825	175	0	0	0	0	7.0	-1.7	
0:38:05	1842	177	0	0	0	0	7.0	-1.7	
0:38:06	1857	178	0	0	0	0	7.0	-1.7	
0:38:07	1869	179	0	0	0	0	7.0	-1.7	
0:38:08	1883	180	0	0	0	0	7.0	-1.7	
0:38:09	1893	181	0	0	0	0	7.0	-1.7	
0:38:10	1897	182	0	0	0	0	7.0	-1.7	
0:38:11	1903	185	0	0	0	0	7.0	-1.7	
0:38:12	1903	188	0	0	0	0	7.0	-1.7	
0:38:13	1906	192	0	0	0	0	7.0	-1.7	
0:38:14	1907	193	0	0	1	0	7.1	-1.7	Trim UP AP
0:38:15	1906	199	0	0	1	0	7.4	-1.7	Trim UP AP
0:38:16	1906	199	0	0	0	0	7.6	-1.7	
0:38:17	1908	200	0	0	0	0	7.6	-1.7	
0:38:18	1910	203	0	0	0	0	7.6	-1.7	
0:38:19	1914	204	0	0	0	0	7.6	-1.7	
0:38:20	1920	203	0	0	0	0	7.6	-1.7	
0:38:21	1922	205	0	0	0	0	7.6	-1.7	
0:38:22	1937	203	0	0	0	0	7.6	-1.7	
0:38:23	1950	206	0	0	0	0	7.6	-1.7	
0:38:24	1967	207	0	0	0	0	7.7	-1.7	
0:38:25	1984	208	0	0	0	0	7.7	-1.7	
0:38:26	2005	209	0	0	0	0	7.7	-1.7	
0:38:27	2032	209	0	0	0	0	7.7	-1.7	
0:38:28	2061	209	0	0	0	0	7.7	-1.7	
0:38:29	2102	211	0	0	0	0	7.7	-1.7	
0:38:30	2144	209	0	0	1	0	7.7	-1.7	Trim UP AP
0:38:31	2188	209	0	0	0	0	7.8	-1.7	
0:38:32	2240	208	0	0	0	0	7.8	-1.7	
0:38:33	2292	205	0	0	0	0	7.8	-1.7	
0:38:34	2346	204	0	0	0	0	7.8	-1.7	
0:38:35	2407	204	0	0	0	0	7.8	-1.7	
0:38:36	2465	203	0	0	0	0	7.8	-1.7	
0:38:37	2526	201	0	0	0	0	7.8	-1.7	

0:38:38	2587	199	0	0	0	0	7.8	-1.5	
0:38:39	2649	198	0	0	0	0	7.8	-1.3	
0:38:40	2705	198	0	0	0	0	7.8	-1.1	
0:38:41	2761	196	0	0	0	0	7.8	-0.9	
0:38:42	2819	197	0	0	0	0	7.9	-0.7	
0:38:43	2870	196	0	0	0	0	7.9	-0.5	
0:38:44	2919	196	0	0	0	1	8.0	-0.3	Trim UP Manual
0:38:45	2963	197	0	0	0	1	8.4	-0.1	Trim UP Manual
0:38:46	3005	196	0	0	0	1	8.7	0.0	Trim UP Manual
0:38:47	3048	197	0	0	0	0	8.8	0.0	
0:38:48	3094	197	0	0	0	0	8.8	0.0	
0:38:49	3143	198	0	0	0	0	8.8	0.0	
0:38:50	3189	198	0	0	0	0	8.8	0.0	
0:38:51	3236	199	0	0	0	0	8.8	0.0	
0:38:52	3278	198	0	0	0	0	8.8	0.0	
0:38:53	3319	198	0	0	0	0	8.8	0.0	
0:38:54	3360	200	0	0	0	0	8.8	0.0	
0:38:55	3400	200	0	0	0	0	8.8	0.0	
0:38:56	3437	199	0	0	0	0	8.8	0.0	
0:38:57	3473	201	0	0	0	0	8.8	0.0	
0:38:58	3501	202	0	0	0	0	8.8	0.0	
0:38:59	3533	201	0	0	0	0	8.8	0.0	
0:39:00	3561	203	0	0	0	0	8.8	0.0	
0:39:01	3588	205	0	0	0	0	8.8	0.0	
0:39:02	3606	205	0	0	0	0	8.7	0.0	
0:39:03	3620	207	0	0	0	0	8.7	0.0	
0:39:04	3624	209	0	0	0	0	8.8	0.0	
0:39:05	3622	212	0	0	0	0	8.8	0.0	
0:39:06	3617	215	0	0	0	0	8.7	0.0	
0:39:07	3611	218	0	0	0	0	8.7	0.0	
0:39:08	3608	219	0	0	0	0	8.7	0.0	
0:39:09	3599	217	0	0	0	0	8.7	0.0	
0:39:10	3595	221	0	0	0	0	8.8	0.0	
0:39:11	3582	225	0	0	0	0	8.8	0.0	
0:39:12	3588	228	0	0	0	0	8.7	0.0	
0:39:13	3595	227	0	0	0	0	8.7	0.0	
0:39:14	3614	230	0	0	0	0	8.7	0.0	
0:39:15	3616	233	0	0	0	0	8.7	0.0	
0:39:16	3641	232	0	0	0	0	8.7	0.0	
0:39:17	3684	231	0	0	0	0	8.7	0.0	
0:39:18	3721	231	0	0	0	0	8.7	0.0	
0:39:19	3770	229	0	0	0	0	8.7	0.0	
0:39:20	3817	229	0	0	0	0	8.7	0.0	
0:39:21	3862	229	0	0	0	0	8.7	0.0	
0:39:22	3917	227	0	0	0	0	8.7	0.0	
0:39:23	3970	228	0	0	0	0	8.8	0.0	

0:39:24	4021	226	0	0	0	0	8.8	0.0	
0:39:25	4072	224	0	0	0	0	8.8	0.0	
0:39:26	4117	225	0	0	0	0	8.8	0.0	
0:39:27	4169	223	0	0	0	0	8.8	0.0	
0:39:28	4214	225	0	0	0	0	8.7	0.0	
0:39:29	4261	223	0	0	0	0	8.8	0.0	
0:39:30	4296	224	0	0	0	0	8.8	0.0	
0:39:31	4328	228	0	0	0	0	8.7	0.0	
0:39:32	4347	229	0	0	0	0	8.7	0.0	
0:39:33	4351	231	0	0	0	0	8.7	0.0	
0:39:34	4346	233	0	0	0	0	8.7	0.0	
0:39:35	4336	238	0	0	0	0	8.7	0.0	
0:39:36	4327	238	0	0	0	0	8.7	0.0	
0:39:37	4346	236	0	0	0	0	8.7	0.0	
0:39:38	4359	238	0	0	0	0	8.7	0.0	
0:39:39	4397	239	0	0	0	0	8.7	0.0	
0:39:40	4447	240	0	0	0	0	8.7	0.0	
0:39:41	4505	242	0	0	0	0	8.7	0.0	
0:39:42	4581	243	0	0	0	0	8.7	0.0	
0:39:43	4676	243	0	0	0	0	8.7	0.0	
0:39:44	4778	240	0	0	0	0	8.7	0.0	
0:39:45	4893	234	0	0	0	0	8.7	0.0	
0:39:46	5003	227	0	0	0	0	8.8	0.0	
0:39:47	5165	227	0	0	0	0	8.7	0.0	
0:39:48	5313	226	0	0	0	0	8.8	0.0	
0:39:49	5446	213	0	0	0	0	8.8	0.0	
0:39:50	5594	214	0	0	0	0	8.8	0.0	
0:39:51	5731	198	0	0	0	0	8.7	0.0	
0:39:52	5864	194	0	0	0	0	8.8	0.0	
0:39:53	5994	193	0	0	0	0	8.8	0.0	
0:39:54	6129	192	0	0	0	0	8.7	0.0	
0:39:55	6270	187	0	0	0	0	8.7	0.0	
0:39:56	6417	179	0	0	0	0	8.7	0.0	
0:39:57	6555	177	0	0	0	0	8.8	0.0	
0:39:58	6684	167	0	0	0	0	8.8	0.0	
0:39:59	6810	163	0	0	0	0	8.8	0.0	
0:40:00	6941	159	0	0	0	0	8.7	0.0	
0:40:01	7057	154	1	0	0	0	8.7	0.0	Trim Down AP
0:40:02	7166	152	1	0	0	0	8.6	0.0	Trim Down AP
0:40:03	7267	141	1	0	0	0	8.6	0.0	Trim Down AP
0:40:04	7364	136	1	0	0	0	8.5	0.0	Trim Down AP
0:40:05	7449	129	1	0	0	0	8.4	0.0	Trim Down AP
0:40:06	7543	125	1	0	0	0	8.3	0.0	Trim Down AP
0:40:07	7612	121	1	0	0	0	8.2	0.0	Trim Down AP
0:40:08	7674	119	0	0	0	0	8.1	0.0	
0:40:09	7710	118	0	0	0	0	8.2	0.0	

0:40:10	7736	118	0	0	0	0	8.2	0.0	
0:40:11	7739	121	0	0	0	0	8.2	0.0	
0:40:12	7700	120	0	0	0	0	8.2	0.0	
0:40:13	7689	121	0	0	0	0	8.1	0.0	
0:40:14	7662	123	0	0	0	0	8.1	0.0	
0:40:15	7603	128	0	0	0	0	8.1	0.0	
0:40:16	7474	133	0	0	0	0	8.2	0.0	
0:40:17	7287	142	0	0	0	0	8.1	0.0	
0:40:18	7165	151	0	0	0	0	8.1	0.0	
0:40:19	7028	158	0	0	0	0	8.1	0.0	
0:40:20	6935	164	0	0	0	0	8.2	0.0	
0:40:21	6776	169	0	0	0	0	8.1	0.0	
0:40:22	6687	178	0	0	0	0	8.2	0.0	
0:40:23	6564	184	0	0	0	0	8.2	0.0	
0:40:24	6443	187	0	0	0	0	8.2	0.0	
0:40:25	6355	195	0	0	1	0	8.2	0.0	Trim UP AP
0:40:26	6284	203	0	0	1	0	8.2	0.0	Trim UP AP
0:40:27	6191	206	0	0	1	0	8.3	0.0	Trim UP AP
0:40:28	6135	209	0	0	1	0	8.4	0.0	Trim UP AP
0:40:29	6097	217	0	0	1	0	8.5	0.0	Trim UP AP
0:40:30	6033	218	0	0	1	0	8.6	0.0	Trim UP AP
0:40:31	5999	215	0	0	1	0	8.7	0.0	Trim UP AP
0:40:32	6007	223	0	0	1	0	8.8	0.0	Trim UP AP
0:40:33	6016	225	0	0	1	0	8.8	0.0	Trim UP AP
0:40:34	6015	227	0	0	1	0	8.9	0.0	Trim UP AP
0:40:35	6050	229	0	0	1	0	9.1	0.0	Trim UP AP
0:40:36	6075	234	0	0	1	0	9.1	0.0	Trim UP AP
0:40:37	6131	237	0	0	0	0	9.3	0.0	
0:40:38	6224	239	0	0	0	0	9.3	0.0	
0:40:39	6317	238	0	0	0	0	9.2	0.0	
0:40:40	6413	230	0	0	0	0	9.2	0.0	
0:40:41	6520	228	0	0	0	0	9.2	0.0	
0:40:42	6664	220	0	0	0	0	9.3	0.0	
0:40:43	6790	216	0	0	0	0	9.2	0.0	
0:40:44	6929	210	0	0	0	0	9.2	0.0	
0:40:45	7062	219	0	0	0	0	9.3	0.0	
0:40:46	7191	215	0	0	0	0	9.3	0.0	
0:40:47	7338	208	0	0	0	0	9.3	0.0	
0:40:48	7494	202	0	0	0	0	9.3	0.0	
0:40:49	7672	197	0	0	0	0	9.3	0.0	
0:40:50	7833	195	0	0	0	0	9.3	0.0	
0:40:51	7996	190	0	0	0	0	9.3	0.0	
0:40:52	8163	185	0	0	0	0	9.3	0.0	
0:40:53	8308	180	0	0	0	0	9.3	0.0	
0:40:54	8448	174	0	0	0	0	9.3	0.0	
0:40:55	8586	170	0	0	0	0	9.3	0.0	

0:40:56	8708	166	0	0	0	0	9.3	0.0
0:40:57	8798	170	0	0	0	0	9.2	0.0
0:40:58	8873	167	0	0	0	0	9.3	0.0
0:40:59	8913	160	0	0	0	0	9.2	0.0
0:41:00	8957	154	0	0	0	0	9.4	0.0
0:41:01	9021	153	0	0	0	0	9.2	0.0
0:41:02	9051	150	0	0	0	0	9.2	0.0
0:41:03	9041	149	0	0	0	0	9.3	0.0
0:41:04	9006	147	0	0	0	0	9.3	0.0
0:41:05	9010	153	0	0	0	0	9.2	0.0
0:41:06	9029	159	0	0	0	0	9.2	0.0
0:41:07	9022	159	0	0	0	0	9.2	0.0
0:41:08	8950	156	0	0	0	0	9.3	0.0
0:41:09	8923	153	0	0	0	0	9.3	0.0
0:41:10	8807	159	0	0	0	0	9.2	0.0
0:41:11	8742	166	0	0	0	0	9.2	0.0
0:41:12	8634	173	0	0	0	0	9.4	0.0
0:41:13	8471	183	0	0	0	0	9.3	0.0
0:41:14	8236	186	0	0	0	0	9.3	0.0
0:41:15	7961	193	0	0	0	0	9.3	0.0
0:41:16	7697	209	0	0	0	0	9.4	0.0
0:41:17	7367	228	0	0	0	0	9.3	0.0
0:41:18	6964	243	0	0	0	0	9.2	0.0
0:41:19	6483	257	0	0	0	0	9.3	0.0
0:41:20	6068	269	0	0	0	0	9.1	0.0
0:41:21	5671	282	0	0	0	0	9.2	0.0
0:41:22	5114	283	0	0	0	0	9.3	0.0
0:41:23	4762	303	0	0	0	0	9.2	0.0
0:41:24	4276	319	0	0	0	0	9.2	0.0
0:41:25	3774	340	0	0	0	0	9.3	0.0
0:41:26	3214	360	0	0	0	0	9.5	0.0
0:41:27	2671	379	0	0	0	0	9.1	0.0
0:41:28	2023	399	0	0	0	0	9.2	0.1
0:41:29	1291	408	0	0	0	0	9.6	NaN

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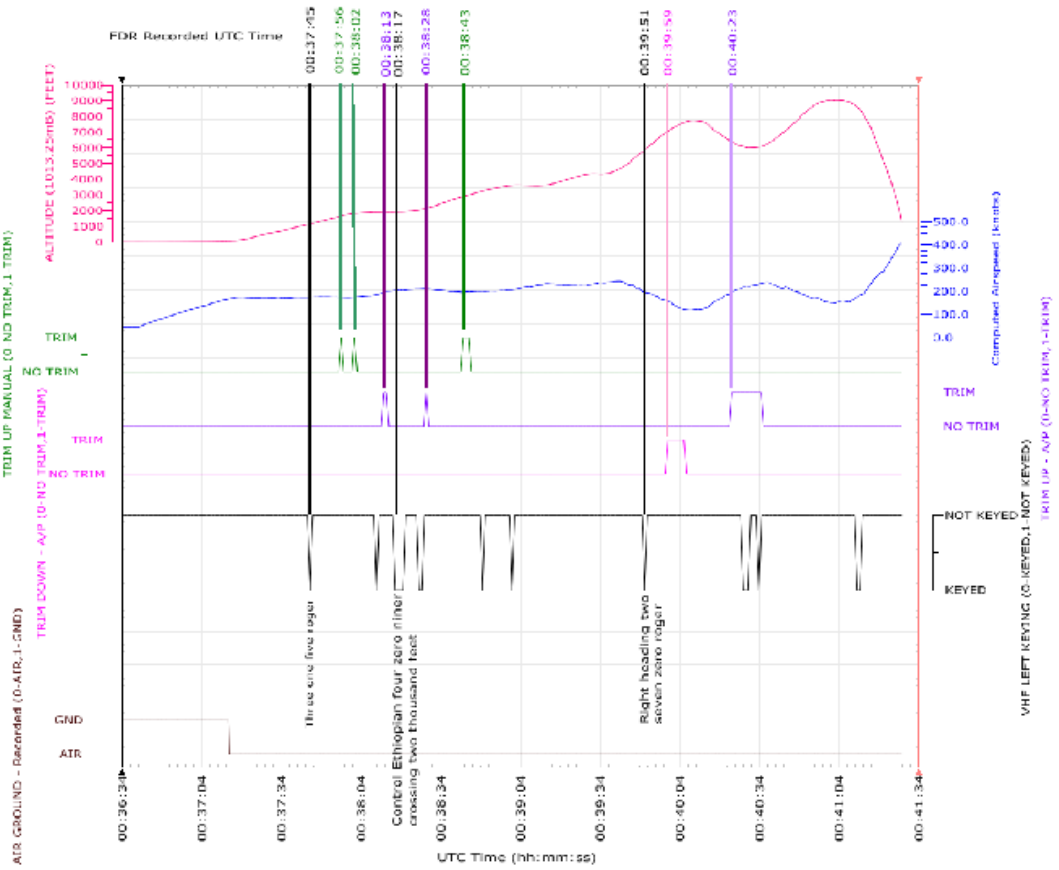
Appendix S: Trim Activation Graph



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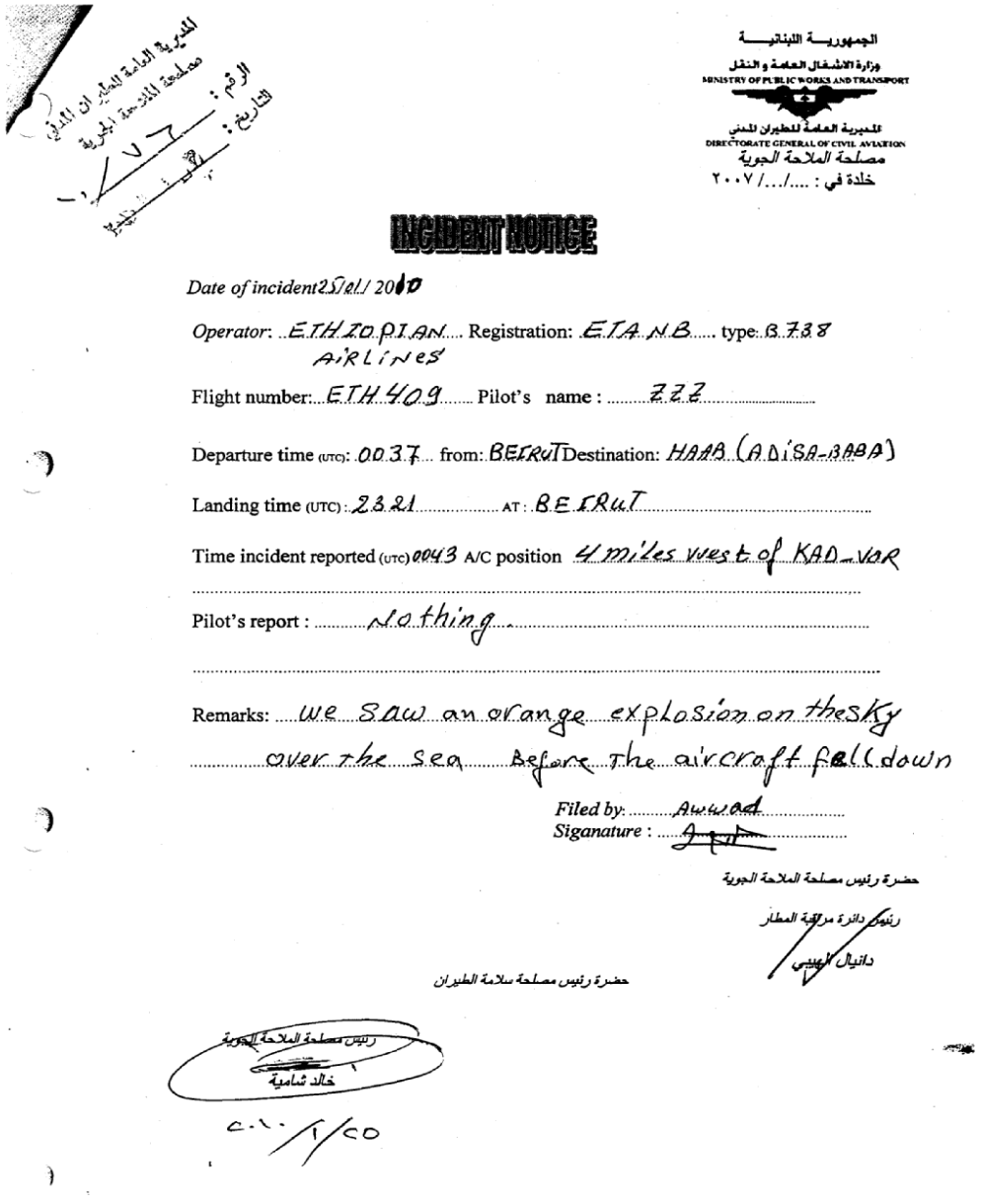
Appendix T: Testimony of ATC Personnel



المديرية العامة للطيران المدني
مصلحة الملاحة الجوية
الرقم :
التاريخ :

الجمهورية اللبنانية
وزارة الأشغال العامة و النقل
MINISTRY OF PUBLIC WORKS AND TRANSPORT
المديرية العامة للطيران المدني
DIRECTORATE GENERAL OF CIVIL AVIATION
مصلحة الملاحة الجوية
خلدة في : ..../.../٢٠٠٧

INCIDENT NOTICE

Date of incident 25/12/ 2010

Operator: ETHIOPIAN AIRLINES Registration: ETANB type: B738

Flight number: ETH409 Pilot's name : ZZZ

Departure time (UTC): 0037 from: BEIRUT Destination: HAAB (ADISA-BABA)

Landing time (UTC): 2321 AT : BEIRUT

Time incident reported (UTC) 0043 A/C position 4 miles west of KAD-VOR

Pilot's report : nothing

Remarks: we saw an orange explosion on the sky over the sea before the aircraft fell down

Filed by: Awwad
Siganature :

حضرة رئيس مصلحة الملاحة الجوية

رئيس دائرة مراقبة المطار
دانيال الهبيبي

حضرة رئيس مصلحة سلامة الطيران

رئيس مصلحة الملاحة الجوية
خالد شامية

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Appendix U: Testimonies of the crew in the vicinity of the flight
Please double click on this page to open the first report in this Appendix

1- Etihad Airways Flight EY 533

Dr. Hamdi Chaouk
Head of the Investigation Committee

Cc: CEO James Hogan
COO Richard Hill

Monday, 01 February 2010 REF: EY/HCSQ/10/ 18

Subject – Investigation of the Accident involving ET-409 on 25/01/2010

Dear Dr. Hamdi Chaouk

Referring to your request we are providing the investigation Committee with the relevant available data. Attached you find environmental information taken from our Flight Data Monitoring system. In order to facilitate the process we prepared the same material in graphical as well as in numerical format.
Below we added the initial statement received by the pilots involved:

"During the approach there was bad weather all around the airport with reported thunderstorm and lightning. We encircled the weather for the approach to Rwy 16 in OLBA. Reported surface wind was less than 10kts. As we started our final approach on the glide for Rwy 16 it seemed stable at first but 5 DME short it started to become turbulent. Tail wind started picking up. The approach became unstable and we both decided to go-around.
After the go-around we requested Rwy 03 for the approach as thunderstorms were all around. We made a successful approach and landing for Rwy 03 with crosswinds of 15kts or more.
It was the same day and time when the Ethiopian B737 crashed. In fact after the go around from the approach Rwy 16 the ATC requested if we picked up any traffic as they had lost the Ethiopian B737 from the radar screens."

Etihad Corporate Safety would like to assist and support as much as needed by your authorities. Please do not hesitate to contact our department should you require any additional information.

Best Regards,

Capt. Paolo La Cava
Head of Corporate Safety and Quality

Tel: +971 (2) 5[illegible] 2489
Fax: +971 (2) 5[illegible] 2497
Mob: +971 (0) 50 618 6047
Email: pcava@etihad.ae

2- Malev Flight MA 240

Please double click on this page to open the second report in this Appendix

Dear Mr Keszöcze,

On 24/25th January 2010 we performed flight MAH240 to Beirut Intl Airport.

As for the weather conditions and other circumstances of our flight I can tell you the following:

1) About the G forces encountered during our approach and landing please see attachment named „MAH240_25....“ issued by Malév FOQA (Flight Operation Quality Assurance). According to the table max. G force was 1.224 min. 0.739 during the approach phase (from 5500 ft to 1000 ft).During the final approach the max. G force 1.389 we encountered at the time of touch down. It also can be found in the above mentioned table.

2) As for the weather conditions I can say that it was irregularly stormy. In spite of top of the clouds being at FL200-220 we experienced light to moderate turbulence during the approach and observed embedded and isolated thunderstorm piles. Therefore we had to deviate from the original track. All data concerning our approach (track, wind velocity and direction) can be found in enclosed attachment named „Route09_MAH240_25....“ In the last phase of the flight we didn't experience any extreme phenomena like windshear, severe turbulence or severe icing. Landing was in normal conditions in light tailwind (8.5 kts) and light rain shower with appropriate visual conditions.

Yours sincerely,

Mr Alejos Ásin

Captain of flight MAH 240/24-25Jan 2010.

3- Olympic Flight OA 463

To: Dr Harndi Chaouk

Subject: Information to assist in the investigation of the accident involving ET-409 on 25.01.2010.

Dear sir,

By this letter, I wish to answer your letter concerning the accident of the aircraft of the flight ET-409 from Beirut to Addis Abeba, on the 25.01.2010, for investigation purposes.

On the 25.01.2010, around 00:30 UTC, flight OA 463, was indeed on final approach to BRHIA international airport of Beirut and we were about of ET-409.

1. During the approach and landing there was to significant G Force that our flight OA 463 encountered.
2. The weather at that time was the following: 20 miles from Beirut Airport and on a long right base for approach and landing on R/W 17, our path was clear from significant w/x, but there was thunderstorm activity N, NW of the airport in a distance of 5-15 NM from the coast.

I would also like to mention that about the time of the crash and in the area N, NW of the airport I saw a bright light of the shape of a ball which lasted for 2-3 seconds, and which I considered to be a lightning due to the thunderstorm activity at the area, so I did not pay attention to it, but I mention it as something which could help the investigation.

I hope that the above mentioned will be of help to you.

Athens, 08.02.2010

Cpt Charalambos Metallidis

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Appendix V: ET 409 Flight Documents

Please double click on this page to open the Appendix

Daniel Muluken

From: "Flt Disp3" <Dispatcher3@ethiopianairlines.com>
To: "Airport Office - BEY" <beyapt@ethiopianairlines.com>; "Airport Agents - BEY" <BEYAgt@ethiopianairlines.com>; "Daniel Muluken" <DanielMl@ethiopianairlines.com>
Cc: "Mgr Flight Dispatch" <MgrFltDisp@ethiopianairlines.com>; "Sup. Flight Dispatch" <SupFltDisp@ethiopianairlines.com>
Sent: Sunday, January 24, 2010 9:52 PM
Subject: Computer Flight Plan

E T H I O P I A N A I R L I N E S STANDARD FLIGHT PLAN
ET 409 . OLBA-HAAB 25JAN10 CI15 %K0.1 737-800W ET-ANE
COMP 1851Z/ETD 0010Z WX24/1200 SCHED 0010Z/0140/0450Z RTE NO.001

CAPT.NEGASSA H [redacted] DISP. MRNGISTALEM M.

WC M007/P006	DIST	FUEL	TIME	FL	ZFW	57250
DEST HAAB	1031	10510	04.17	350	T/O F	14600
ARR MNVR		400	00.05		T/O WT	71850
CONT 5%		530	00.15		TRIP F	10510
ALTN HDAM	303	2120	00.51	330	LND WT	61340
HOLD		1050	00.30			
OH DIFF		00			PLD 12915	OWE 044337
MIN		14600	05.58		TIME	
EXTRA		00	00.00		BLK OUT-	LDN-
T/O		14600	05.58			
TAXI		200	00.05		T/O-	BLK IN-
TANKS		14800				

PLANNED LANDING FUEL - 4390

T/O ALTN	DIST	FUEL	TIME	FL
HECA	376	2960	01.08	310

PERFORMANCE SCHEDULE CLIMB/CRUISE - CI15 DESCENT- CI15D

FUEL PRICE
BEY 2.41 USD/USG
ADD 2.31 USD/USG

EXTRA FUEL BURNED DUE TANKERING = 0 KGS
TANKER FUEL SAVINGS = 0 USD

ADDITIONAL FUEL BURN PER TONNE(1000KGS) 120KGS

----------FLIGHT PLAN CONTINGENCIES----------

FL/STEP	BURN	TIME	WCOMP	DIST	CRZ
FL 350 S	10515	04.17	M011	1831	CI15
FL 330 S	10651	04.18	M012	1831	CI15
FL 310 S	10882	04.20	M012	1831	CI15

MNPS / RVSM

RAMP COORDINATE- ..... COAST OUT COORD- .....
ALTIMETER NO.1- ..... ALTIMETER NO.1- .....

25-Jan-10

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Appendix W: Procedure for the use of Auto-Pilot

Pilot Flying	Pilot Monitoring
	Set the FLAP lever as directed. Monitor flaps and slats retraction.
After flaps and slats retraction is complete, call "VNAV."	
	Push the VNAV switch.
Engage the autopilot when above the minimum altitude for autopilot engagement.	
	After flap retraction is complete: • Set or verify engine bleeds and air conditioning packs are operating • Set the engine start switches as needed • Set the AUTO BRAKE select switch to OFF • Set the landing gear lever to OFF after landing gear retraction is complete.
Call "AFTER TAKEOFF CHECKLIST."	
	Do the AFTER TAKEOFF checklist.

CAUTION: Do not allow the shoulder harness straps to retract quickly. Buckles can pull or damage circuit breakers.

1.0 NORMAL OPERATING PROCEDURES

1.1 INTRODUCTION

The primary purpose of SOPs is to identify and describe the standard tasks and duties of the flight crew for each phase. The procedures are to be used in conjunction with Operation Manuals and the Flight Crew Training Manual.

The captain has the overall responsibility for all aspects of each flight. He will ensure adherence to the established procedures at all times.

Each crewmember must devote all possible attention to the progress of flight, aircraft systems, look out and monitoring of other crewmember's actions. All configuration changes shall be accomplished with an announcement of intention, a check on appropriate limitations and confirmation of completion.

Both crewmembers shall be aware of altitude, airplane position and situation. Avoid casual and nonessential conversation during critical phases of flight, particularly during taxi, takeoff, approach and landing. There should be no crew seat change below 5000 feet AGL. In addition, during the flight at least one pilot shall have full access to the flight control and be vigilant as to the safe operation of the aircraft. The pilot flying (PF) shall verify the condition/location from the flight instruments and acknowledge. If the pilot monitoring (PM) does not make the required call out, the PF shall make it. A crewmember must be able to supplement or act as a backup for the other crewmember. The PF shall acknowledge all EGPWS voice callout during approach except altitude call outs while below minimum.

If required all normal and non-normal checklists ought to be read repeatedly from the checklist no matter how few the items are. Under non-normal conditions, the recall items shall be done from memory and only then the checklist has to be read.

The normal company operating procedure is to fully utilize the automatic system, which must be closely monitored. However, manually following flight director commands below 10,000 ft AAL in good weather low traffic areas may also be used to maintain proficiency.

Refer FOPM 2.12.3.1 Flight Deck to Cabin briefing which must be accomplished at a convenient time before departure. Preferably before crew are disseminated to their assigned positions.

- **Preparation**

  - Act with respect to time available
  - Avoid distractions
  - Anticipate factors affecting the flight
  - Recognize factors affecting the flight

- **Processing**

  - Evaluate factors affecting the flight
  - Choose appropriate course of action
  - Monitor execution
  - Monitor development of the situation
  - Apply **FOR-DEC** for complex decisions
    F-facts, O-Options, R-Risks & benefits, D-decision, E-execution, C-check

- **Interaction**

  - Involve others in the process
  - Discuss discrepancies

2.10.15 POLICY ON THE USE OF AUTOPILOT AND ATOTHROTTLE

Crews should always use the highest available level of automation during all phases of flight. The PF must at all times, be aware of the autopilot / flight director system mode engaged/change and the PF should cross-check mode control panel status. And if the use of automation results in a conflict between flight requirements and actual flight path, the PF must announce and discontinue the use of automation immediately. The discrepancy must be resolved before re-engagement automation.

The autopilot must be engaged as early as practical, at altitudes above the minimum engage altitudes specified in the FCOM or 500 feet whichever is higher, to enable accurate tracking of the departure path.

Approaches with a disengaged automation should be carried out after due consideration is given to the level of fatigue, the likelihood of a go-around, the ATC environment and the present weather conditions. The PF must communicate his/her intent and use of automation.
The autopilot should be left engaged until approaching Minima during a NPA or turning final on a visual approach.

Standard calls are to be used for mode selections, and all resultant changes are to be confirmed by announcing FMA changes as per FCOM.

2.10.16 TASK SHARING IN THE COCKPIT

The task sharing in the cockpit requires a clearly defined assignment of tasks to PF and PM with the aim to guarantee that the full attention of PF is concentrated on the

primary task of piloting the airplane. The captain determines the assignment of PF and PM at the start of each flight.

PF Task Sharing:

- Control of airplane
- Observance of SOPs
- Compliance with flight safety releases
- Altitude and speed restrictions
- Airspace observation
- Correct use of checklists.

Whenever other activities or special events prevent the PF from focusing their full attention to piloting, they shall hand over to the PM with the call out **'you have control'**, who confirms the takeover with the reply **'I have control'.**

PM Task Sharing:

- Monitoring flight progress
- Assistance and supervision of PF
- Airspace observation
- Monitoring airplane systems
- Operating airplane systems in accordance with PF
- R/T communication and correct use of checklists.
- Keeping the necessary flight records.
- Setting, identifying and checking navigational aids according to the instructions of PF.

Task assignment to PF and PM shall be strictly observed.
Whenever a task is performed by the PF the PM must be consulted or advised as applicable. Unnecessary interventions and interruptions shall be avoided at all times.
Whenever the captain, with due consideration of all relevant circumstances, decides:

- that any phase of flight (i.e. take-off, landing) may be critical, they shall assign themselves as PF.
- that in any portion of the flight it is a safer course of action to take over control of the airplane they shall do so, even if the Co-pilot originally had been assigned as PF.

2.10.17 PROCEDURE FOR ACCEPTANCE OF ATC CLEARANCE

a. The use of standard radio phraseology when communicating with ATC is mandatory at all times, this includes, as a minimum,
   - To use call sign whenever addressing ATC and also during read back
   -Whenever ATC gives clearance it must be accepted and read-back for confirmation

Appendix X: Approach to stall Recovery Procedure

1- Procedure in force at the time of the accident

737 Flight Crew Operations Manual

Maneuvers — **Chapter MAN**

Non-Normal Maneuvers — **Section 1**

Approach to Stall Recovery

The following is immediately accomplished at the first indication of stall buffet or stick shaker.

Pilot Flying	Pilot Monitoring
• Advance thrust levers to maximum thrust*. • Smoothly adjust pitch attitude** to avoid ground contact or obstacles. • Level the wings (do not change flaps or landing gear configuration). • Retract the speedbrakes.	• Verify maximum thrust. • Monitor altitude and airspeed. • Call out any trend toward terrain contact. • Verify all required actions have been completed and call out any omissions.
When ground contact is no longer a factor: • Adjust pitch attitude to accelerate while minimizing altitude loss. • Return to speed appropriate for the configuration.	

Note: *If an approach to stall is encountered with the autopilot engaged, apply maximum thrust and allow the airplane to return to the normal airspeed.

Note: **At high altitude, it may be necessary to descend to accelerate.

Note: If autopilot response is not acceptable, it should be disengaged.

Rejected Takeoff

The captain has the sole responsibility for the decision to reject the takeoff. The decision must be made in time to start the rejected takeoff maneuver by V1. If the decision is to reject the takeoff, the captain must clearly announce "REJECT," immediately start the rejected takeoff maneuver and assume control of the airplane. If the first officer is making the takeoff, the first officer must maintain control of the airplane until the captain makes a positive input to the controls.

2- Procedure revised at later date to the accident

BOEING

737 Flight Crew Operations Manual

Approach to Stall or Stall Recovery

All recoveries from approach to stall should be done as if an actual stall has occurred.

Immediately do the following at the first indication of stall (buffet or stick shaker).

Note: Do not use flight director commands during the recovery.

Pilot Flying	Pilot Monitoring

• Initiate the recovery:
  • Hold the control column firmly.
  • Disconnect autopilot and autothrottle.
  • Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops. Nose down stabilizer trim may be needed.*
	• Monitor altitude and airspeed.
	• Verify all required actions have been done and call out any omissions.
	• Call out any trend toward terrain contact.

• Continue the recovery:
  • Roll in the shortest direction to wings level if needed.**
  • Advance thrust levers as needed.
  • Retract the speedbrakes.
  • Do not change gear or flap configuration, except
  • During liftoff, if flaps are up, call for flaps 1.
	• Monitor altitude and airspeed.
	• Verify all required actions have been done and call out any omissions.
	• Call out any trend toward terrain contact.
	• Set the FLAP lever as directed.

• Complete the recovery:
  • Check airspeed and adjust thrust as needed.
  • Establish pitch attitude.
  • Return to the desired flight path.
• Re-engage the autopilot and autothrottle if desired.
	• Monitor altitude and airspeed.
	• Verify all required actions have been done and call out any omissions.
	• Call out any trend toward terrain contact.

Appendix Y: Upset Recovery Procedure

Pilot Flying	Pilot Monitoring
If maneuvering is required, disengage the autopilot and autothrottle. Smoothly adjust pitch and thrust to satisfy the RA command. Follow the planned lateral flight path unless visual contact with the conflicting traffic requires other action.	
Attempt to establish visual contact. Call out any conflicting traffic.	

For a climb RA in landing configuration:

Pilot Flying	Pilot Monitoring
Disengage the autopilot and autothrottle. Advance thrust levers forward to ensure maximum thrust is attained and call for FLAPS 15. Smoothly adjust pitch to satisfy the RA command. Follow the planned lateral flight path unless visual contact with the conflicting traffic requires other action.	Verify maximum thrust set. Position flap lever to 15 detent.
Verify a positive rate of climb on the altimeter and call "GEAR UP."	Verify a positive rate of climb on the altimeter and call "POSITIVE RATE." Set the landing gear lever to UP.
Attempt to establish visual contact. Call out any conflicting traffic.	

Upset Recovery

An upset can generally be defined as unintentionally exceeding the following conditions:

- Pitch attitude greater than 25 degrees nose up, or
- Pitch attitude greater than 10 degrees nose down, or
- Bank angle greater than 45 degrees, or
- Within above parameters but flying at airspeeds inappropriate for the conditions.

The following techniques represent a logical progression for recovering the airplane. The sequence of actions is for guidance only and represents a series of options to be considered and used depending on the situation. Not all actions may be necessary once recovery is under way. If needed, use pitch trim sparingly. Careful use of rudder to aid roll control should be considered only if roll control is ineffective and the airplane is not stalled.

These techniques assume that the airplane is not stalled. A stalled condition can exist at any attitude and may be recognized by continuous stick shaker activation accompanied by one or more of the following:

- Buffeting which could be heavy at times
- Lack of pitch authority and/or roll control
- Inability to arrest descent rate.

If the airplane is stalled, recovery from the stall must be accomplished first by applying and maintaining nose down elevator until stall recovery is complete and stick shaker activation ceases.

Nose High Recovery

Pilot Flying	Pilot Monitoring
• Recognize and confirm the situation	
• Disconnect autopilot and autothrottle • Apply as much as full nose-down elevator • * Apply appropriate nose down stabilizer trim • Reduce thrust • * Roll (adjust bank angle) to obtain a nose down pitch rate • Complete the recovery: - When approaching the horizon, roll to wings level - Check airspeed and adjust thrust - Establish pitch attitude.	• Call out attitude, airspeed and altitude throughout the recovery • Verify all required actions have been completed and call out any omissions.

Nose Low Recovery

Pilot Flying	Pilot Monitoring
• Recognize and confirm the situation	
• Disconnect autopilot and autothrottle • Recover from stall, if required • * Roll in shortest direction to wings level (unload and roll if bank angle is more than 90 degrees) • Recover to level flight: - Apply nose up elevator - *Apply nose up trim, if required - Adjust thrust and drag as required.	• Call out attitude, airspeed and altitude throughout the recovery • Verify all required actions have been completed and call out any omissions.

WARNING: * Excessive use of pitch trim or rudder may aggravate an upset situation or may result in loss of control and/or high structural loads.

Windshear

Windshear Caution

For predictive windshear caution alert: ("MONITOR RADAR DISPLAY" aural).

Pilot Flying	Pilot Monitoring
Maneuver as required to avoid the windshear.	

Windshear Warning

Predictive windshear warning during takeoff roll: ("WINDSHEAR AHEAD, WINDSHEAR AHEAD" aural)

- prior to V1, reject takeoff
- after V1, perform the Windshear Escape Maneuver.

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Appendix Z: Comments by Ethiopia on the Final Investigation Report

Comments by the Ethiopian Civil Aviation Authority

On

The Investigation of the Accident of Ethiopian Flight 409, Boeing 737-800 ET-ANB, January 25, 2010 By The Ministry of Public Work & Transport of Republic of Lebanon

To Be Appended to the Final Report

Part II

Prepared pursuant to Annex 13 to the Convention on International Civil Aviation

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