THE FEDERAL DEMOCRATIC REPUBLIC OF ETHIOPIA
MINISTRY OF TRANSPORT AND LOGISTICS

AIRCRAFT ACCIDENT INVESTIGATION BUREAU

INVESTIGATION REPORT ON

ACCIDENT TO THE B737-MAX8 REG. ET-AVJ OPERATED BY ETHIOPIAN AIRLINES

10 MARCH, 2019

Report No. AI-01/19
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AIRCRAFT ACCIDENT INVESTIGATION BUREAU

ቀን 23-12-2022
Date
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Ref.

The Honorable Mrs. Dagmawit Moges

Minister, Ministry of Transport & Logistics

Addis Ababa

Subject: ET 302, B737-8MAX Registration ET-AVJ Accident Investigation final report

Dear Minister;

Enclosed is the Aircraft Accident Investigation Bureau (EAIB) report to the Minister on the final investigation report of the **ET 302, B737-8MAX** aircraft.

This document describes the Bureau's final investigation report regarding the ET302, B737-8MAX registration ET-AVJ accident that occurred on 10 March, 2019 and crashed shortly after takeoff from Addis Ababa Bole International Airport (HAAB), 28 NM, and South East of Addis Ababa near Ejere Town.

Kind Regards

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FOREWORD

THE AIRPLANE ACCIDENT INVESTIGATION BUREAU OF ETHIOPIA

TheEthiopian Airplane Accident Investigation Bureau (EAIB) is the investigation authority in Ethiopia responsible to the Ministry of Transport and Logistics for the investigation of civil Airplane accidents and serious incidents in Ethiopia.

The mission of the EAIB is to promote aviation safety through the conduct of independent, separate investigations without prejudice to any judicial or administrative action consistent with Annex 13 to the Convention on International Civil Aviation.

The EAIB conducts the investigations in accordance with the proclamation No 957/2016 and Annex 13 to the Convention on International Civil Aviation Organization, which governs how member States of the International Civil Aviation Organization (ICAO) conduct Airplane accident investigations internationally.

The investigation process involves the gathering, recording and analysis of all available information on the accidents and incidents; determination of the causes and/or contributing factors; identification of safety issues; issuance of safety recommendations to address these safety issues; and completion of the investigation report. In carrying out the investigations, the EAIB will adhere to ICAO's stated objective, which is as follows:

"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents; it is not the purpose of this activity to apportion blame or liability''.

I. ORGANISATION OF THE INVESTIGATION

On 10th March 2019 at around 05:47UTC, the FDRE Ministry of Transport& Logistics and EAIB were informed the loss of radio and radar contact with flight ET 302 a few minutes after take-off from Addis Ababa Bole International Airport.

After having established without doubt that the Airplane had disappeared, the Ethiopian Authorities launched a technical investigation team. In accordance with Article 26 of the Convention and ICAO Annex 13 "Airplane Accident and Incident Investigation", an Investigation Committee (IC) from Ethiopian EAIB investigators was formed by a ministerial decree issued by the Minister of Transport& Logistics in order to conduct the investigation. An investigator-in-charge (IIC) was designated in the same decree to lead and initiate the investigation immediately. As per Annex 13 provisions, in the investigation participated:

ECAA and Ethiopian Airlines Group - Technical Advisors to EAIB
NTSB - Accredited Representative State of Design and Manufacturer
BEA - Accredited representative, State which provided facilities & experts for the read out of DFDR & CVR and
EASA- Accredited representative during the preliminary report only

As per the Ethiopian Government decision and agreement between the EAIB and the French Bureau d'Enquêtes et d' Analyses pour la sécurité de l'aviation civile (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 EAIB and readings were performed by BEA personnel in association with and under the direct supervision of the IIC. At the request of Ethiopia and as per Annex 13 Article 5.23, BEA has appointed an accredited representative and assisted EAIB for the analysis of FDR data.

For this investigation, working groups were initially built up as follows:

- Operations
- Maintenance & Airworthiness
- Power plant
- DFDR and CVR

Later on the group merged into operations, systems and DFDR- CVR groups until thisinvestigationreport prepared.

A Search & Rescue (SAR) team performed search by Ethiopian Air force, Ethiopian Airlines Group and Abyssinian flight service. Search operations were conducted in full coordination with Federal, Regional police and other Government bodies.

II. ACRONYMS

AC	Advisory Circular
ACO	Airplane Certification Office
ADIRS	Air Data Inertial Reference System
ADIRU	Air Data Inertial Reference Unit
ADM	Air Data Module
AD	Airworthiness Directive
ADR	Air Data Reference/Air Data System
ADC	Air Data Computer
ADS	Air Data System
AFCS	Automatic Flight Control System
AFDS	Autopilot Flight Director System
AGB	Accessory Gear Box
AGL	Above Ground Level
AFM	Airplane Flight manual.
EAIB	Accident Investigation Bureau
Alpha vane	Angle of Attack Vane
AMM	Airplane Maintenance Manual
AML	Airplane Maintenance Log
ARM	Armed
AND	Airplane Nose Down
ANU	Airplane Nose Up
AOAS	Angle Of Attack Sensor

AOC	Air Operator Certificate
A/P	Auto Pilot
APU	Auxiliary Power Unit
ARINC	Aeronautical Radio Incorporated
A/T	Auto-Throttle
ATC	Air Traffic Control
ATPL	Airline Transport Pilot Licence
BASOO	Boeing Aviation Safety Oversight Office
BEA	Bureau d'Enquêteset d'Analyses pour la sécurité de l'aviation civile
BOV	Bias Out of View
CAS	Computed or calibrated Air Speed
CG	Center of Gravity
CGD	Crew General Description
CGO	Cargo
CLB	Climb
CMD	Command – Auto pilot may engage in command (CMD) or in Control Wheel Steering (CWS)
CPL	Commercial Pilot Licence
CPN	Certification Project Notification
CRM	Crew Resource Management
CSMU	Crash Survivable Memory Unit
CVR	Cockpit Voice Recorder
CWS	Control Wheel Steering
DFDAU	Digital Flight Data Acquisition Unit
DFDR	Digital Flight Data Recorder
DFCS	Digital Flight Control System
DME	Distance Measuring Equipment
DPC	Display Processing Computer

DSCO	Deligation Systems Certification Office
DU	Display Unit
EAIB	Ethiopian Accident Investigation Bureau
EASA	European Aviation Safety Agency
ECAA	Ethiopian Civil Aviation Authority
ECAB	Engineering Cab (Flight Simulator)
ECARAS	Ethiopian Civil Aviation Rules and Standards
ECO	Engine Certification Office
EDFCS	Enhanced Digital Flight Control System
EEC	Electronic Engine Control
EFS	Elevator Feel Shift
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
EGT	Exhaust Gas Temperature
EIS	Entry into Service
EWIS	Electrical Wiring Interconnection System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCC	Flight Control Computer
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
F/D	Flight Director
FCTR	Flight Control Test Rig
F/O	First Officer
FOM	Flight Operation Manual
FDAU	Flight Data Acquisition Unit
FDR	Flight Data Recorder

FL	Flight Level
FMA	Flight Mode Annunciator
FMC	Flight Management Computer
FTA	Fault Tree Analysis
FW	Failure Warning
GA	Go Around
GE	General Electric
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GVI	General Visual Inspection
HAAB	Addis Ababa Bole
HDG	Heading
HPC	High Pressure Compressor
HPT	High Pressure Turbine
HUD	Head Up Display
IAS	Indicated Airspeed
IC	Investigation committee
ICAO	International Civil Aviation Organization
IFSO	In-flight Security Officer
IIC	Investigator In Charge
IR	Instrument Rating
IRS	Inertial Reference System
ISFD	Integrated Standby Flight Display
ILS	Instrument Landing System
KCAS	Knots Calibrated Airspeed
Kt	Knots
LBS	Pound

LGT	Light
LGW	Landing Weight
LMC	Last Minute Change
LPC	Low Pressure Compressor
LE	Leading Edge
LH/RH	Left Hand, Right Hand
LNAV	Lateral Navigation (A/P or F/D mode)
LPT	Low pressure Turbine
MAC	Mean Aerodynamic Chord
MCAS	Maneuvering Characteristics Augmentation System
MCO	Military Certification Office
MCP	Mode Control Panel
MCP	Master Certification Plan
MEL	Minimum Equipment List
MLB	Maintenance Log Book
MMO	Mach number – Maximum Operating value
MRO	Maintenance Repair & Overhaul
MPL	Multi crew Pilot Licence
MSA	Minimum Safe Altitude
N/A	Not Applicable
NDT	Non Destructive Testing
NCD	No Computed Data
NM	Nautical Miles
NOTAM	Notice to Air Men
NTSB	National Transportation Safety Board
OMB	Operational Manual Bulletien
OM	Operation Manual

ODA	Organization Designation Authorization
PC	Personal Computer
PCU	Power Control Unit
PF	Pilot Flying
PFD	Primary Flight Display
PLI	Pitch Limit Indicator
PNL	Programme Notification Letter
QNH	Altimeter sub-scale setting to obtain elevation when on the ground
QRH	Quick Reference Handbook
RA	Radio Altitude
RH	Right Hand
RUDOL	Navigation Waypoint near Lake Turkana, on the Ethiopia/Kenya border (formerly Lake "Ruduolf")
RWY	Runway
SAE	Safran A/C Engine
SAR	Search and Rescue
SAT	Static Air Temperature
SHALA	Lake "Shala"
SMYD	Stall Management and Yaw Damper
SMS	Safety Management System
SPD	Speed
SRM	Safety Risk Management
STAB Trim	Stablizer Trim
SSEC	Static Source Error Correction
SSA	System Safety Analysis
SSM	Status Sign Matrix
STS	Speed Trim. System
SWS	Stall Warning System

TAS	True Air Speed
TAF	Terminal Aerodrome Forecast
TAT	Total Air Temperature
TC	Type Certifiate
TCDS	Type Certificate Data Sheet
TE	Trailing Edge
TEM	Threat and Error Mmanagement
THR HLD	Throttle Hold (A/T mode)
TGB	Transfer Gear Box
TO	Take Off
TOGA	Take Off / Go Around
TRA	Throttle Resolver Angle
TWY	Taxi Way
UPRT	Upset Prevention and Recovery Training
UTC	Coordinated Universal Time
VHF	Very High Frequency
VFR	Visual Flight Rule
VMO	Velocity – Maximum Operating value
VNAV	Vertical Navigation (A/P or F/D mode)
VOR	VHF Omnidirectional Range
VS	Vertical Speed
YD	Yaw Damper

III. SYNOPSIS

The Accident was notified by the operator/ATC to the Accident Investigation Bureau the same day right after the accident occurred.

TABLE1: SYNOPSIS

Airplane	Boeing 737-MAX8 registered ET-AVJ
Date and time	10 March 2019 at 05:44 UTC
Operator	Ethiopian Airlines Group
Place of the Accident	28 NM South East of Addis Ababa, Bole International Airport
Type of flight	Scheduled passengers flight ET-302 Addis Ababa (Ethiopia) – Jomo Kenyatta (Kenya)
Persons on board	Captain; First-Officer; 5 Cabin Crew; 1 In Flight Security Officer (IFSO); 149 passengers from different countries with different nationalities
Consequences and damage	157 fatalities; Airplane destroyed

IV.EXECUTIVE SUMMARY

On March 10, 2019, at 05:38 UTC, Ethiopian Airlines flight 302, Boeing 737-8(MAX), ET-AVJ, took off from Addis Ababa Bole International Airport bound to Nairobi, Kenya Jomo Kenyatta International Airport.

ET302 was being operated under the provisions of the Ethiopian Civil Aviation Regulations (ECARAS) as a scheduled international flight between Addis Ababa Bole International Airport (HAAB), Ethiopia and Jomo Kenyatta Int. (HKJK) Nairobi, Kenya. It departed Addis Ababa with 157 persons on board: 2 flight crew (a Captain and a First Officer), 5 cabin crew and one IFSO, 149 regular passengers.

At 05:36:12 the Airplane lined up on runway 07R at field elevation of 7,656 ft with flap setting of 5 degrees and a stabilizer trim setting of 5.6 units[1]. Both flight directors (F/D) were ON with LNAV and VNAV modes armed. At 05:37:17the F/O reported to Tower ready for takeoff andat 05:37:36ATC issued take off clearance to ET-302 and advised to contact radar on 119.7MHz.

The takeoff roll and lift-off was normal, including normal values of left and right angle-of-attack (AOA). During takeoff roll, the engines stabilized at about 94% N1. Shortly after liftoff, the left Angle of Attack sensor recorded value became erroneous and the left stick shaker activated and remained active until near the end of the recording. In addition, the airspeed and altitude values from the left air data system began deviating from the corresponding right side values. The left and right recorded AOA values began deviating. Left AOA decreased to 11.1° then increased to 35.7° while the right AOA indicated 14.94°. Then after, the left AOA

Stabilizer trim setting of 5.6 units[1].

valuereached 74.5° in ¾ seconds while the right AOA reached a Maximum value of 15.3°, the difference between LH and RH AOA was59°and near the end of the recording it was 49^0.
At 05:39:30, the radar controller identified ET-302 and advised to climb FL 340 and when able to turn right direct to RUDOL. At 5:39:51, the selected heading increased from 072° to 197°.

After the flaps were fully retractedthe1st automatic nose-down trim activated and engaged for 9 secondspositioning the stabilizer trim to 2.1 units. The pilot flying pulled to pitch up the Airplane with a force more than 90lbs. He then applied electric trim-up inputs. Five seconds after the end of these inputs a second automatic nose-down trim activated.

At 5:40:22, the second automatic nose-down trim activated. Following nose-down trim activationGPWS DON'T SINK sounded for 3 seconds and "PULL UP" also displayed on PFD for 3 seconds.At 05:40:43, approximately five seconds after the end of the crew manual electrical trim up inputs, a third automatic trim nose-down was recorded but with no associated movement of the stabilizer.

At 05:40:50, the captain told the F/O:"advise we would like to maintain one four thousand. We have a flight control problem". The F/O complied and the request was approved by ATC. Following the approval of the ATC, the new target altitude of 14,000ft was set on the MCP.The Captain was unable to maintain the flight path and requested to return back to the departure airport.At 05:43:21, approximately five seconds after the last mainelectric trim up input, an automatic nose-down trimactivated for about 5s. The stabilizer moved from 2.3 to 1 unit. The rate of climb decreased followed by a descentin 3s after the automatic trim activation.

One second before the end of the automatic trim activation, the average force applied by the crew decreased from 100 lbs to 78 lbs in 3.5 seconds. In these 3.5 seconds, the pitch angle dropped from 0.5° nose up to -7.8° nose down and the descent rate increased from -100 ft/min to more than -5,000 ft/min.
Following the last automatic trim activation and despite calculated column force of up to 110lbs, the pitch continued decreasing. The descent rate and the airspeed continued increasing between the triggering of the 4th automatic trim activation and the last recorded parameter value. At the end of the flight, Computed airspeed values reached 500Kt, Pitch values were greater than 40° nose down and descent rate values were greater than 33,000 ft/min. Finally, both recorders stopped recording at around 05 h 43 min 44s.

At 05:44 The Airplane impacted terrain 28 NM South East of Addis Ababa near Ejere(located 8.8770 N, 39.2516 E.) villageat a farm field and created a crater approximately 10 meters deep (last Airplane part found) with a hole of about 28 meters width and 40 meters length. Most of the wreckage was found buried in the ground; small fragments of the Airplane were found scattered around the site in an area by about 200 meters width and 300 meters long. The damages to the Airplane were consistent with a high energy impact. All157 persons on board: 2 flight crew (a Captain and a First Officer), 5 cabin crew and one IFSO, 149 regular passengers were fatally injured.

INTENTIONALLY

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1. FACTUAL INFORMATION

1.1 HISTORY OF THE FLIGHT

On March 10, 2019, at about 05:44 UTC[2], Ethiopian Airlines flight ET-302, a Boeing 737-MAX8, Ethiopian registration ET-AVJ, crashed shortly after takeoff from Addis Ababa Bole International Airport (HAAB), South East of Addis Ababa near Ejere Town. The flight was a regular scheduled international passenger flight from Addis Ababa to Jomo Kenyatta International Airport (HKJK), Nairobi, Kenya. There were 149 passengers and 8 crews on board. All were fatally injured, and the Airplane was destroyed.

The following chronological history of flight was reproduced from verified data retrieved from the Airplane DFDR, CVR, Air Traffic Control (ATC) radar recordings and transcripts. According to the CVR data and the control column forces recorded in the DFDR, the captain was the pilot flying.

Phase1:From takeoff to Autopilot engagement (from 5h 36 min 12 s until 5h 39 min 23 s)

At 5:36:12 the Airplane lined up on runway 07R at field elevation of 7,656ft with a flap setting of 5 degrees and a stabilizer trim setting of 5.6 units[3].Both flight directors (F/D) were ON with LNAV and VNAV modes armed. Auto throttle (A/T) was armed.

At 05:37:17the F/O reported to Tower ready for takeoff. ATC advised the crew to stand by. The F/O confirmed standing by.

At 05:37:36, ATC issued take off clearance to ET-302 and told the crew to contact radar on 119.7 MHz when airborne. Following the take-off clearance, the crew advanced the throttle and checked the stability of the engines parameters.

At 05:37:51, take-off roll began from runway 07R

At 5:37:53, the crew engaged the automatic takeoff and climb sequence (F/D TO mode and A/T TO sequence) by pushing the TOGA switch and the A/T moved the throttle forward.

The takeoff roll and lift-off was normal, including normal values of left and right angle-of-attack (AOA). During takeoff roll, the engines stabilized at about 94% N1. From this point for most of the flight, the N1 Reference remained about 94%.

[2]All times listed is Universal Coordinated Time (UTC), as recorded on the FDR.

[3]The value of 5.6 units was a consistent setting for the takeoff. The stabilizer positions ranges from 0 unit nose down to 17 unit nose up. A value of 4 units corresponds to a neutral position.

At 05:38:14the F/O called 80Kt.

At 05:38:32 Automatic V1 call

Once V_R was reached, at 05:38:34the F/O called "rotate" and the Airplane liftoff

At 05:38:43 "positive rate" confirmed, at about 50ft radio altitude, the flight director roll mode changed to LNAV.

At 05:38:44, shortly after liftoff, the left and right recorded AOA values began deviating. Left AOA decreased to 11.1° then increased to 35.7° while value of right AOA indicated 14.94° **(point "A" in Figure 1).** Then after, the left AOA value reached 74.5° in ¾ seconds while the right AOA reached a Maximum value of 15.3°, the difference between the left and the right AOA values decreased from 59° to approximately 49° near the end of the recording, prior to the final dynamic behavior that was exhibited.

- As a result of the erroneous left AOA value, the left stick shaker activated and the red and black stripe band exceeded the displayed LH airspeed. The left stick shaker remained active until near the end of the recording.
- Right and left altitude and airspeed indications started diverging (the computations of LH values were affected by erroneous LH AOA values). From that time:
- LH displayed altitude values became lower than the actual pressure altitude values displayed on the RH side.
- LH displayed airspeed values became lower than the actual airspeed values displayed on the RH side.
- The left pitch bar and the left Pitch Limit Indicator (PLI) rapidly moved downward (left pitch bar to -10°, the PLI to around 0°)[4].
- The captain reduced the Pitch from 15° to around 7-8°.

At 5:38:48, the "MASTER CAUTION" and "ANTI-ICE" lights on the glare shield Illuminated. The F/O called out "Master caution/anti ice". It was acknowledged by the Captain.

[4]A note in the QRH -Non Normal Manoeuvres "Approach to Stall or Stall Recovery" requests not to use the flight director commands during the stall recovery.

At 05:38:51:

- The Pitch F/D bars disappeared ("Bias Out of View" – BOV) on both RH and LH Primary Flight Displays (PFD), as the threshold for the comparator between LH and RH F/D pitch display below 400ft RA was reached.
- On the LH PFD, invalid operational speeds, corrupted by the erroneous left AOA value, were displayed (LH stick shaker speed and LH minimum operation speed being greater than the LH computed airspeed).The current LH airspeed was inside the barber pole of the speed tape (black and red stripes underlying a dangerously too low speed or dangerously too high speed).

At 05:38:56, the captain stated "command" to engage the autopilot (A/P). A/P disconnect warning sounded for 2 seconds.

At 5:38:59, as the Airplane crossed 400ft Radio Altitude, VNAV mode engaged. From that time, the F/D TO mode and associated pitch comparatorwas no longer active and the F/D pitch bars reappeared.

- VNAV pushbutton light illuminated.
- LNAV pushbutton light illuminated again.

At 05:39:01, the captain called out "Command" again.A/P disconnection warning sounded for 2 seconds. The captain asked "what's going on?"

At 05:39:06, the captain requested the F/O to contact ATC radar **(point B).** The F/O contacted the radar controller, calling out on"SHALA 2A departure, crossing 8,400ftclimbing 320". At the time the RH baro-corrected altitude recorded values reached 8,400ft, the LH baro-corrected altitude values were about 400ft lower. During that communication, at 5:39:14 HDG select mode was manually engaged. The heading displayed on the MCP was 72^0 which is consistent with runway heading for RWY 07R.

During the first phase of flight, the Airplane was kept in trim through the use of the crew-initiated main electric trim commands, there was limited force required on the control column.

BeforeCMD A engaged, the stabilizertrim position was around 5.6 units, with elevator positions around 4° (consistent with the elevator neutral position for the stabilized flight condition).

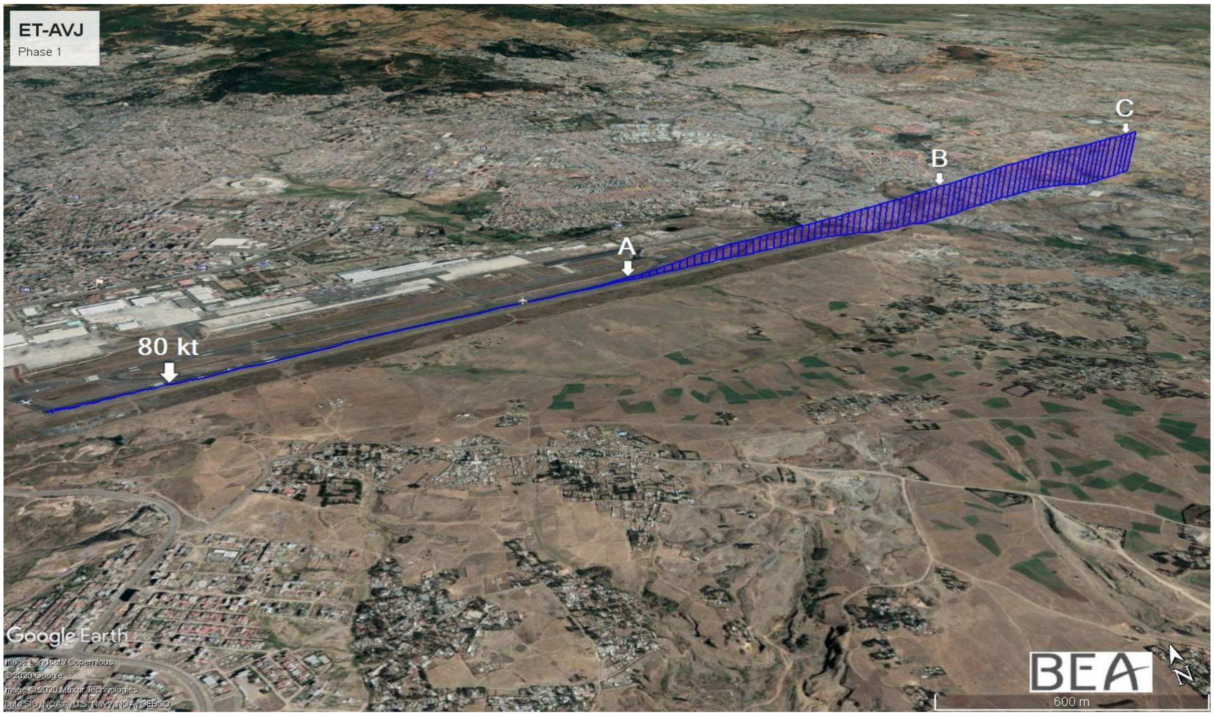


FIGURE 1: PHASE1 FROM TAKEOFF TO AUTOPILOT ENGAGEMENT

Phase 2: Under Autopilot engagement (from 5h 39 min 23 s until 5h 39 min 56s)

At 05:39:23, at about 1,000 feet Radio Altitude, the crew attempted a third auto-pilot engagement **(point C).** CMD A (LH autopilot) engaged in HDG/VNAV modes. The pitch trim position started to decrease to 4.6 units. Six seconds after the autopilot engagement, there were small amplitude roll oscillations (± 5° of bank) accompanied by lateral acceleration, rudder oscillations and slight heading changes. This was most likely the result of reduced yaw damper gains due to erroneous LH AOA values.These oscillations also continued after the autopilot was disengaged.

While the autopilot was engaged, systems continued to be suppliedby the erroneous LH AOA values. As a result, the LH SMYDC[5] computed erroneous LH minimum operational speed values which were higher than the current LH computed airspeed and the FMC selected airspeed. As the LH minimum operational speed was greater than the FMC selected speed at that time, speed reversion occurred (selection of the erroneous

[5]Stall Management and Yaw Damper Computer

minimum operational speed as target speed) and autopilot commanded a pitch down to accelerate towards the erroneous minimum operating speed.

At 05:39:30, the radar controller identified ET-302 and cleared the flight to climb FL 340 and when able to turn right direct to RUDOL.

At 05:39:37, the F/O read back the clearance to ATC.

At 5:39:38: 800ft above field elevation was reached (with the reference of the LH baro-corrected altitude reference). As per automatic takeoff and climb sequence design, the A/T switched to the ARM mode.

At 05:39:42, the crew engaged Level Change mode and set MCP speed to 238Kt.

At 05:39:45, flaps retraction was commanded by the captain and the F/O complied.

At 5:39:51, selected heading increased from 072° to 197°.

At the same time, the captain told the F/O"advice we are unable, request to maintain runway heading". The F/O didn't acknowledge nor complied with the captain's request.

At 05:39:56, the A/P disconnected automatically (**point D**) after remaining engaged for 32 seconds as the following logic conditions were reached:

- Climb command with climb rate too low for five seconds

At the beginning of this phase, the Airplane was climbing with an increasing vertical speed and a trend to pitch up. Oncethe autopilot engaged it tried to increase the airspeed, because of the minimum speed reversion (erroneous LH minimum operational speed based on erroneous LH AOA value).

The A/P initially trimmed nose down 0.5 units. This nose-down trimstopped the increase in pitch at8.4°.Then the pitch started to decrease. It also stopped increasing in vertical speed at 1,500 ft/min, which then also started to decrease.

The engagement of the LVL CHG mode and the new associated target speed most probably led to several transient AP mode computations leading to the decrease in vertical speed to stop at around 450 ft/min and the pitch values to stabilize at around 4°. After that, the erroneous excessive minimum speed related to the erroneous AOAtriggered again an AP pitch down command to increase the speed. After reaching a Maximum altitude of around 9,100 ft (RHbaro corrected altitude) during this phase, the Airplane started descending, triggering the autopilot to disconnect.

At the end of this phase, the pitch angle was around 1°, the stabilizer was at 4.6 units and the vertical speed was around -1,400 ft/min Flaps were still moving up.

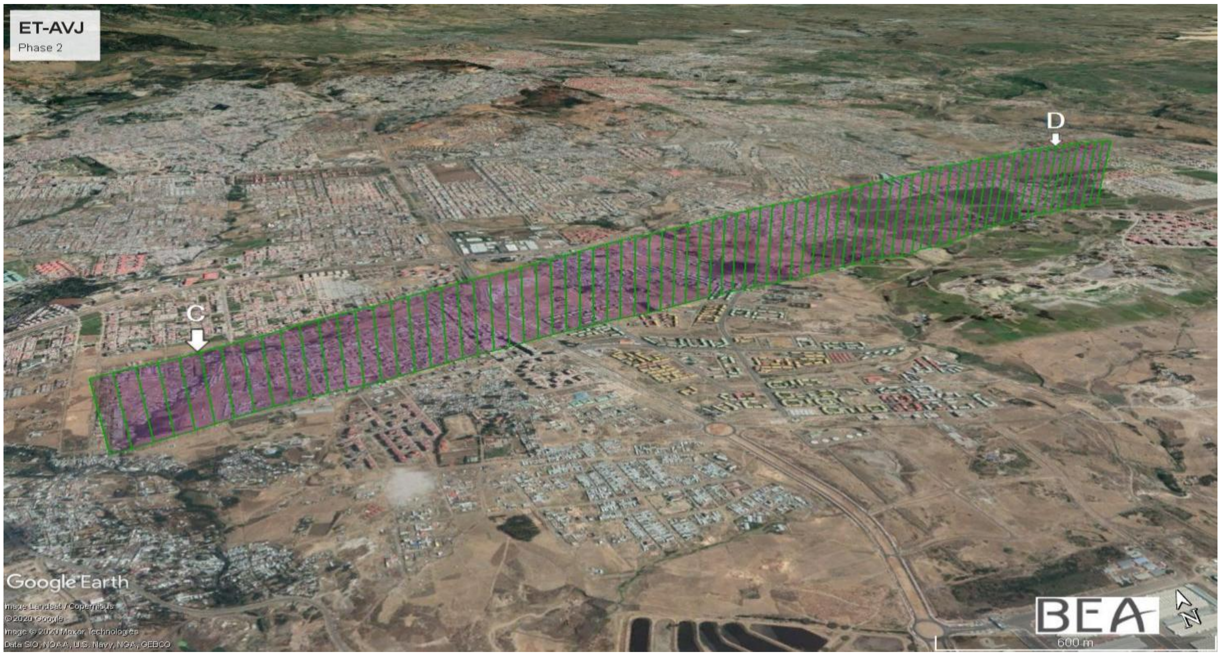


FIGURE 2: PHASE 2 DURING AUTOPILOT CONTROL

Phase 3: From A/P disconnect to stabilizer trim cutout (from 5h 39 min 56s until 5h 40 min 38s)

At the time A/P disconnected, LH pitch F/D bar disappeared due to the same logic conditions that caused the APdisconnection. The LH pitch F/D bar appeared and disappeared several times as the climb rate varied above and below the minimum threshold.The PF applied an increasing force towards pitch up.

Between5:39:59 and 5:40:02 the captain said:"Request to maintain runway heading; "We are having flight control problems".

During this transmission:

At 5:40:00: As the flaps reached the up position with the autopilot OFF and because of the erroneous left AOA value, the FCC activated the 1st automatic nose down trim (MCAS) during 9 seconds. Two seconds after the MCAS activation, the Captain told the F/O: "We are having flight control problems" **(point E).**

Almost at the same time:

- On the LH PFD, a red and black stripes band was displayed all along the speed tape. It stayed displayed until the end of the recording. The LH computed airspeed was 246Kt while the RH computed airspeed was 267Kt.
- GPWS DON'T SINK warning sounded for 3 seconds.
- PULL UP message appeared on both PFD for 14 seconds.

At 5:40:04, the F/O reportedto ATC that they were unable to maintain SHALA 1A

At 5:40:09, the MCAS stopped.At the end of the MCAS activation, the stabilizer position was 2.1 units with the PF pulling to pitch up the Airplane, with a force of around 90lbs.

At 5:40:11, the captain again told the F/O "request runway heading"... The F/O complied. This request was approved by ATC.

At 5:40:14, the Captain trimmed nose up for about 2 seconds with the main electric trim switches located on the control wheel. The stabilizer reached 2.3 units.

At 5:40:17, the captain said "OK, Flaps up speed".

At 5:40:22, Five seconds after the end of the Captain's trim inputs a secondautomatic nose-downtrim (MCAS) occurred **(point F).** Duringthe nose-down trim activation, GPWS DON'T SINK sounded and PULL UP was displayed on the PFDs. The Captain said "cut it".Manual electric trim up inputs started at 5h 40min 28s for 9s, which stopped the second automatic nose-downtrim activation two seconds before its expected end (automatic nose-down trim activated for around 7 s instead of 9 s). The trim up inputs from the Captain stopped at 5 h 40 min 37safter the GPWS alerts disappeared.

The F/Othen twice suggested "stab trim cut out?" The Captain replied "yes yes do it". The stab trim cut-out switches were most likely put in the cut-out positionat about 5 h 40 min 38 s**(point G Figure 3).** At this time:

- the stabilizer position was at 2.3 units,
- The Airplane was 1,500 ft above the airfield elevation (computed from the RH pressure altitude) but, the LH pressure altitude was 1,000ft lower.
- The actual computed airspeed was 332Kt (value displayed on RHPFD) while the erroneous value displayed on the LH PFD was 308Kt.
- Pitch attitude was around 2.5° with a vertical speed of 350 ft/min.
- Roll oscillations continued and the heading slightly increased. At the end of the phase, the Airplane heading was around 80°.

During this phase:

At the beginning, FMC detected a significant difference between the RH and LH True Airspeed (erroneous LH ADIRUcomputed values due to erroneous LH AOA value). From this time, FMC did not send any valid commandto A/T. The A/T stayed in the Arm Mode. The loss of valid FMC command did not triggeran explicit alert but did result in the FMA continuing to display "ARM" instead of changing to "N1" as would normally be expected.

As a result of the erroneous LH AOA value and the increasing airspeed, SMYDC 1 computed LH minimum operational speed and LH stick shaker speed greater thanVMO (340Kt) without any alert or invalidity detection.

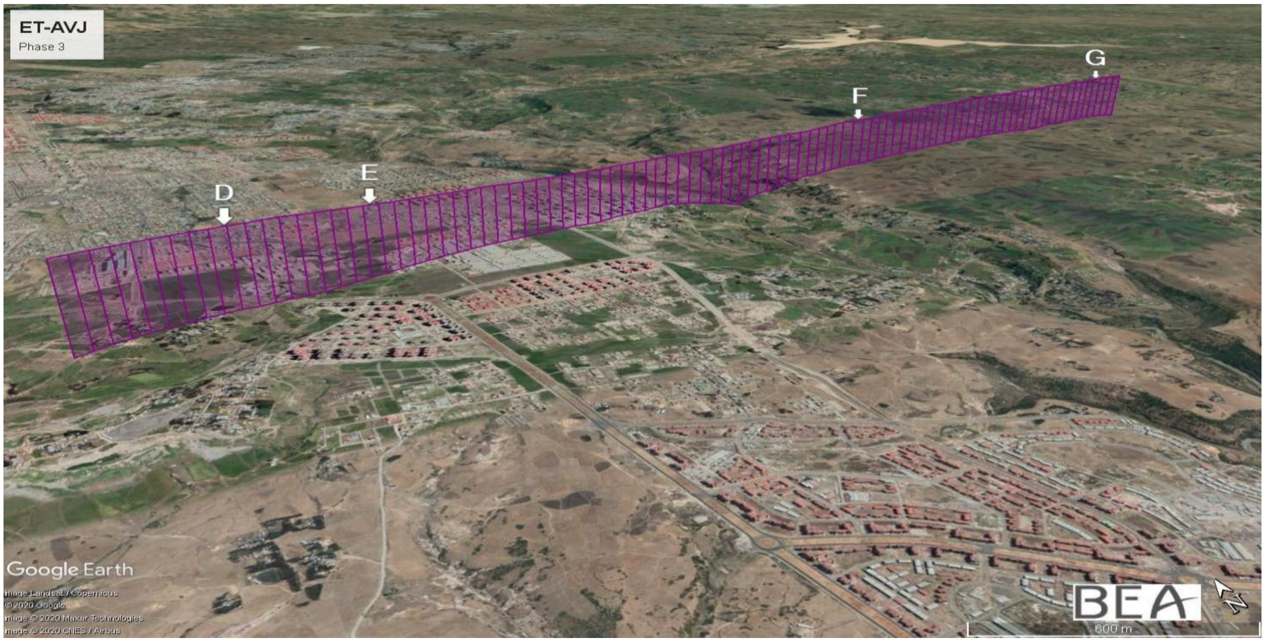


FIGURE3: PHASE 3 FROM A/P DISCONNECT TO STABILIZER TRIM CUTOUT

Phase 4: flight while the stab trim cutout switches were in the cutout position (from 5h 40 min 38 s until 5h 43 min 11 s)

At 05:40:43: approximately five seconds after the end of crew manual electrical trim up inputs, a third automatic nose-down trim (MCAS) triggered. There was no corresponding motion of the stabilizer, which is consistent with the stabilizer trim cutout switches beingin the ‘’cutout’’ position

At the beginning of this phase, the captain succeeded in pitching up the Airplane, the vertical speed value was 1,800 ft/min, increasing.

At 5:40:45, the captain repeatedly requested the F/O to pull up with him. Both pilots applied force on the control column.

From that time until the end of this phase, pitch values oscillated between 7° nose up and -2° nose down. Pitch increased when both pilots applied forces, pitch decreased when a single pilot applied force (force oscillated between 80 lbs and 110lbs). The vertical speed variations followed the variations of the pitch angle, with vertical speeds oscillating between -2,500 ft/min and + 4,400 ft/min.

At 05:40:50, crossing 9,500 ft (RH Baro corrected altitude – erroneous, LH baro corrected altitude: 8,500 ft), the captain told the F/O:"advise we would like to maintain one four thousand[6]. We have flight control problem". The F/O complied.

The request was approved by ATC. The ATC asked about intentions. The F/O answered he would call back. Following the approval of ATC, the new target altitude was set on the MCP.

At 5:41:21 the RH speed exceeded 340Kt and the overspeed warning sounded**(point H).**The captain said "the speed", the F/O replied: "Captain! Speed" The overspeedwarning remained active until the end of the recording as RH airspeed remained above VMO. The RH speed values stabilized between 360Kt and 375Kt and on the LH PFD, the LH computed airspeed oscillated between 335 and 350Kt. At this time, the altitude of the Airplane was oscillating around 10,800ft.

At 05:41:23, the selected altitude reached 14,000 ft. The captain called out "speed", which was acknowledged by the F/O.

From 05:41:31 until 05:41:40, the captain asked the F/O to pitch up with him.

At 05:41:47, the Captain asked the F/O if the trim was functional. The First-Officer replied that the trim was not working and asked if he could try it manually. The Captain told him to try **(Point I Figure 4).**

At 5:41:56 the F/O stated "It is not working"[7]. The captain replied "OK keep with me" and repeated on several occasions "keep with me" with sounds of strains in his voice. He added that they should go up to 14,000 ft.

At 5:42:12, the Captain requested a vector to return to the airport **(point J).**

At 5:42:15, the F/O requested "Radar Ethiopian three zero two request vector to return to home » Following ATC instruction to turn to 260°, a new target heading of 262 ° was set.The Airplane heading at that time was 102^0.

At 5:42:47, the captainsaid« Ok, what was it? Master Caution? The F/O says« Master caution? » The captain asked the F/O to verify. The FDR data at this time is consistent with the crew pressing the MASTER CAUTION recall button to review the existing faults.The F/O answered "Master Caution Anti Ice". The Captain said"Left Alpha Vane". The F/Oacknowledged"Left Alpha Vane".

[6]14,000 ft is the Minimum Safe Altitude in that sector
[7]At this time, the trim value is -2.7 units and the CAS is 340kt.

At 5:43:04, the Captain asked "Should we pitch together? Pitch is not enough" with a straining voice he then said "Put them up"[8].

During this phase, the crew was applying an average force of 94 lbs on the control column.

At the end of the phase:

- The Airplane was at an altitude of 6,200 ft above the airfield elevation (computed from the RH pressure altitude). LH altitude values were 1,250 ft lower.
- Computed airspeed was around 367Kt (RH value), LH erroneous value was 344 Kt.
- The pitch angle of the Airplane was lower than 1°
- The vertical speed was around + 125 ft/min and decreasing
- The bank angle was around 21° right, with a slight trend to increase.

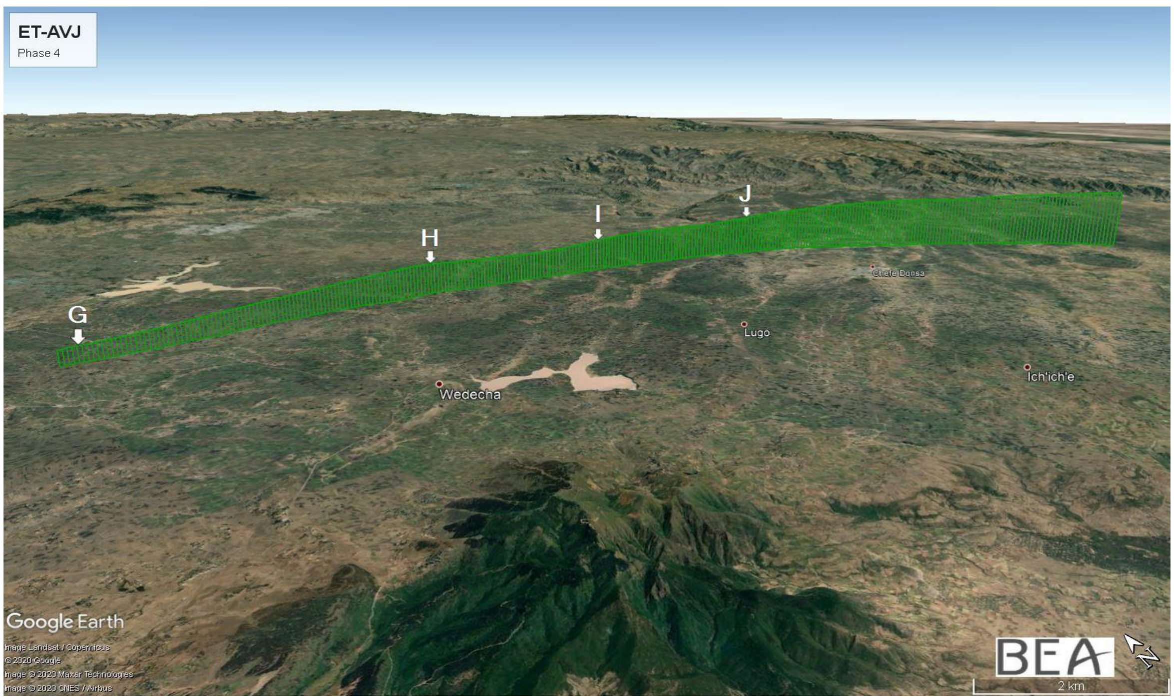


FIGURE 4: PHASE 4 FLIGHT WHILE THE STAB TRIM CUTOUT SWITCHES WERE IN THE CUTOUT POSITION

[8]A click similar to the Stabilizer trim cut-out switches being put back on was heard on the CVR.

Phase 5: Stab trim cut out switches back in normal position (point K) until the end of the flight (from 5h 43 min 11 s until 5h 43 min 44 s)

At 5:43:11, the crew tried to engage the A/P and A/P warning sounded for 3 s.

At the time of the A/P engagement attempt, 2 short-time manual electrical trim up inputs were recorded, which confirms that the stabilizer cutout switches had been restored to the normal position[9]; at this time, the stabilizer position was 2.3 units.

At 05:43:21, approximately five seconds after the last main electric trim up input, an automatic nose-down trim (4th MCAS) triggered for about 5s **(point L).** The stabilizer moved from 2.3 to 1 unit. 3 seconds after the automatic nose-down trim activation, the vertical speed decreased and became negative.One second before the end of the automatic trim nose-down activation, the average force applied by the crew decreased from 100 lbs to 78 lbs in 3.5 seconds.

In these3.5 seconds, the pitch angle dropped from 0.5° nose up to -7.8° nose down and the descent rateincreased from -100 ft/min to more than -5,000 ft/min. Following the last automatic nose-downtrim activation and despite calculated force of up to 180lbs, thepitch continued decreasing. The descent rate and the airspeed continued increasing.

At 05:43:36the EGPWS sounded: “Terrain, Terrain, Pull Up, Pull up”

The recordings stopped 23 seconds after the activation of the 4th automatic nose down trim.

At the end of the recording:

- Computed airspeed values reached 500Kt
- Pitch values were greater than 40° nose down
- Vertical speed values were greater than 33,000 ft/min.

Both recorders stopped recording at around 05 h 43 min 44 s.

[9]The FDR discrete parameter of the manual electric trim command records command (up or down) only when both stab trim cutout switches are in the normal position

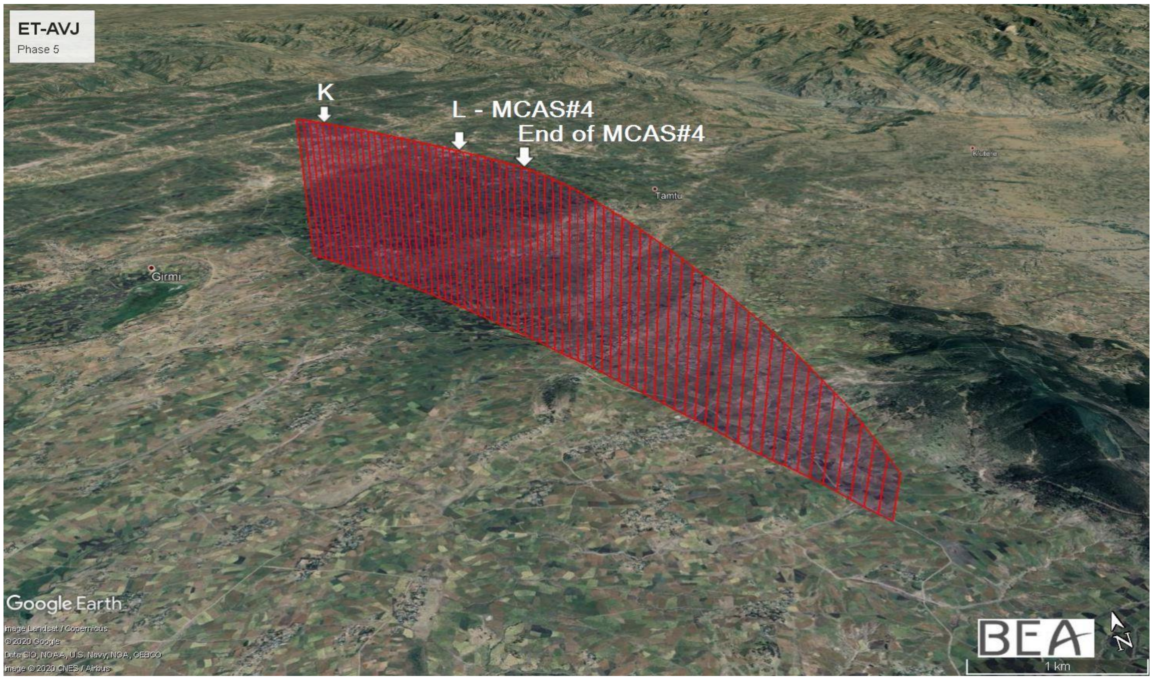


FIGURE 5: PHASE 5 STAB TRIM CUT OUT SWITCHES BACK IN NORMAL POSITION

1.2 INJURIES TO PERSONS

TABLE: 2 INJURIES TO PERSON

Injuries	Flight Crew	Passengers	Total in Airplane	Others
Fatal	8	149	157	-
Serious	-	-	-	-
Minor	-	-	-	-
None	-	-	-	-
TOTAL	8	149	157	-

1.3 DAMAGE TO AIRPLANE

The Airplane was destroyed.

1.4 OTHER DAMAGE

The farm land was excavated with a deep and wide hole not to be used for further farming.

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). All crew were certified in accordance with the ECAA requirements.

1.5.1.1 Pilot in Command

The pilot in command was 29 years old. According to Ethiopian Civil Aviation Authority (ECAA) records, the Captain's most recent simulator proficiency check was October1, 2018. The captain graduated from Ethiopian Aviation Academy on July 23, 2010. A review of the captains training records indicated that he received his 737-800 First Officer type rating on January 31, 2011 and completed his PIC type rating for the 737-800 October 26, 2017, B737MAX differences training on 03 July, 2018.

According to Ethiopian Airlines records, the captain has the following flying experiences:

PIC has flown as first officer on different airplanes, like B737 from 22 April, 2011 to 06 February 2013 for 2600hrs, 767 from February 2013, to October, 2014 and B777 and 787 for 2145hrs for consecutive periods. From 26 October, 2017 until the end of the event he was a captain on B737 and flew for 1,417 hrs as PIC on type.

TABLE 3: PILOT IN COMMAD INFORMATION

PILOT IN COMMAND	Male,aged 29
Licenses	CPL issued on 23-07-2010
	ATPL issued on 27-07-2017
Simulator Based training B737-7/800	Renewed on 01-10-18 valid until 30-03-19
Annual Medical Check	Renewed on 12-12-18 valid until 11-12-19
Rest before Last flight	72 hrs
AVIATION CARRIER DETAILS	
Student Pilot, EAL Aviation Academy	From August 2008 To July2010
B737-700/800 (First Officer)	Qualified on 31-01-11
B767/757 (First Officer)	Qualified on 09-05-13
B777 (First Officer)	Qualified on 04-02-15

B787(First Officer)	Qualified on 17-08-15
B737- 700/800 (Captain)	Qualified on 26-10-17
B737- MAX (Captain)	Qualified on 03-07-18
FLYING EXPERIENCE	
Total Flying Hours	8122:00 hrs
B737-700/800	4017:00 hrs
B737-700/800/as PIC	1417:00 hrs
B737-8 MAX	103:00
Flying time within last ninety days	266:09
Flying time within last thirty days	62:00
Flying time within last seven days	17:43
Flying time on the day of Occurrence	06minutes

TRAINING RECORD SUMMARY

Pilot flying: checkout and simulator training

TABLE 4: PFTRAINING RECORD SUMMARY

Date	Type of TRG check	A/C type	Training Device	Comment	Result
10-04-18	Proficiency Check	Boeing 737 NG	Simulator	Completed satisfactorily	Good
02-04-18	Proficiency check	Boeing 737 NG	Simulator	Proficiently executed	V. good
30-09-18	Proficiency check	Boeing 737 MAX	Simulator	Satisfactory	
01-10-18	Proficiency check	Boeing 737 MAX	Simulator	Satisfactorily completed	V. good
03-07-18	Differences Training NG/MAX	Boeing 737 NG/MAX	CBT	standard	
30-11-18	Line check	Boeing 737 NG	Airplane	Verygood performance	Satisfactory
13-07-18	Low Visibility	Boeing737 MAX	Simulator	Very professional	V. good

The Captain'smost recent simulator proficiency check was conducted on October 1, 2018. Line check was performed on 30 Nov 2018. His flying time within the last ninety days before the accident was 266.09 hrs; Last thirty and seven days 62.00hrs and 17.43hrs respectively.

The pilot had a first-class medical certificate with no limitations dated December 12, 2018. A review of the medical exam that resulted in the issuance of this certificate showed no vision or hearing deficiencies, and on the certificate application, the pilot stated he was taking no prescription or non-prescription medications.

1.5.1.2 First-Officer

According to Ethiopian Airlines records, the First-Officer has the following flight experience:

TABLE 5: FIRST OFFICER INFORMATION

FIRST OFFICER	Male, Aged 25
License	CPL issued on 12-12-18
Simulator Based training B737-700/800	Renewed on 03-12-18 valid until 02-12-19
Annual Medical Check	Renewed on 30-08-18 Valid until 29-08-19
Rest Before Last Flight	65 hrs
AVIATION CARRIER DETAILS	
Student Pilot,EAL Aviation Academy	From March 2017 to August 2018
B737-700/800 (First Officer)	Qualified on 12-12-18
B737-8 MAX(First Officer)	Qualified on 12-12-18
FLYING EXPERIENCE	
Total Flying Hours	361:00hrs
B737-700/800/MAX	207:26 hrs
Flying hour last ninety days	207:26hrs
Flying hour last thirty days	71hrs
Flying hour last seven days	10:57hrs
Flying hour on the day of occurrence	06 minutes

According to ECAA records, the first-officer's most recent simulator event was listed as a proficiency check and occurred on December 3, 2018. His line training/check (conducted in the B737 Airplane) was completed on January 31, 2019.

The first-officer's ECAA license was permitted to act as first-officer in commercial air transport operations in Boeing 737-700/800 dated December 12, 2018 and Boeing 737 MAX dated December 12, 2018 and qualified to act in the capacity of first officer effective February 01, 2019.

The first-officer had a first-class medical certificate with no limitations dated July 30, 2018. A review of the medical exam that resulted in the issuance of this certificate showed no vision or hearing deficiencies, and on the certificate application, the pilot stated he was taking no prescription or non-prescription medications. He reported no medical conditions.

1.5.1.3 Flight Attendants

According to records provided by ET, the cabin crew consisted of 5 female flight attendants. They were fully licensed in accordance with the provisions of the ECAA.

1.5.1.4 IFSO

The IFSO was seated in the front passenger's 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 (CGD) 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 Ethiopian Airplane in the capacity of IFSO sitting with the regular passengers.

1.6 AIRPLANE INFORMATION

1.6.1 General

The B737-8 (MAX) is a low wing, narrow body single aisle, jet transport with a conventional tail unit configuration, powered by two bypass turbofan CFM Leap-1B engines mounted on pylons beneath the wings. The Airplane is manufactured by Boeing Commercial Airplane and is the fourth generation of the 737 series. According to the Boeing Company's website, the Airplane was designed to carry 162-178 passengers, depending on seating configuration. The 737-8 MAX took its maiden flight on January 29, 2016, and was type certificated with the FAA on March 8, 2017.

ET-AVJ was a B737-8 MAX single aisle transport Airplane configured in a 160 passenger multi-class arrangement manufactured by the Boeing Company and delivered to Ethiopian Airlines on 15 November, 2018. The Airplane was powered by two LEAP-1B Turbo Fan Engines manufactured by CFM International. The Airplane had 1,330.3 hours with a total of 382 cycles at the time of the accident.

TABLE 6: AIRPLANE INFORMATION

Airplane Type:	**Fixed Wing Multi-Engine**
Model:	737-8 (MAX)
Registration Number	ET-AVJ
Airplane Serial Number	62450
Airplane Manufacturer	Boeing Commercial Airplane
Airplane Category:	Transport
Seating arrangement:	Multi-Class
PAX Seating Capacity:	160
MAX. T/O Weight:	82,190 kg
Total Time:	1330.3 hours
Total Cycles:	382
Engine Type:	Turbo Fan
Number of Engines:	2
Engine Manufacturer:	CFM International
Engine Model:	LEAP-1B28B1G05
Manufactured Year:	2018
Airplane Owner	Ethiopian Leasing (5-737) LTD
Address:	C/O WALKERS CORPORATE LIMITED, CAYMAN CORPORATE CENTER, 27 HOSPITAL ROAD, GEORGE TOWN, GRAND CAYMAN KY1-9008, CAYMAN ISLANDS
Airplane Operator	Ethiopian Airlines Group
Address:	Bole International Airport P.O. Box 1755 Addis Ababa, Ethiopia Operator Certificate Number: CATO-01/270295

1.6.2 Airplane Flight and Maintenance Log

The Maintenance Log Book (MLB) was reviewed in detail for the last 39 flights from 26 February 2019 until 09 March 2019 (previous flight to the accident flight). In addition, the records were reviewed for the 1A check conducted in early February.

Over the previous 39 flights, the MLB cited in particular: Captain's flight compartment PC power outlet has no power; the crew oxygen cylinder was replaced due to low pressure; and the APU would not start. All three issues led to maintenance actions and did not reoccur.

In addition, the MLB was reviewed at a higher level for all flights back to the delivery flight in November 2018. Maintenance actions of relevance occurred in early December 2018 and involved several write-ups involving temporary fluctuations of vertical speed and altitude as well as a report of the Airplane rolling during autopilot operation and altitude and vertical speed indication on the PFD showed an erratic and exaggerated fluctuation indication. Maintenance actions were performed and none were reported to have recurred. However, the erratic and intermittent nature of the fluctuations made it difficult to insure a permanent solution of these parameters.

The ET302 airplane experienced flight control system and miscellaneous electrical faults prior to the accident flight.

a. Flight control problems started occurring on the ET302 airplane on Dec 3, 2018, eighteen days after delivery. Pilot write ups included temporary fluctuations of vertical speed and altitude as well as a report of the aircraft rolling during autopilot operation and altitude and vertical speed indication on the PFD showed an erratic and exaggerated indication;
b. Three days before the accident the Auxiliary Power Unit (APU) Fault Light illuminated, and the APU had a protective shutdown;
c. The onboard maintenance function computer message also indicated the Start Converter Unit (SCU) showed the APU's start system was inoperative;
d. The Captain's personal computer power outlet had no power;
e. None of these pre-accident problems can be explained by a bird strike.

According to the Ethiopian Civil Aviation Authority (Document number ECAA/AWS/OF/025, Ethiopian Airlines (the 'operator') is authorized to conduct maintenance on various Airplane'spercertificate number 002/88. The Op. Spec issued to the operator states that operations shall be conducted in accordance with the Ethiopian Civil Aviation Authority Rules and Standards (ECARAS), part 6.

Authorized Maintenance Program: Certificate number 002/88 authorizes the following airframe maintenance:

TABLE 7: OPERATOR MAINT. PROGRAM

Manufacturer	Make/Model	Capability	Limitations
Boeing	B737-300/400/500/600/700/800/900	Line and Base Maintenance	No limitation
Boeing	B737MAX	Line and Base Maintenance	Limited up to and including 1’A’ checks
Boeing	B757/767	Line and Base Maintenance	No limitation
Boeing	B777-200/300	Line and BaseMaintenance	No limitation
Boeing	B787-8/-9	Line and BaseMaintenance	Limited up to and including all ‘2C’ checks
Airbus	A350 XWB-900	Line and BaseMaintenance	Limited up to and including all “1C” checks
Bombardier	DHC-8-400 & DHC-8-100/200/300	Line and BaseMaintenance	No limitation
Fokker	F27MK050	Line and BaseMaintenance	No limitation
Diamond	DA40NG	Line and BaseMaintenance	No limitation
Diamond	DA42NG	Line and BaseMaintenance	No limitation
De Havilland	DHC-6	Line and BaseMaintenance	No limitation

1’A’ Check:

Per the maintenance limitations noted above, a 1’A’ check was conducted on the accident Airplane between 01 February and 04 February, 2019.This check primarily concentrates on routine inspection for airworthiness (General Visual Inspection - GVI) as well as check and replacement of lubrication.

Airworthiness Directives (AD)

The Ethiopian Airlines provided an AD compliance report for review by the EAIB. This included airworthiness directives being tracked for the airframe, the two installed engines and appliances.

The AD summary report included the limits, intervals, and current status (as applicable). A review of the Airworthiness Directive status report for the Airplane, power plants and appliances was conducted. All applicable AD's had been incorporated during Airplane production. No AD's affected the two installed engines or APU.

There was one AD service bulletin listed as open; this involves the prevention of fires in the lavatories from burning paper, etc. This is an inspection bulletin with an interval of flight hours of 940. The next inspection was scheduled at 1940 flight hours.

One of the entries in the AD compliance report was AD-2018-23-51, Titled "To Address this potential resulting nose down trim". This emergency AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. This condition, if not addressed, could cause the flight crew to have difficulty controlling the Airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.The compliance report indicates that compliance was through AFM revision on 11.08.2018.

Service Bulletin (SB) Summary:

A review of the service bulletin list includes the installation of engine Electronic Engine Control (EEC) control software version 6.5 (07 January, 2019) as well as the installation of new shoulder bearings and a hinged loop clamp on a fuel tube located on the engine. The installation is intended to improve reliability of the clamp.

1.6.3 Maintenance History

The Airplane maintenance history containing daily flight and maintenance information was reviewed from the date range of November 15, 2018 (delivery date) through March 10, 2019 (accident flight).

Maintenance Record Logbook

On March 15, 2019, the Maintenance Group performed a review and documented Ethiopian Airlines daily maintenance record logbook pages 518301 to 502140 for Airplane ET-AVJ. Additionally, all the daily technical logs that extend back to the delivery flight (Nov 15, 2018) were reviewed. Special emphasis was put on any log entry pertaining to abnormal indication or Airplane behavior.

TABLE: 8 ALL DAILY TECHNICAL LOGS

Log Ref	Date	DEP	ARR	Write ups	Rectify Action	Other work performed
502140	10Mar, 19	JNB	ADD	None	None	
502139	9Mar, 19	ADD	JNB	Installed 3 each LG Down lock pins	Removed 3each LG down lock pins	
502138	9Mar, 19	JNB	ADD	None	None	
502137	8Mar, 19	ADD	JNB	1.Installed3 each LG down lock pins 2. APU fault Light is on (APU is INOP) to clear add remark	1. Removed 3 each LG down lock pins 2. (ref IFIM 49-61-00-700-801 rev# 201901150301, 15 Jan 2019) Bite done on OMF, fund msg #1 (49-41254). Replaced the SCU and APU success fully started with APU limited restart	Engine diagnosis data downloaded
502136	8-Mar-19	PAR	ADD	APU Fault Light is on (APU is INOP)	Transferred to ADD page (501137)	
502135	8-Mar-19	NA	NA	Green sheet - parked per above	Green sheet - parked per above	
502134	7-Mar-19	JNB	ADD	None	None	
502133	7-Mar-19	ADD	JNB	APU Fault Light is on, APU had a protective shutdown	Rev# 201902150301 15 Jan 2019 - OMF Bite shows mnt msg 49-41254 (start converter unit shows start system in op); Re-racked unit and APU started with APU limited restart function as per IFIM 49-40-00- 810-818	
502132	7-Mar-19	TLV	ADD	None	None	
502131	6-Mar-19	ADD	TLV	All landing gear down lock pins installed	Removed 3 each landing gear down lock pins	Gaspath cleaning of engines
502130	5-Mar-19	NBO	ADD	Installed all gear pins	Removed all three landing gear pins	
502129	5-Mar-19	ADD	NBO			Downloaded engine diagnostic data

502128	5-Mar-19	TLV	ADD	None	None	
502127	4-Mar-19	ADD	TLV	Installed gear pins	Removed gear pins	
502126	4-Mar-19	ABV	ADD	Crew O2 cylinder pressure is below 1000 psi	Replaced crew O2 cylinder	
502125	4-Mar-19	ADD	ABV	None	None	Downloading engine diagnostic data &recording APU EGT
518324	3-Mar-19	TLV	ADD	None	None	
518323		ADD	TLV	None	None	
518322	3-Mar-19	JNB	ADD	None	None	
518321	2-Mar-19	ADD	JNB	3 each pins installed	Removed all 3 each landing gear down lock pins	Visual check of scheduled
518320	2-Mar-19	EBB	ADD	Auto land accomplished successfully at EBB	Noted	
518319	2-Mar-19	ADD	EBB	None	None	
518317	2-Mar-19	JNB	ADD	None	None	
518316	1-Mar-19	ADD	JNB	Flight Compartment PC Power Outlet Has No Power (Captain)	Performed Captain PC Outlet Initial Evaluation and Found Captain PC Outlet Has No Power	Inspection of TGB scavenge screens
518315	1-Mar-19	WHD	ADD	None	None	
518314	1-Mar-19	ADD	WHD	None	None	
518313	N/A	N/A	N/A	Pc power outlet no power, Captain's (pre flight)	Deferred to ADD	
518312	28-Feb-19	JNB	ADD	Daily check performed in JNB without specific task card / no MX data made either. Check if needs to be performed for a legal dispatch	Noted and daily check performed as per BTC 32-270-01102-01	

				Check both nose wheels for proper inflation. During ground roll vib increasing with wheel spin up ----- Ktocking of gear strut.	Balanced tire pressure and inspect both tires for wear, all landing gear components, also shock struts all found normal as per IFIM 32-1-00 809 810. Rev# 201902150301 is Feb 2019	
518311	28-Feb-19	N/A		Installed 3 each landing gear down lock pins.	Removed 3 each landing gear down lock pins,	TGB inspection task performed
				Daily check expired at 18092 and now at 19582	Performed daily check at 20:28 on 28-02-2019 (not logged in the MX system)	
518310	27-Feb-19	WHD	ADD	None	None	
518309	27-Feb-19	ADD	WHD	None	None	None
518308	26 Feb19	TLV	ADD	None	None	None
518307	26-Feb19	ADD	TLV	None	None	NAVdata update, engine diagnostic data Download,down loading engine diagnostic data
518306	26-Feb-19	TLV	ADD	None	None	
518305	25-Feb-19	ADD	TLV	Installed gear pins	All three landing gears are removed	Performed OP checked of SPCU
518304	25-Feb-19	NBO	ADD	None	None	
518303	25-Feb-19	ADD	NBO	None	None	
518302	25Feb19	NBO	ADD	None	None	
518301	25-Feb-19	ADD	NBO	None	None	

Log Ref	**Date**	**DEP**	**ARR**	**Write ups**	**Rectify Action**
24640	10Dec-18	LAD	ADD	Capt. Side altimeter indication erratically showed a descent and a lower level and back to normal indication at FL 380	BITE on OMF shows no related fault. GVI performed for static ports, no damage found; no FOD found BITE done on FMC for ADIRU falts, found none. OPC performed as per AMM 34-21-00-710-806; test passed

24628	7 Dec-18	LAO	ADD	During approach @1000' AGL the A/C starts rolling to the righ twith the auto pilot engaged.	BITE done of FMCCDU (DFCS); no fault found as per 22-11-34-040-80. Performed land verify test as per AMM22-11-00-700-801; found normal
23645	4Dec-18	DOH	ADD	During approach at 8600 feet, altimeters rapidly descend and returned to normal causing auto pilot to revert to CWS"P", L-NAV remained engaged.	IFIM 34-31-00-810-819- No existing fault found on OMF. Fault history found on OMF is that MMR is not giving valued input From OMF, as per them annual MMR operational test Preformed test-passed. Per AMM34-37-00-710-801, ranop test; passed
23639	3-Dec-18	DAR	ADD	After take-off, altitude and vertical speed indicator on both PFD's showed anerratic and exaggerated indications (movigp and down very rapidly) for about 2 sec. and then returned to back normal	AMM46-13-02-710-801OMF shows no fault in bound FDEF fault has no fault history and also has no related fault. FMC operational test performed as per AMM34-61-00-710-801 and tests how no fault.

The only scheduled check of the Airplane occurred from 01 February and 04 February 2019. This is a routine check and General Visual Inspection (GVI) of various areas of the airframe. No major discrepancies or repairs were noted for this check.

1.6.4 Engines

The accident engines were CFM LEAP-1B28B1, a high bypass, dual rotor, axial flow turbofans. The engine consists of 3 major assemblies: low pressure compressor (LPC), core engine, and low-pressure turbine (LPT). The core engine consists of a two-stage high pressure turbine (HPT) which drives the ten-stage high pressure compressor (HPC). The four-stage integrated fan and low-pressure compressor (booster) is driven by a five-stage LPT. The annular designed combustion chamber increases the HPC discharge air velocity to drive the high- and low-pressure turbines. An accessory drive system provides drive requirements for engine mounted Airplane accessories and is driven by the high-pressure module. The accessory drive system includes two sub-modules which can be removed or installed at engine level, the accessory gearbox (AGB) and the transfer gearbox (TGB).

The engine control system supplies manual and automatic control inputs to operate the engine.The engine control system has these components:

- Thrust levers (forward and reverse)
- Thrust lever resolvers
- Engine start levers
- Thrust lever interlock solenoids

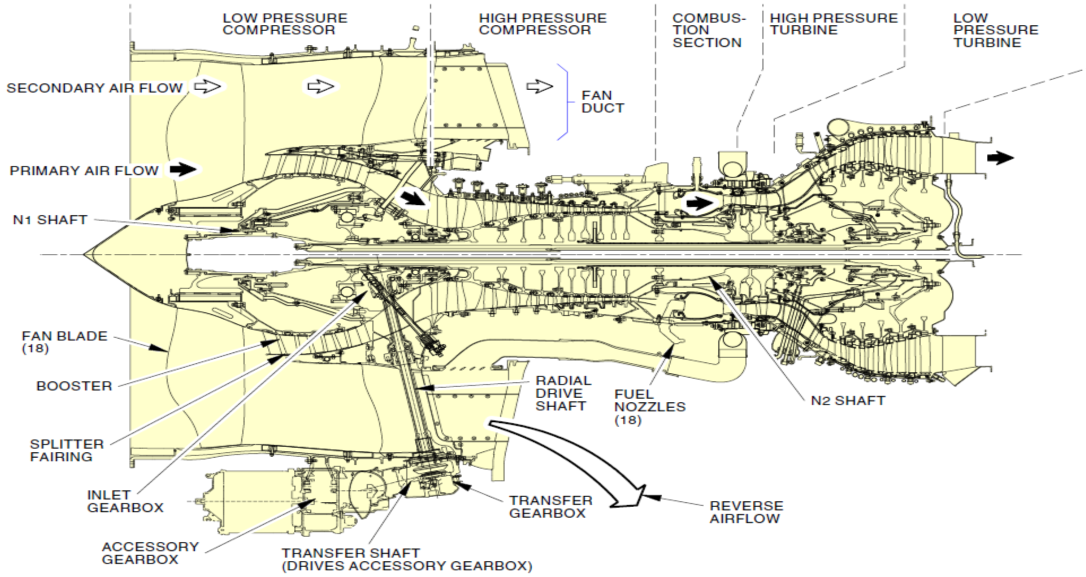


FIGURE: 6 – CFM LEAP 1B - CROSS SECTION

1.6.4.1 Engine History

According to the engine's FAA Type Certificate Data Sheet (TCDS) E00088EN, Revision 4, dated November 30, 2018, the engine has a Maximum takeoff thrust rating of 29,317 pounds flat-rated[1] to 86°F (30°C) and a Maximum continuous thrust rating of 28,690 pounds flat-rated to 77°F (25°C).

TABLE 9: ENGINE INFORMATION

Engine Serial Number	**602722 (L/H)**	**602695 (R/H)**
Last Install Date	October 2018	October 2018
Last Shop Visit	N/A	N/A
Cycles SinceInstall	382	382
Cycles Since New	382	382
Cycles Since Shop Visit	N/A	N/A
Time Since Install	1330 hours	1330 hours
Time Since New	1330 hours	1330 hours
Time Since Shop Visit	N/A	N/A

The engines were designed and built by CFMI, a joint venture between General ElectricAviation (GE) of the USA and Safran Airplane Engines (SAE) (formerly Snecma (Société Nationale d'Etude et de Construction de Moteurs d'Aviation) Moteurs of France). The division of labor is such that Safran is responsible for the Fan and LPT modules while GE is responsible for the remainder of the engine – HPC, Combustor, and HPT.

1.6.4.2 Maintenance Records & Reports

According to CFM record, both engines were compliant with the following service bulletins: SB 72-0222 – Inspect TGB scavenge screens (Feb 22, 2019)

SB73-0014 - PSS Blow Out and vacuum proc. (Jan. 16, 2019)

SB 73-0016 – New EEC software Version 6.5 (Jan. 8, 2019)

CFM also reported that no monitoring alerts, customer notification reports (CNR), or abnormal records were reported on these engines since entry into service (EIS). Additionally, no recent maintenance tasks were declared on either engine. The engine sends electronic 'snapshots' to CFM at engine start and after takeoff and no anomalies were noted during the previous flights.

The exhaust gas temperature (EGT) margin was routinely monitored on the Airplane and electronically transmitted to CFM for maintenance surveillance. A review of these records revealed an EGT margin on both engines at the time of the accident was greater than 80°C.
CFM has reviewed snapshot reports from ET-AVJ over the last four flights – three on March 9th and the event flight on March 10th. These reports were reviewed for engine parameter content with no unexpected or unusual engine conditions identified. All parameters were within expected values for the respective phase of flight with no engine faults detected.
According to the Ethiopian logbooks, only two procedures had been accomplished in the last 30 days: a water wash and an Engine Data Diagnosis Download.

Examination of the Engines

Identification of Installed Location ofEngines

Because the serial number plates were not found, the handedness of the engines was not readily identifiable, so the serial numbers of some internal components were used to make this determination. The serial numbers were compared to the CFM build records to confirm the engine serial number and therefore Airplane location. See (Table 9&10).

TABLE 10: RIGHT HAND ENGINE PART IDENTIFICATION S/NS

ESN 602722 (Installed Left Position)					
Designation	**Part Number**	**Serial Number***	**Recovered**	**S/N Identified**	**Note**
Fan Disk	364-040-010-0	HB150486			Not Recovered
LPC Stage 2-4 Spool	364-905-100-0	MA510264			Not Recovered
HPC Stage 1 Blisk	2639M71G02	GWN13E24	x		Remained with core
HPC Stage 2 Blisk	2552M02P02	GLHW0C40	x		Remained with core
HPC Stage 3-4 Blisk Spool	2552M03G02	GLHW0A6N	x		Remained with core
HPC Stage 5 Blisk	2552M05P02	TMT138N0	x		Remained with core
HPC Stage 6-10 Spool	2552M06G04	GWN13ENJ	x		Remained with core
HPT Rotor Disk Stage 1	2600M21G02	GWN13ECE	x		Remained with core, Rim not recovered
HPT Rotor Disk Stage 2	2547M01G02	TMT130CR	x		Remained with core
LPT Rotor Disk Stage 1	364-021-030-0	PC740173	x	x	Separated from engine core
LPT Rotor Disk Stage 2	364-021-130-0	PC738557	x	x	Separated from engine core
LPT Rotor Disk Stage 3	364-021-230-0	PC738549	x	x	Separated from engine core
LPT Stage 4, Disk STBSHF	364-001-611-0	HC278966	x	x	Separated from engine core
LPT Rotor Disk Stage 5	364-600-011-0	GA005072	x		Foundwithstage5rotatingairsealattachedP/N364-062-010-0,S/N DY168293

Left Hand Engine Part Identification S/No

ESN 602695 (Installed Right Position)					
Designation	**Part Number**	**Serial Number***	**Recovered**	**S/N Identified**	**Note**
Fan Disk	364-040-010-0	HB150564	x	x	Separated from engine core
LPC Stage 2-4 Spool	364-905-100-0	MA510373			Not Recovered
HPC Stage 1 Blisk	2639M71G02	TMT146AG	x		Separatedfromenginecore(stage 1-3 recovered together)
HPC Stage 2 Blisk	2552M02P02	GLHW0A66	x		Separatedfromenginecore(stage 1-3 recovered together)
HPC Stage 3-4 Blisk Spool	2552M03G02	GLHW0A67	x		Stage 3 recovered with Stage 1-2. Stage 4 not recovered.
HPC Stage 5 Blisk	2552M05P02	GLHW0CKH	x		Separated from engine core.
HPC Stage 6-10 Spool	2552M06G03	GWN13EAH	x		Spoolseparatedfromengine.Stage 7hub/webseparatedfromengine, rimnotrecovered.Otherstagesnotrecovered.
HPT Rotor Disk Stage 1	2600M21G02	GWN13EEE	x		Separated from engine core. Rim section liberated and found Protruding from HPT Case.
HPT Rotor Disk Stage 2	2547M01G02	TMT1469H	x		Remained with engine core
LPT Rotor Disk Stage 1	364-021-030-0	PC735264	x		Remained with engine core
LPT Rotor Disk Stage 2	364-021-130-0	PC681407	x		Remained with engine core
LPT Rotor Disk Stage 3	364-021-230-0	DY386829	x		Remained with engine core
LPT Stage 4, Disk STBSHF	364-001-611-0	PC640864	x		Remained with engine core
LPT Rotor Disk Stage 5	364-600-011-0	GA004847	x		Separated from engine core. Found with stage 5 rotating air seal attachedP/N364-062-010-0,S/NHB301273
**Serial Number based on CFMI Delivery Records*					

1.6.5 AIRPLANE SYSTEMS DESCRIPTION

The systems described in this document are the systems on the airplane at the time of the accident.

1.6.5.1 AOA over View

The angle of attack (AOA) system senses angle of airflow between a reference line on the Airplane and the wind direction.

Angle of Attack (AOA) Sensors

The Boeing 737-MAX8 has two independent angle-of-attack (AOA) sensors, one on each side of the forward fuselage. The AOA sensors consist of an external vane which rotates to align with the local airflow connected to two internal resolvers which independently measure the rotation angle.

A wedge vane is mounted external to the Airplane to accurately sense local airflow angle. Embedded heater in a vane thermally compensates to increase vane surface temperature in high flow and icing. It is coupled to electrical transducers via mechanical shaft. The vane is mechanically balanced with an internal counterweight.

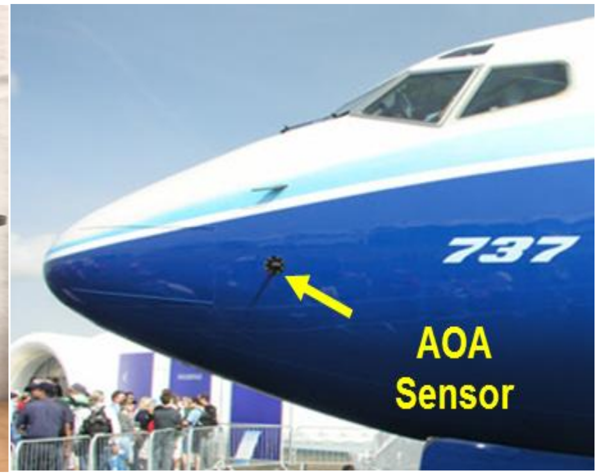


FIGURE7: AOA SENSOR **FIGURE8: AOA LOCATION ON A BOEING 737**

The AOA sensor used on the Boeing 737-MAX8 is made by Collins Aerospace.

For each AOA sensor (left and right), one resolver is connected to the respective Stall Management Yaw Damper (SMYD) computer and the second resolver is connected the respective ADIRU. Both the SMYD and ADIRU monitor the resolver circuits within the AOA sensor. If a fault is detected, the AOA resolver information is not used and the fault is annunciated.

There is no scheduled maintenance for AOA sensors. Any required maintenance is a consequence of annunciated faults or observed malfunctions. This practice is "on-condition" maintenance.

1.6.5.2 Use of AOA Values

The AOA values directly used by the ADIRU to compute static source error correction, which affects all computations involving static pressure such as:

- Mach corrected values
- CAS corrected values
- Altitude corrected values
- By the SMYDC

  - to manage the Stall warning activation
  - to compute the loop gain of the yaw damping system
  - to compute stick shaker speed
  - to compute operational speeds
  - to compute the Pitch Limit Indicator (PLI)
- By the FCC
  - To trigger MCAS activation
  - To compute MCAS duration

Erroneous AOA values would also impact the following systems (non-exhaustive list)

- ADIRU, for the computation of TAS, Baro corrected altitude,…etc
- F/D and autopilot: with invalid CAS, Baro altitude,…etc
- FMC through baro altitude values, with potential impact on the auto throttle commands.

1.6.5.3 AOA Vane and Anti-Ice Protection

AOA vane heating belongs to the anti-ice protection. In case of a fault of the vane heating, the following systems activate:

- the master caution triggers (master caution light illuminates)
- the ANTI-ICE light (right system annunciator) illuminates
- The [L/R] ALPHA VANE message illuminates (on the Probe heat panel of overhead panel).

The vane heating monitoring is based on current detection circuit. After the current drops, there is a delay of 3 to 5 s before the light “[L/R] Alpha Vane” illuminates and the master caution triggers. In other words, the airplane suffered a loss of power to the left AOA Sensor Heater.

FIGURE9: MASTER CAUTION ANTI-ICE

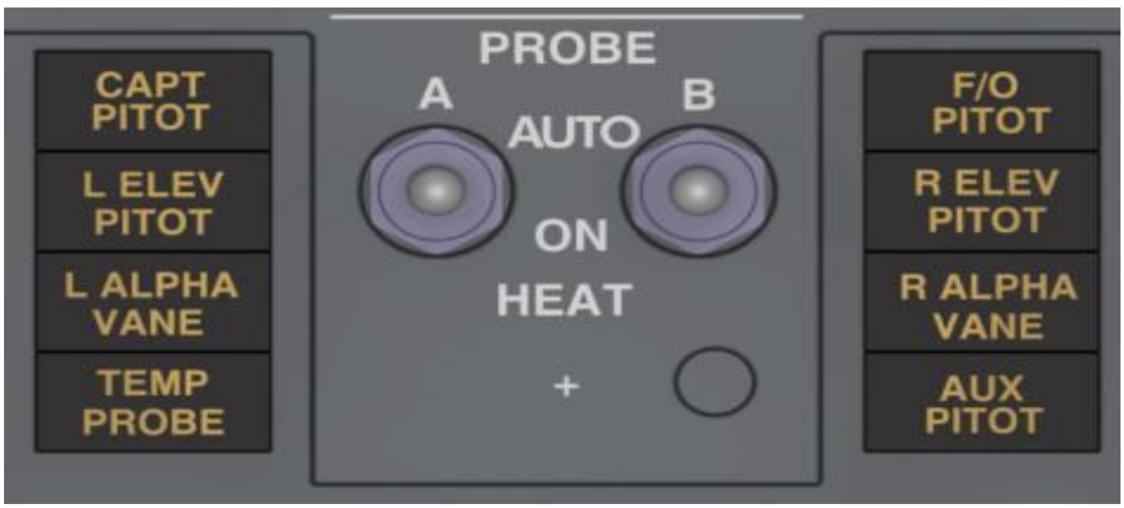


FIGURE10: PROBE HEAT PANEL

AOA Monitoring

The ADIRU performed a limited monitoring of the AOA sensor, based on the signal received from the resolver. The ADIRU generates “AOA signal failed” information if it detects one or more of the following conditions:

- the resolver output is zero volts
- the combined amplitude is outside the acceptable range
- The calculated AOA vane shaft angle is outside the range defined by the mechanical stops.

The ADIRU generates “AOA failed” information when it detects any of the above conditions or if the reference (excitation) voltage signal provided to the AOA sensor from the Airplane 28VAC power bus is out of range.

Impact ofAOA Failure on ADIRU

One input of the ADIRU is of AOA vane heating failure. In this case, ADIRU goes on providing its parameters without any information of failure. ADIRU only records a failure code inside its BITE memory.

If the ADIRU detects any failure through its AOA monitoring the ADIRU provides its output data with invalidity information (NCD – No Computed Data or FW – Failure warning). In this case, the systems receiving these data do not use them; in particular, the Display Processing Computer (DPC), sets up flag on the PFD:

- SPD flag appears on the PFD and speed tape is no more displayed

- ALT flag appears on the PFD and altitude tape is no more displayed.

Effects of Erroneous Angle of Attack

The effects of erroneous Angle of Attack (AOA) that is not declared invalid vary depending on the magnitude and direction of the error.

Flight Deck Effects:

- Display of erroneous airspeed and barometric corrected altitude on one Primary Flight Display (PFD)
- Potentially erroneous stick shaker functions on one side and incorrect lower barber pole, lower amber band, and Pitch Limit Indicator on one PFD
- Possible autopilot disconnect warning for disconnect conditions (light and aural), NO AUTOLAND recall in fail-op auto land configuration (displayed on the engine format).
- If the displays software option for AOA Indication is displayed, erroneous AOA information on one PFD is displayed
- The following are displayed on both PFDs if display system thresholds are tripped:
    - IAS DISAGREE
        - When captain’s and first officer’s airspeed indications disagree by 5+Kt for 5 continuous seconds
    - ALT DISAGREE
        - When captain’s and first officer’s barometric altitude disagree by 200+ feet for 5 continuous seconds

- AOA DISAGREE
    - When the left and right AOA signals from the Air Data Inertial Reference Unit (ADIRU) disagree by 10+ degrees for 10 continuous seconds
- If EFS command is longer than 30-45 seconds, the FEEL DIFF PRESS light will illuminate
- Possible indications of a Predictive Wind Shear (PWS) event in regions where those indications would be otherwise inhibited ("WINDSHEAR" text on the ND/PFD, PWS Audio messages).

AOA DISPLAY OPTION

Boeing provides the option for the operator to install the AOA indicator on the PFD for Boeing 737-8 (MAX). The respective PFD will show the AOA information as shown in the figure-11 below.

FIGURE 11: AOA indicator on

AOA Disagree Alert

As shown in (figure 12) the "AOA DISAGREE" message appears on the Captain and First Officer PFD when the values of the left and right AOA transmitted by the ADIRUs differ by 10° or more for 10 continuous seconds. The annunciation is only displayed in the air because AOA values are unreliable when the Airplane is stationary on the ground.
The AOA DISAGREE message was first implemented on the Boeing 737NG fleet in 2006 in response to customer requests. Since 2006, the AOA DISAGREE alert has been installed on all newly manufactured Boeing 737 NG Airplanes, and is available as a retrofit for older Airplanes.

The AOA DISAGREE alert has not been considered as a safety feature by Boeing, and is not necessary to safely operate the Airplane. Airspeed, attitude, altitude, vertical speed, heading and engine thrust settings are the primary parameters the flight crews use to safely operate the Airplane in normal flight. Stick shaker

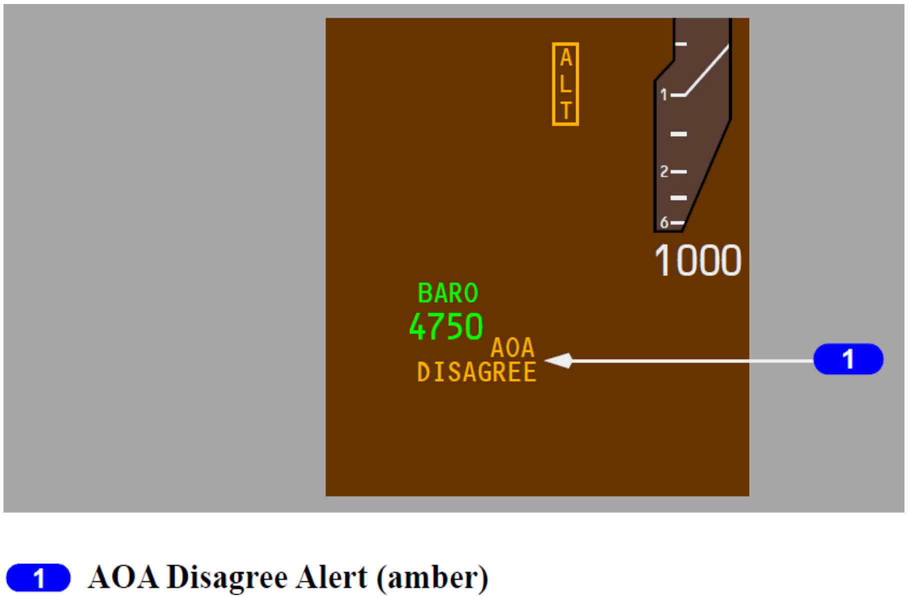


Figure 12: AOA Disagree message on the PFD

and the pitch limit indicator are the primary features used for the operation of the Airplane at elevated angles of attack. The AOA DISAGREE alert provides supplemental information only.

At the time of the accident, the AOA DISAGREE non-normal procedure[10]alerted pilots to the possibility of airspeed and altitude errors, and of the IAS DISAGREE and ALT DISAGREE alerts occurring, but did not include any flight crew action in response to the AOA DISAGREE ALERT[11]. The requirements for the AOA DISAGREE alert were carried over from the Boeing 737NG to the Boeing 737-8 (MAX). In 2017, however, within several months after beginning Boeing 737- 8 (MAX) deliveries, Boeing identified that the Boeing

[10]The AOA DISAGREE non-normal procedure was revised to direct flight crew to the Airspeed Unreliable NNC as part of the Return to Service activities conducted prior to the resumption of commercial 737 MAX flights in 2020.
DISAGREE alert[11]

737-8 (MAX) display system software did not correctly implement the AOA DISAGREE alert requirements. As with the Boeing 737 NG, the Boeing display system requirements for the Boeing 737-8 (MAX) called for the activation of the AOA DISAGREE alert as a standard feature on all Airplanes. The software delivered to Boeing, however, linked the AOA DISAGREE alert to the AOA position indicator, which is an optional feature on the Boeing 737 (MAX) series. Accordingly, the software activated the AOA DISAGREE alert only if an airline opted for the AOA indicator. At the time of the accident, Boeing advised that the AOA indicator hadbeen selected by approximately 20% of airlines.

When the discrepancy between the AOA display requirements and the software was identified, Boeing determined that the absence of the AOA DISAGREE alert did not adversely impact Airplane safety, certification or operation. Accordingly, Boeing concluded that the existing functionality was acceptable until the originally intended functionality could be implemented in a display system software upgrade scheduled for the third quarter of2020.

Ethiopian Airlines did not select the optional AOA indicator feature on the PFD of their 737-MAX8 Airplane; thereforeas a result, the AOA DISAGREE did not appear on ET-AVJ Airplane, even though the necessary conditions were met.

1.6.5.4 Air Data System

The Boeing 737 MAX 8 is equipped with an Air Data Inertial Reference System (ADIRS) that provides flight data to the flight deck display panels, flight management computers, flight controls, engine controls and all other systems requiring inertial and air data information. The ADIRS combines the Air Data System (ADS) function and the Inertial Reference System (IRS) function into a single device identified as an Air Data Inertial Reference Unit (ADIRU). The ADIRUs provide inertial position and track data to the flight management system and provide attitude, altitude and air speed data to theflight deck displays. The ADIRUs process information measured by internal gyros and accelero meters and information from the air data sensors.

Pitot and Static System

The pitot static system is comprised of three separate pitot probes and six flush static ports; two of these pitot probes and four of the static ports interface with the Air Data Modules (ADM), which convert pneumatic pressure to electrical signals and send these data to the ADIRUs. The remaining auxiliary pitot probe and alternate static ports provide pitot and static pressure to the standby instruments. The auxiliary pitot probe is located on the first officer’s side of the Airplane.

The ADM connected to the Captain's pitot probe sends information to the left ADIRU, while the ADM connected to the First Officer's pitot probe sends information to the right ADIRU. The remaining ADMs are located at the balance centers of the Captain's and First Officer's static ports. The ADM connected to the Captain's static ports sends information to the left ADIRU for display of the captain's instruments, while the ADM connected to the First Officer's static ports sends information to the right ADIRU for display on the first officer's instruments.

AIRDATA REFERENCE (ADR)

The Air Data Reference (ADR) function of the ADIRU is to sense the Airplane's pitot and static pressures external to the Airplane and convert them into digital electrical signals. These pressures, in conjunction with the Total Air Temperature (TAT) and the Airplane's AOA are used by the ADIRU to calculate basic air data information (parameters) for transmission to various systems on the Airplane. Some of the parameters that the ADIRU transmits include: altitude, computed airspeed, and true airspeed. Another function of the ADIRU is to provide AOA information (indicated angle of attack) directly to the Flight Control Computers as an input to the MCAS function.

Both the altitude and airspeed use static pressure which includes calculations for a correction factor of the Static Source Error Correction (SSEC). This is compensation for pressure errors caused by the airframe's aerodynamic effects on the static port. The static ports have been located to minimize errors. Compensation for the remaining errors is provided by a correction algorithm composed of three factors: basic correction, thrust effect compensation and ground effects compensation.

The ADR uses the following parameters as primary parameters:

- The static pressure coming from the static ports
- The total pressure coming from the pitot probes
- The AOA values coming from the AOA vanes
- The Total Air Temperature (TAT) parameters coming from the TAT probes

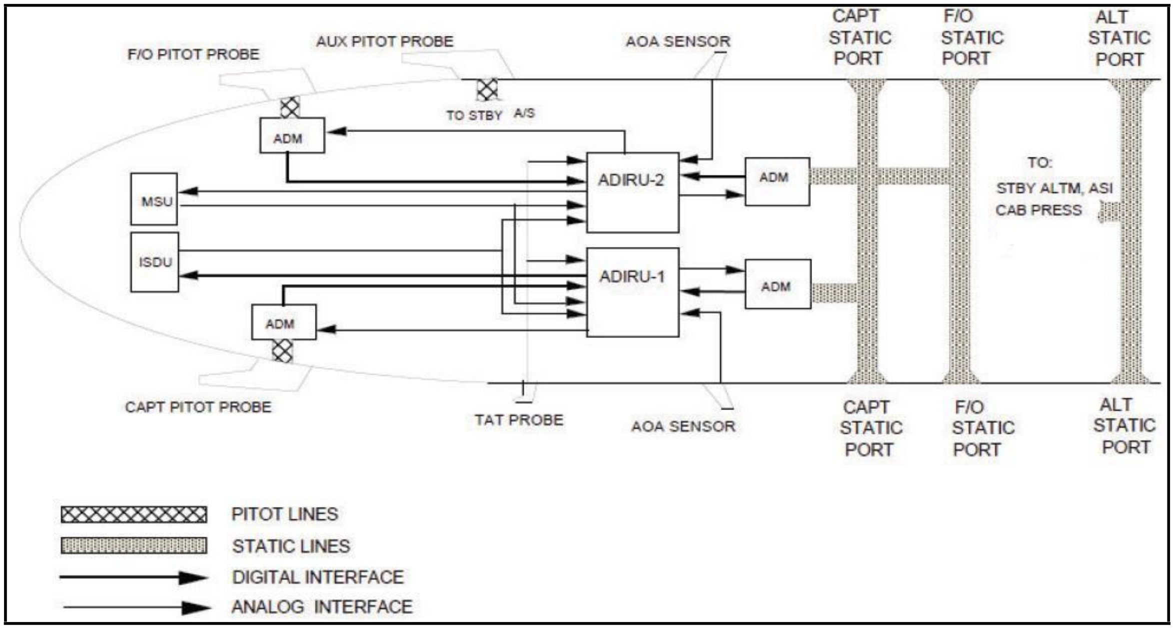


FIGURE13: Illustrated static and total air pressure system

1.6.5.5 Enhanced Digital Flight Control System (EDFCS)

The Boeing 737 MAX8 is equipped with an Enhanced Digital Flight Control System (EDFCS). The EDFCS system on the 737 MAX8 is the same as the 737NG with the following added functionality in the flight control computer (FCC) software:

1. Maneuvering Characteristics Augmentation System (MCAS),
2. Emergency Descent in Autopilot and Flight Director Level Change Mode,
3. Spoiler Control Electronics Interface,
4. Autopilot Roll Command Alerting System.

The EDFCS provides integrated operation of the following major flight control functions:

- Altitude Alert
- Autopilot (including Autoland)
- Flight Director
- Speed Trim
- Mach Trim
- Maneuvering Characteristics Augmentation System (MCAS)

- FMC Interface & Mode Control
- Autothrottle Interface, N1 Limits, & Mode Commands and Mode control

The EDFCS has a mode control panel (MCP), two FCC's, and actuator inputs to the flight control system. The MCP is the primary interface between the flight crew and the FCCs. The FCCs get inputs from several systems such as the Air Data Inertial Reference System (ADIRS) and the Flight Management Computer (FMC) and send commands to the aileron and elevator actuators. These actuators control the movement of the ailerons and elevators, which control the flight path of the Airplane whenthe autopilot is engaged. There are two autopilots, autopilot A from FCC A and autopilot B from FCC B. When you engage an autopilot from the MCP, the autopilot can control the Airplane attitude through these phases of flight: Climb, Cruise, Descent, Approach, Go-around and Flare.

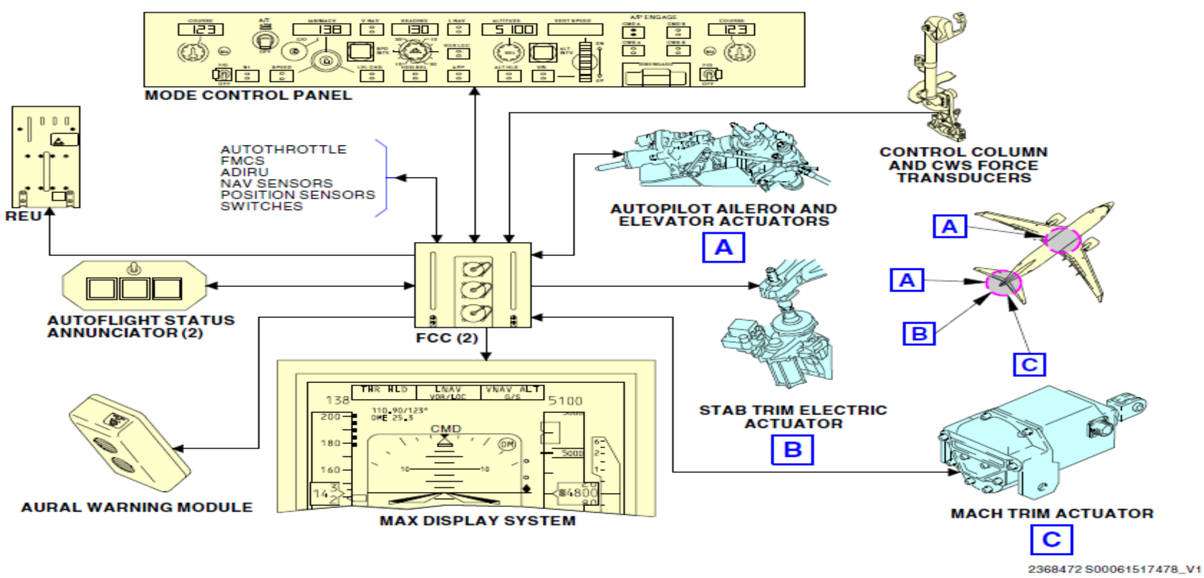


FIGURE14: EDFCS GENERAL DESCRIPTION

1.6.5.6 Autopilot

The autopilot is engaged by selecting one of two autopilot push button engage switches located near the right edge of the MCP, between the Vertical Speed display window and the right hand Flight Director toggle switch.

The control column force must be less than 5 lbs and the control wheel force must be less than 3 lbs for the autopilot to engage. If the forces exceed these values, then attempting to engage the autopilot results in an autopilot disconnect warning.

The normal autopilot disengagement mechanism is via the quick disconnect pushbutton switches on the captain's and first-officer's control wheels. An alternate disengage mechanism is provided by the disengage bar located on the bottom edge of the MCP just below the engage buttons. An amber strip is exposed when the bar is down to positively indicate activation of the disengage bar. Pressing a lighted engage pushbutton also disconnects the autopilot (except when dual engaged for failed operational autoland—in this case only the corresponding channel disconnects).

Certain failures of the EDFCS or interfacing systems will cause the autopilot to automatically disconnect when the failure occurs. The autopilot may also automatically disconnect upon use of certain source select switches but can (sometimes) be reengaged.

Upon autopilot disconnect, the autopilot disengage light on the Autoflight Status Annunciator will indicate disconnect by flashing red. The annunciator is located just above both the Captain's and First Officer's inboard displays. This will be accompanied by an aural warning. The pilot may reset the warnings by pressing the autopilot disengage switch on the wheel or the light on the Warn Annunciator. The warning will continue for 2 seconds regardless of how quickly the pilot might reset the warning.

1.6.5.7 Flight Director

Selecting a Flight Director toggle switch to the ON position activates the Flight Director. The left switch enables the Flight Director Command bars on the captain's primary flight display (PFD). The right switch enables them on the first officer's display. When a Flight Director is initially selected ON, the bars will be out of view and there will be no active mode. Subsequent use of the TOGA switch or an MCP mode selection will bring the bars into view.

The Flight Director Master light located next to the switch indicates which baro correction is currently in-use by the autopilot/Flight Director for calculations such as Altitude Alert or Altitude Acquire. Under normal operations, the left FCC provides the Flight Director commands for the left display and the right FCC provides similar commands for the right display. The Flight Director Command bars are biased out of view in the event of a mode failure. Flight Director Selection is annunciated by a green "FD" on the primary EFIS display when the autopilot is not engaged. Flight Director Modes may be engaged and used alone or may be displayed in conjunction with autopilot operation.

1.6.5.8 AutoThrottle

Overview

The auto throttle (A/T) system provides automatic thrust control from the start to takeoff through climb, cruise, descent, approach and go–around or landing. The A/T system controls engine thrust in response to the mode selected by the flight crew through the EDFCS, Mode Control Panel (MCP), Flight Management Computer (FMC) and ADIRU.

The speed information taken from the ADIRU is used to calculate throttle lever rate commands to set engine thrust during changing flight conditions. All the information is processed by FCC, which provides commands to the thrust lever servo motors controlling thrust lever movement.

The auto throttle Arm switch is a magnetically held two-position switch, located on the left side of the MCP, between the IAS/MACH display window and the left Flight Director toggle switch. Arming the A/T is preparing thesystemto engage in the N1, MCP SPD, or FMC SPD mode. A green light near the auto throttle Arm switch is illuminated when the auto throttle Arm switch is in the ARM positionand "ARM" appears on the Flight Mode Annunciator (FMA) portion of the PFD.In the ARM state the auto throttle will accept mode requests from the autopilot or TOGA switch and engage the appropriate auto throttle mode. While on the ground, the FMC thrust reference must be takeoff mode for the auto throttle ARM switch to hold in the ARM position and arm the system. When in the ARM state, the flight crew can set thrust lever position manually and the auto throttle will not alter those flight crew inputs.

Moving the auto throttle Arm switch to OFF or activating an auto throttle quick disengage switch (which causes the auto throttlearm switch to move to the OFF position) disconnects the auto throttle. There was an auto throttle quick disengage switch installed on the outside edge of each thrust lever. The A/T disengage light will illuminate when A/T is disengaged. In addition to the ARM state, there are fiveauto throttle modes: N1, Speed, Go-Around, Retard and Throttle Hold. For each flight phase, the flight crew can select the A/TN1 or speed modes from the MCP or directed by the FMC. During take off, pushing TO/GA switch engages the A/T in N1mode and causes the engine thrust to increase to the take off (TO) N1.

TABLE11: AUTOTHROTTLE MODES

Mode	Function
Speed	Maintain a user-selected speed. Throttle will be controlled from idle up to the N1 thrust limit shown on the EICAS display as needed. Throttle movements occur at a slow throttle rate.
N1	Maintains thrust at the full N1 limit.
Go-Around	Advances thrust sufficient for a reasonable climb. Further advances thrust to G/A limit if TOGA switch pressed a second time.
Retard	Retard throttles to idle during level change descents and flare.
Throttle Hold	Holds thrust lever position (autothrottle servomotors depowered) during takeoff when speed exceeds 80kts to protect against autothrottle erroneous retard failures.

A/T and computers

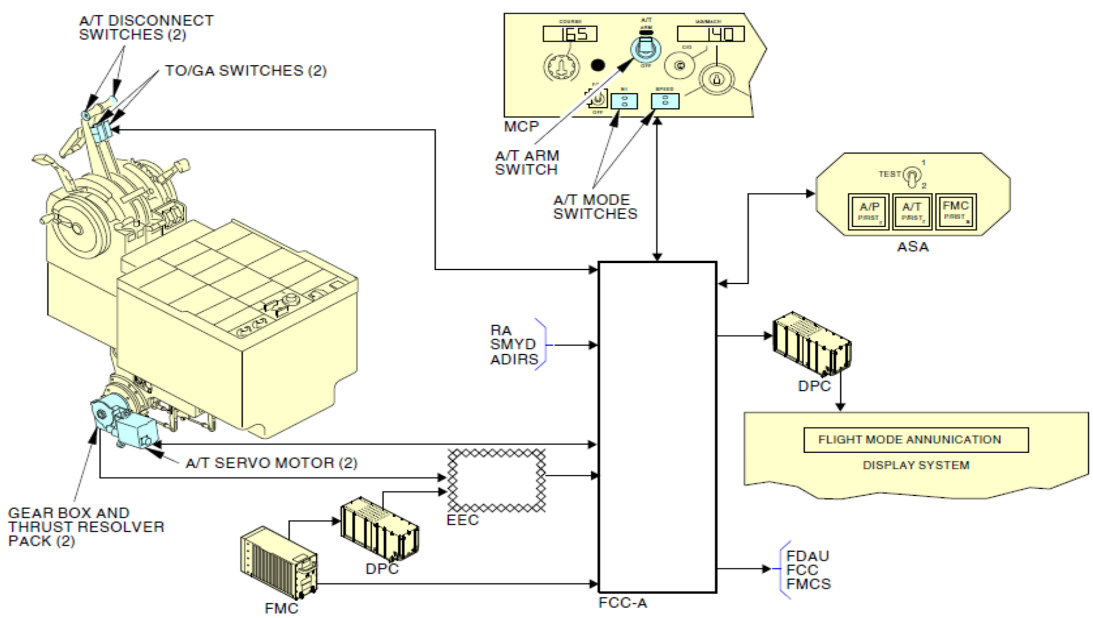


FIGURE 15: A/T SYSTEM - GENERAL DESCRIPTION

The FMC calculates thrust N1 limits and N1 targets for each flight phase. The data goes to the Display Processing Computers (DPC). The DPC shows the N1 limits on the engine display. The DPC send the N1 targets to the EECs which calculate equivalent TRA targets to send to the A/T to set thrust. The A/T uses the EEC TRA targets to set thrust during takeoff, climb, and MAX thrust go-around.

The FMC also sends N1 targets directly to the A/T. During takeoff and MAX thrust go-around, the A/T uses EEC TRA targets and FMC N1 targets to set thrust.If certain air data parameters from left and right ADIRUs are sufficiently far apart to fail a reasonableness check, the FMC invalidates its N1 limit mode output.

The A/T function converts the target N1 values from the FMC to an equivalent TRA target. The target N1 rating is dependent on the FMC engaged mode.

During takeoff, climb, and MAX thrust go-around, the FMC N1 targets are the same as the N1 limits.

The A/T function in FCC A sends A/T discrete digital data to both FCCs. The FCCs use this data to determine the mode the A/T is in and to which modes it will allow a change.

The FCCs send mode request discretes to the A/T to select A/T modes consistent with the active EDFCS mode. The A/T needs also a valid N1 target from the FMC to switch from the ARM mode into another mode.

1.6.5.9 SMYDC

AUTOSLATS

The autoslat system is designed to enhance airplane stall characteristics at high angles of attack during takeoff or approach to landing. When the flaps 1 through 25 are selected, the leading edge slats are normally in the extended position. As the airplane approaches the stall angle with the slats in the extended position, the slats automatically begin driving to the full extended position prior to stick shaker activation. The slats return to the extended position from the full extended position when the angle of attack is sufficiently reduced below the stall critical attitude, when flaps are raised to up, or when computed airspeed exceeds 230Kt. Autoslat operation is controlled by the SMYD computers using angle-of-attack to determine when the airplane is approaching stall; either SMYD can provide the autoslat function by itself.

YAW DAMPER (YD)

At low angle of attack, YD dampens sideslip induced lateral-directional motion and provides turn coordination. At high angle of attack, turn coordination is disabled, yaw damper does not suppress sideslip and has a reduced Dutch roll damping.

The yaw damper system consists of a main and standby yaw damper. Both yaw dampers are controlled through Stall Management/Yaw Damper (SMYD) computers. The SMYD computers receive inputs from both ADIRUs, both control wheels and the YAW DAMPER switch. SMYDs provide yaw damper inputs to the main rudder Power Control Unit (PCU) or standby rudder PCU, as appropriate.

STALL WARNING

Natural stall warning (buffet) usually occurs at a speed prior tostall. In some configurations the margin between stall and natural stall warning is less than desired.Therefore, an artificial stall warning device, astick shaker isused to provide the required warning.

Each control column has an eccentric weight motor which can vibrate the column to alert the pilots before a stall develops.The system is armed in flight at all times.The systemis deactivated on the ground, exceptduring the ground test. Two independent, identical SMYD computers determine when stall warning isrequired based upon:

- Alpha vaneangle of attackoutputs- Wing configurations
- Air/ground - ADIRU outputs
- SensingThrust- Anti–ice controls
- FMC outputs

The AOA sensor is connected to the SMYD and provides the measured angle of direction of air flow relative to the fuselage. If the AOA sensor detects an excessive angle of attack compared to the design characteristic of the737 MAX 8, the SMYD will activate the stick shaker to provide aural and tactile alert to the flight crew. Two SMYD computers provide output for stall warning to include stick shaker, Pitch Limit Indicator, and maneuver and operating air speed limits. The SMYD1 activates the Captain’s stick shaker, and S M Y D 2 activates the F/O stick shaker. Vibrations from either stick shaker can be felt in both columns through the mechanical column interconnect.

SPEED LIMITS

The speed limits computed by SMYD are described in the following table.

TABLE12: SPEED LIMIT

	Recorded parameter	Meaning/display impact
Maximum Maneuver Speed/High Speed Buffet	HIGHSPDBUFFETSPDFDR	Speed tape impact: bottom of the amber bar below VMO/MMO providing 1.3 G manoeuver capability
Minimum Maneuver Speed	FCMINOPERATINGSPDFDR	Speed tape impact: top of the amber bar above the minimum speed (black and red lower stripes)
Minimum Speed	STICKSHAKERSPEEDSMYDC1FDR STICKSHAKERSPEEDSMYDC2FDR	Speed tape impact: top of the black and red lower stripes. Stick shaker speed.

Note: When flaps are up, the bottom of the amber bar indicates the Maximum maneuver speed. This airspeed provides 1.3 G maneuver capability to high speed buffet (or an alternative approved maneuver capability set in the FMC maintenance pages).

1.6.5.10 Pitch Control System

Pitch control for the Boeing737-MAX8 is provided by two elevators and a horizontal stabilizer, which are both moveable control surfaces located on the empennage.

ELEVATOR SYSTEM

The Boeing737-MAX8 elevator control system provides primary pitch control of the Airplane using two elevators that are hydraulically powered with manual reversion availablein the event of a loss of hydraulics.This control system is activated by fore and aft motion of the captain's and first officer's control columns, which are connected via a torque tube with a forward cable control quadrant mounted at each end. Elevator control cables are routed from the quadrants aft and attach to a pair of aft elevator control quadrants, which are mounted on the lower elevator input torque tube[12]. This tube is mechanically connected, via linkages, to each of the two power control units (PCUs) input control arm assembly. When rotated, the lower torque tube input arm assembly provides a simultaneous command to each PCU to extend or retract. The two PCUs operate in unison and are powered by separate hydraulic systems, the left unit from hydraulic system “A” pressure and the right unit from hydraulic system B pressure. The output rod of each PCU is connected to the upper torque tube, which is directly linked by pushrods to each elevator.

ELEVATOR FEEL SYSTEM

An elevator feel computer provides simulated aerodynamic forces on the control column based on total pressure (from two dedicated pitot probes mounted on the vertical stabilizer) and stabilizer position. Feel force is transmitted to the control columns by the elevatorfeel and centering unit.To operate the feel system the elevator feel computer uses either hydraulic system A or B pressure, whichever is higher.

Stall identification is enhanced by the Elevator Feel Shift (EFS) module and the Speed Trim System (STS). The STS is a function within the Flight Control Computers which enhances speed stability characteristics. MCAS is a sub function of the speed trim system. The increased force gradient provided by the MCAS

[12]The aft elevator controls are located in the empennage aft of the stabilizer rear spar.

function, combined with EFS, provides a means for pilots to identify impending stall, along with other cues such as stick shaker, buffet, elevated AOA, and other flight deck indications.

During high AOA operations, the Stall Management/Yaw Damper (SMYD) reduces yaw damper commanded rudder movement. The EFS module increases hydraulic system pressure to the elevator feel and centering unit during a stall. This approximately doubles control column forces for a typical stall entry. The EFS module is armed whenever an inhibit condition is not present. Inhibit conditions are Airplane on the ground, radio altitude less than 100 feet, or autopilot engaged. However, if EFS is active when descending through 100 feet RA, it remains active until AOA is reduced below approximately stickshaker threshold. There are no flight deck indications that the system is properly armed or activated. As airspeed decreases towards stall speed, the speed trim system trims the stabilizer nose down and enables MCAS above stickshaker AOA. With this trim schedule the pilot must pull more aft column to stall the Airplane. With the column aft, the amount of column force increase with the onset of the EFS module is more pronounced.

HORIZONTAL STABILIZER

As shown in Figure-16 the horizontal stabilizer controls the pitch trim of the Airplane; its leading edge can be moved to a maximum position of 4.7 degrees up and 12.4 degrees down by the rotation of a jackscrew, which is connected to the front spar fitting of the stabilizer via a ballnut.

The horizontal stabilizer is positioned by a single electric trim motor controlled through either of the stabilizer trim switches located on the pilots' control wheels or autopilot trim. The Speed Trim System, including the Speed Trim function and the MCAS function, can also command the trim motor when the autopilot is off. The main electric and FCC automatic stabilizer trim functions each have two speed modes: High speed with flaps extended and low speed with flaps retracted.For both flaps extended and flaps retracted, the main electric trim rate is faster than the FCC automatic stabilizer trim rate. If the autopilot is engaged, actuating either pair of stabilizer trim switches automatically disengages the autopilot. The stabilizer trim wheels rotate whenever electric stabilizer trim is actuated. The stabilizer may also be positioned by manually rotating the stabilizer trim wheels.

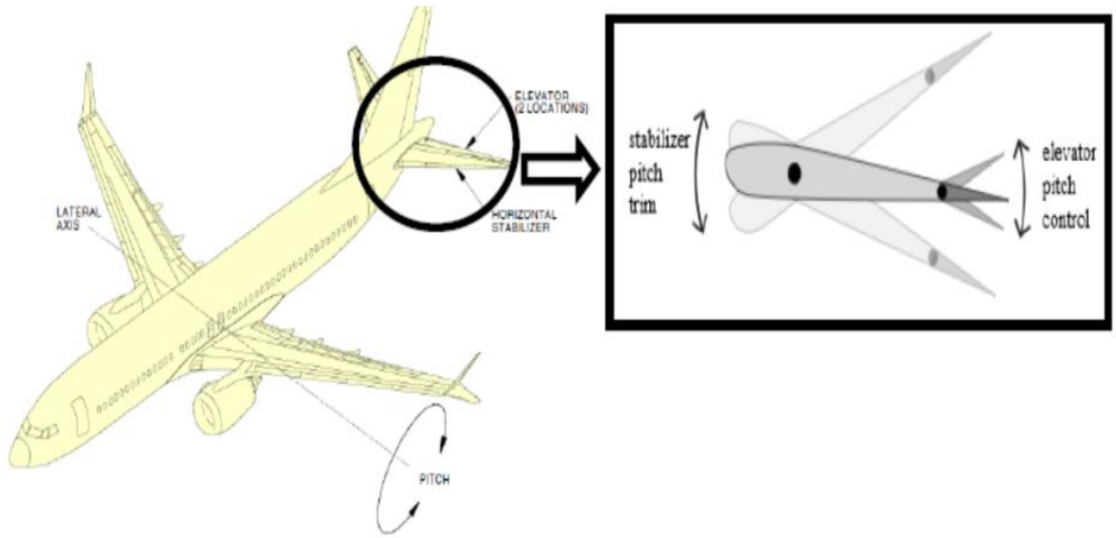


FIGURE 16: HORIZONTAL STABILIZER MOVEMENT

The total range of the Horizontal Stabilizer movementis 17.1degrees or(units) which are depicted on the scale on the stabilizer trim indicator located on the center pedestal in the cockpitas shownin Fig.17, when the stabilizer trim indicator is at the zero position, the Horizontal Stabilizer is at its full leading-edge up position (Airplane is trimmed full Airplane nose-down).

FIGURE 17: STABILIZER TRIM INDICATOR

1.6.5.11 Operation with Autopilot Off

Electric Trim Switch Control

Stabilizer trim can be commanded by the flight crew by using electric trim switches located on the outboard side of the captain's and first officers control wheels. Each control wheel contains two switches (arm and control) mounted side by side; when activated, the arm switch closes a relay to provide the main electric trim arm signal(28V DC) to the stabilizer trim motor; while the control switch provides the directional control to the stabilizer trim motor. Both switches (arm and control) must be activated in an Airplane nose up or nose down direction in order for the stabilizer trim motor to rotate the stabilizer jackscrew to reposition the horizontal stabilizer.

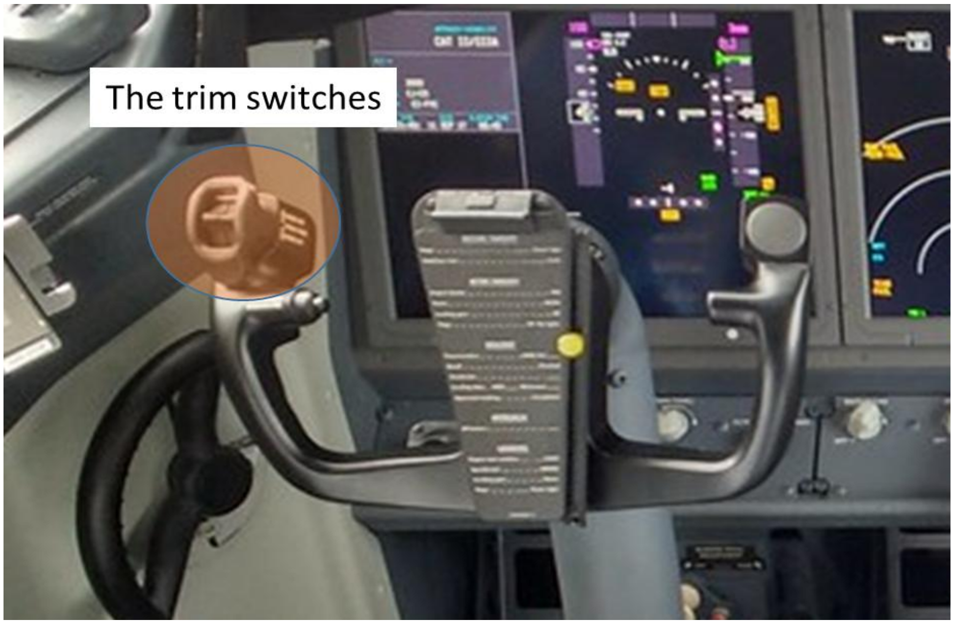


FIGURE 18: TRIM SWITCHES ON THE LH YOKE

Manual Trim Wheel Control

Manual stabilizer control is accomplished through cables which allow the pilot to position the stabilizer by rotating the stabilizer trim wheels. Each trim wheel is equipped with a manually deployable handle (visible in Figure 19), though the wheel can also be moved by grasping the rim without deploying the handle. The stabilizer is held in position by two independent brake systems when there is no electric command present to move the stabilizer. Manual rotation of the trim wheels can be used to override the brake systems, autopilot, or main electric trim. The effort required to manually rotate the stabilizer trim wheels may be higher under certain flight conditions. If the stabilizer trim system is actively trimming, grasping the stabilizer trim wheel will stop stabilizer motion. Approximately15 rotations of the stabilizer trim wheel are required for each degree (unit) of stabilizer movement.

FIGURE 19: THE TRIM WHEEL, WITH THE HANDLE EXTENDED

a) Speed Trim Function

The 737 -300, 400 and 500 (737 Classic) as well as the -600/700/800/900 (737 NG) family of Airplanes incorporated a Speed Trim System to augment the basic Airplane's speed stability during certain low speed, high thrust flight conditions by moving the horizontal stabilizer during manual flight (autopilot not engaged). The STS was carried over to the 737-7/-8/-9 (737 MAX) family of Airplanes. Additionally, on 737MAX Airplanes, the MCAS function was added to the STS to address the pitch characteristics described above

The Speed Trim function, which is part of the Speed Trim System, is implemented as a control law within the flight control computer (FCC[13]), and commands incremental stabilizer trim through the automatic trim control system circuitry. There are two different stabilizer trim rates depending on the position of the flaps[14]. A schedule determines the desired incremental stab deviation from the last trimmed position as a function of airspeed and flap position.

[13] The flight control computers (FCC) are part of the Enhanced Digital Flight Control System.
[14] When the flaps are down, the stabilizer rate is three times faster than when the flaps are up.

b) MCAS

The MCAS is a function within the Speed Trim System and, when activated, moves the stabilizer during non-normal, flaps up, manual flight, high angle of attack maneuvers to provide a desirable increase in stick force gradient and improved static longitudinal pitch stability. Similar to the Speed Trim function, the MCAS function is also a flight control law[15] contained within each of the two FCCs. Only one FCC at a time is permitted to send Speed Trim System commands to the stabilizer trim motor. At Airplane power-up, the master FCC defaults to the left side FCC; and will then alternate between the left and right FCC by flight. Certain failures cause the master FCCto change in flight. The master FCC is not affected by the position of the Flight Director switches. The FCCs receive inputs from several systems including the Air Data Inertial Reference System (Fig. 20). Specific to the MCAS, the control law commands the stabilizer trim as a function of the following: air/ground signal, flap position, angle of attack, pitch rate, true airspeed and Mach.

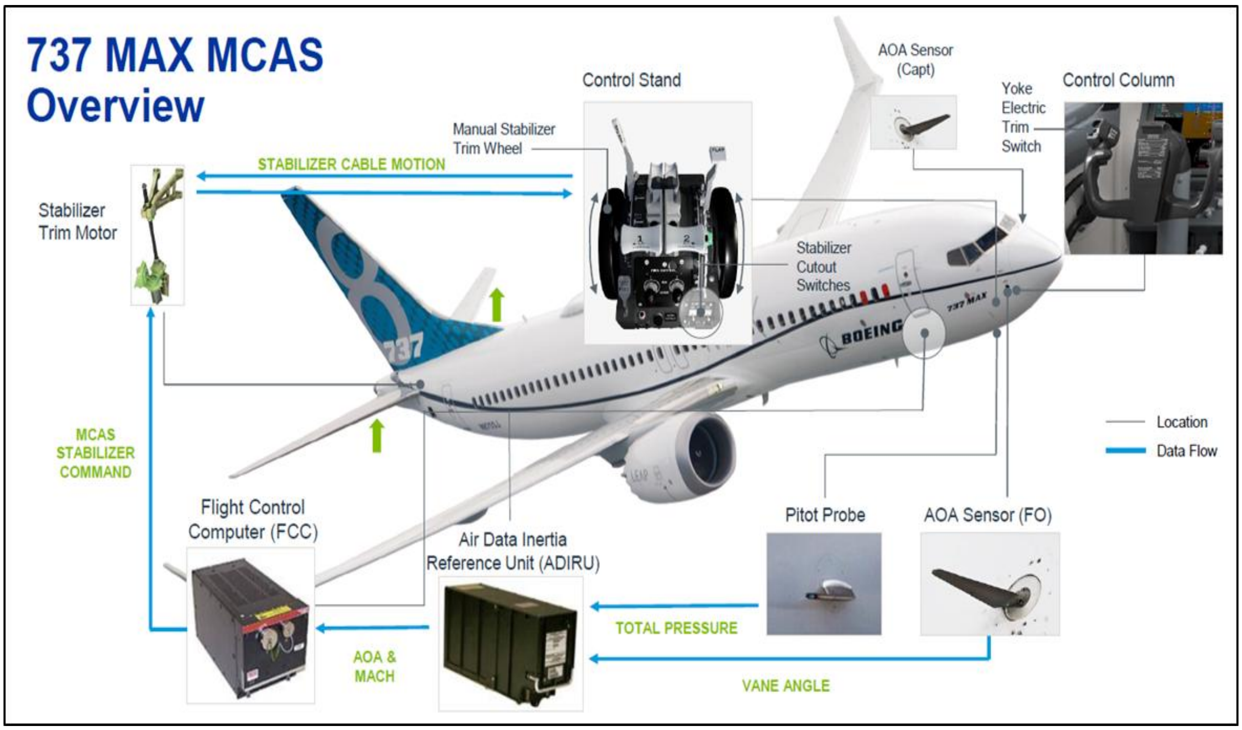


FIGURE 20: DIAGRAM SHOWING THE COMPONENTS OF MCAS[16]

[15] MCAS is an open loop flight control law.

[16] Reference Boeing 737 MAX MCAS briefing, dated March 25, 2019.

The AOA and Mach inputs are provided to each FCC by the associated air data inertial reference unit (ADIRU). Each ADIRU receives AOA information from one of the two resolvers contained within the associated AOA sensor (i.e. the Left ADIRU uses left AOA vane and the Right ADIRU uses the right AOA vane). Information from the other resolver contained within the AOA sensor is provided to the Stall Management Yaw Damper Computer (SMYD), which is used, along with data from other sources, for the purpose of calculating and sending commands to the Stall Warning System (SWS)[17].

As originally delivered, the MCAS became active during manual (autopilot not engaged), flaps-up flight when the AOA value received by the master FCC exceeded a threshold based on Mach number. When activated, the MCAS provided a high rate automatic trim command to move the stabilizer towards Airplane Nose Down. The magnitude of the Airplane nose down command was based on the AOA and the Mach. After the non-normal maneuver that resulted in the high AOA, and once the AOA fell below a reset threshold, MCAS would move the stabilizer to approximately the original position and reset the system. At any time, the stabilizer inputs could be stopped or reversed by the pilots using their yoke-mounted electric stabilizer trim switches, and then the MCAS system will reset after a 5 second delay.

The latter behavior is based on the assumption that flight crews use the trim switches to completely return the Airplane to neutral trim. In the FCC software version current at the time of the accident, if the original elevated AOA condition persists for more than five seconds following completion of a main electric trim input, the MCAS flight control law will command another stabilizer nose down trim input (with the magnitude based on the AOA and Mach sensed at that time).

On all 737 models, column cutout switches interrupt stabilizer commands, either from the autoflight system (e.g. FCC) or the electric trim switches in a direction opposite to elevator command. On the 737NG and MAX, two column cutout switching modules, one for each control column, are actuated when the control columns are pushed or pulled away from zero (hands off) column position. When actuated, the column cutout switching modules interrupt the electrical signals to the stabilizer trim motor that are in opposition to the elevator command.

The MCAS function requires the stabilizer to move nose down in opposition to the column commands when approaching high angles of attack. To accommodate MCAS, the column cutout function in the first officer's switching module was modified to inhibit the aft column cutout switch while MCAS is active, allowing Airplane nose-down stabilizer motion with Airplane nose-up column input. Once MCAS is no longer active, the normal column cutout function in the stabilizer nose down direction is reinstated. Although the column

[17] The SWS operates the control column stick shakers to alert the crew when the Aircraft is nearing an aerodynamic stall.

cutout function will not interrupt an MCAS input, any main electric trim input would immediately override any MCAS command and the stabilizer will move in the direction commanded by the flight crew.

Operation with Autopilot On

When the autopilot is engaged, the autopilot logic provides automatic trim up and trim down commands to the horizontal stabilizer to reduce the need for any sustained deflection of the elevator. Neither Speed Trim nor MCAS are active when the autopilot is engaged.
When the autopilot is engaged, the FCC provides automatic trim up and trim down commands to the horizontal stabilizer and this moves the stabilizer to reduce the amount of trim held by the elevators.

STABILIZER TRIM CUTOUT SWITCHES

There are two stabilizer trim cutout switches located next to each other on the aisle stand just aft of the flap lever. They are identified as the STAB TRIM PRI (stabilizer trim primary) cutout switch and the STAB TRIMB/U (stabilizer trim back up) cutout switch. If either switch is positioned to CUTOUT, power is removed from the stabilizer trim motor and neither main electric trim nor automatic trim can move the stabilizer.

1.6.5.12 PFDIndications

The Display Processing Computer (DPC) in the MAX Display System processes the data displayed on the PFDs. The Boeing 737 MAX 8 has two DPCs. The DPC receives ARINC 429 digital data and analog discrete from various Airplane systems. The DPCs processes these data to be displayed on the Display Units (DU) located within the flight deck. Both DPCs receive data from both the left and right ADIRU and either DPC is capable of driving the captain’s and first officer’s displays.

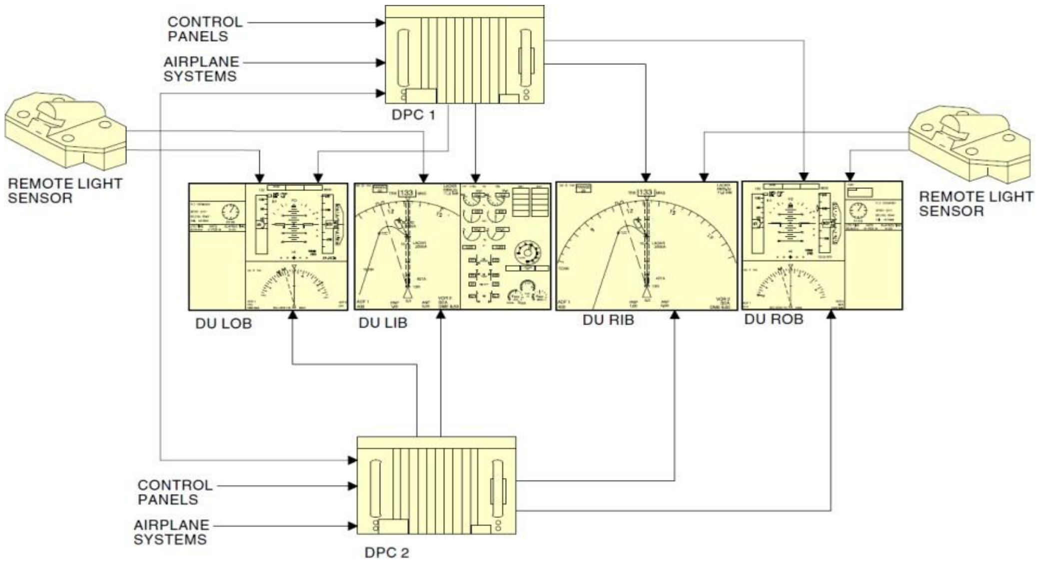


FIGURE 21: MAX DISPLAY SYSTEM

PFD flags

In the event of certain system failures, the data provided to the Display Processing Computer (DPC) may become invalid, e.g. No Computed Data (NCD) or Failure Warning (FW).In response, DPC and the Primary Flight Display (PFD) will show a flag instead of the particular parameter (ALT, SPD, ATT, etc.) with amber color and the particular parameter will not be shown in the PFD.Fig. 22 provide an example of the speed and altitude (ALT) flags.

FIGURE 22: INSTRUMENT SPD AND ALT FLAGS APPEAR ON PFD

1.6.5.13 IAS and ALT Disagree

Both DPCs compare each other's data and in the case that the data is not similar at certain values for a certain period of time, the corresponding disagree message will be displayed on both PFDs.

1. IAS disagree (Indicated Airspeed disagree) message appears if the airspeed indications on both PFDs different by more than 5 Kt for more than 5 seconds.

2. ALT disagree (altitude disagree) message appears if the altitude indication on both PFDs different by more than 200 feet for more than 5 seconds.

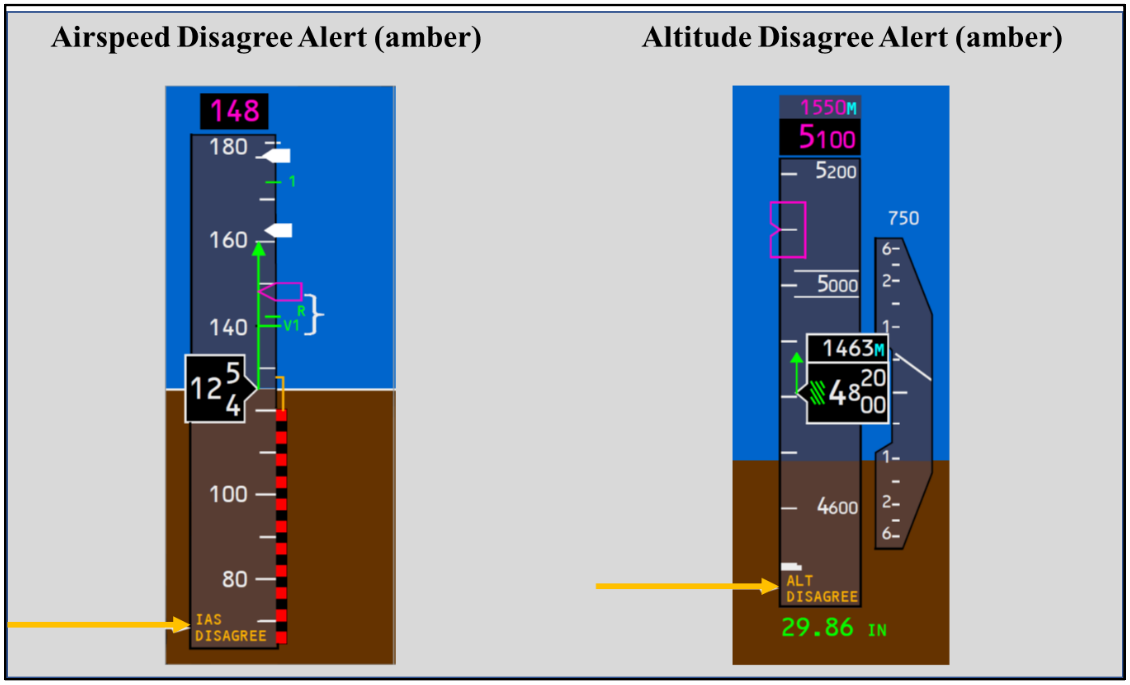


FIGURE23: IAS AND ALT DISAGREE MESSAGES ON THE PFD

MINIMUM MANEUVER SPEED AND MINIMUM SPEED

The minimum maneuver speed is indicated by the top of the amber bar on the PFD when the Airplane is in flight. This airspeed provides:

- The 1.3g maneuvers capability to stick shaker below approximately 20,000 feet.
- The 1.3g maneuver capability to low speed buffet (or an alternative approved maneuver capability set in the FMC maintenance pages) above approximately 20,000 ft.

The minimum speed is indicated by the red and black barber pole. The top of barber pole indicates the speed at which stick shaker occurs.

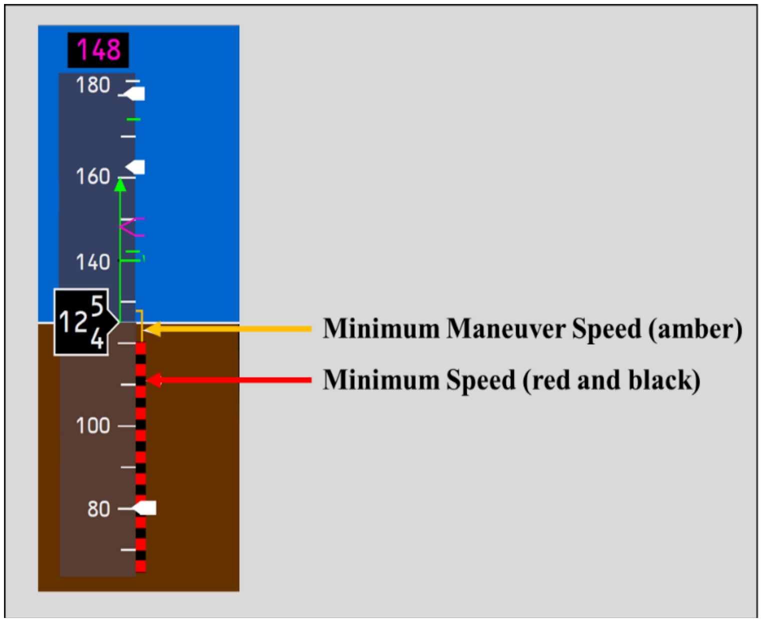


FIGURE24: Minimum Maneuver Speed and Minimum Speed Indications on the PFD

MAXIMUM OPERATING SPEED

The Maximum operating speed (Maximum Mach operating speed (MMO) or Maximum operating speed (VMO) is displayed by the red and black barber pole warning band and the Maximum maneuver speed is displayed by the amber bar on top of the speed tape indication on the PFD. The Maximum operating speed is shown in Figure 25 below. The bottom of the barber pole indicates the Maximum speed as limited by the lowest of the following:

- Vmo/Mmo
- Landing gear placard speed
- Flap placard speed

When an over-speed condition occurs, a clacker aural warning will be active. The warning clackers can be silenced only by reducing airspeed below Vmo/Mmo.

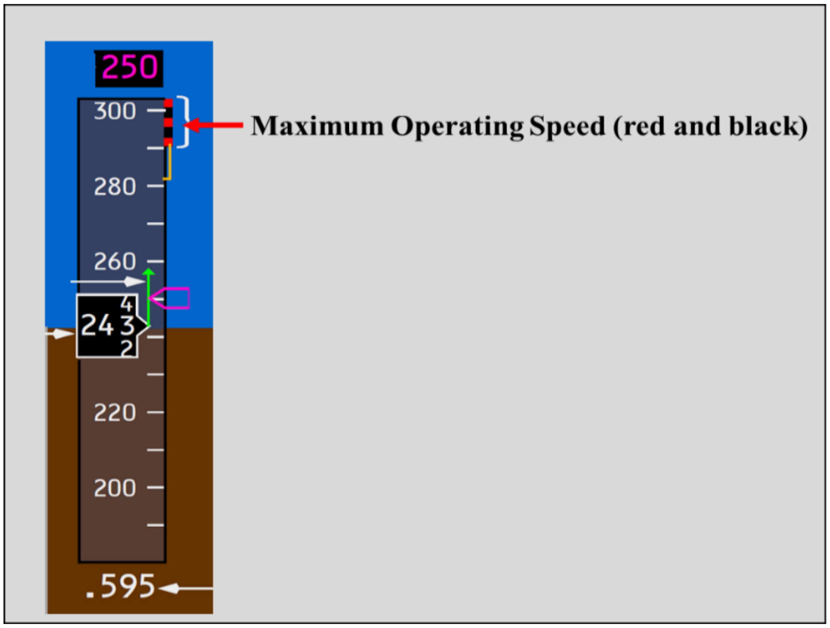


FIGURE 25: MAXIMUM OPERATING SPEED

1.6.5.14 Alerts and Warnings

GPWS Mode 3 A

Mode 3 provides alerts for significant altitude loss after takeoff or low altitude go-around with gear or flaps not in the landing configuration. The amount of altitude loss that is permitted before an alert is given is a function of the height of the airplane above the terrain as shown below. This protection is available until the EGPWS determines that the Airplane has gained sufficient altitude that it is no longer in the takeoff phase of flight. Significant altitude loss after takeoff or during a low altitude go-around activates the EGPWS caution lights and the aural messages “DON’T SINK, DON’T SINK”.
The aural message is enunciated twice for each 20% degradation in altitude. Upon establishing a positive rate of climb, the EGPWS caution lights extinguish and the aural alert will cease.

The following system's inputs are used for Mode 3 operation:

- Radio altimeter transceivers
- Left and right ADIRUs
- GPWS module
- Landing gear handle switch
- SMYDC 1 and 2.

The GPWC uses this data to detect mode 3 alerts:

- Radio altitude
- Inertial altitude
- Inertial vertical speed
- Barometric altitude
- Barometric altitude rate
- Flap angle
- Gear position.

The alert envelope is as follows:

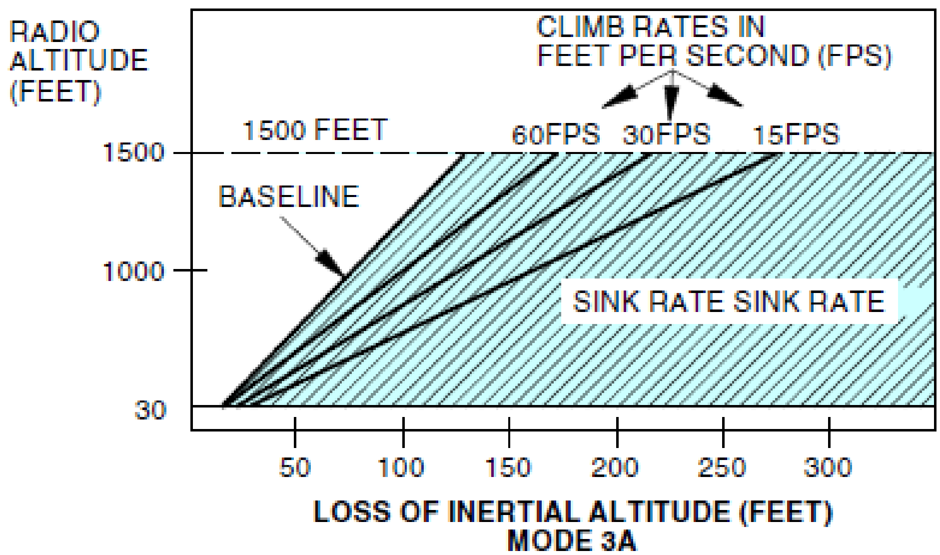


FIGURE26: ALERT ENVELOPE FOR THE MODE 3A (FROM AMM §34-49-00)

1.6.5.15 FEEL DIFF PRESSALERT

The elevator feel computer uses hydraulic pressure from the system A and B flight control modules. When there is a difference of 25% percent between system A and system B metered pressure the feel differential pressure switch closes. When this switch is closed for more than 30 s, the FEEL DIFF PRESS light illuminates (Overhead panel).

The FEEL DIFF PRESS belongs to the flight control (FLT CONT) master caution group (left side glareshield).

1.6.5.16 Overspeed

Two independent Mach/airspeed warning systems (one for each side) provide a distinct aural warning (clacker sound), as long as the Maximum operating airspeed (VMO/MMO) is exceeded. The signal is triggered by the ADIRU.

1.6.6 WEIGHT AND BALANCE

The Airplane left the stand with a weight of 72,011kg; the weight was distributed as follows:

- Operating Empty Weight: 47,090kg;
- Passenger weight (148 adults and 2 children): 11,309kg;
- A last-minute change (LMC) corrected the final weight to take into account the no-show of one passenger (- 100 kg).
- Hold weight (baggage[18]): 2,912kg;
- Block fuel: 10,700 kg.

The taxing fuel weight was 115kg. The takeoff weight was 71,896kg. The regulated takeoff weight is 72,400 kg.Takeoff Center of Gravity (CG) was 23.12.

For this flight, the weight and balance determined by the crew of the Airplane was within the limits defined by the manufacturer.

1.7 METEOROLOGICAL INFORMATION

The accident occurred at 05:44 UTC. The pertinent Addis Ababa Bole International Airport, (HAAB) surface weather observations provided by the National Meteorological Agency of Ethiopia are as follows:-

TABLE 13: MET DATA DURING THE EVENT

MET REPORT HAAB 100300Z	**MET REPORT HAAB 100330Z**	**MET REPORT HAAB 100400Z**
Wind RWY 25 06010KT	Wind RWY 25 06010KT	Wind RWY 25 05008KT
RWY 07 07004KT	RWY 07 06006KT	RWY 07 05006KT
Vis 10km	Vis 10km	Vis 10km
CLD FEW 750M	CLD FEW 750M	CLD FEW 750M
T/TD 13/11^0 C	T/TD 13/11^0 C	T/TD 13/11^0 C
QNH 1028 HPA	QNH 1028 HPA	QNH 1028 HPA
QFE 776.0 HPA	QFE 776.2 HPA	QFE 776.5 HPA
METREPORT HAAB 100430Z	**MET REPORT HAAB 100500Z**	**MET REPORT HAAB 100530Z**

[18]There was 205 kg of mail on board the Aircraft according to the load sheet

Wind RWY 25 05008KT	Wind RWY 25 06008KT	Wind RWY 25 07010KT
RWY 07 05006KT	RWY 07 05008KT	RWY 07 05010KT
Vis 10km	Vis 10km	Vis 10km
CLD FEW 750M	CLD FEW 750M	CLD FEW 750M
T/TD 15/11^0 C	T/TD 16/11^0 C	T/TD 17/09^0 C
QNH 1028 HPA	QNH 1029 HPA	QNH 1029 HPA
QFE 776.6 HPA =	QFE 776.8 HPA =	QFE 777.0 HPA =
METAR HAAB 100300Z	**METAR HAAB 100500Z**	
07004KT9999FEW025 13/11 Q1028=	06008KT 9999 FEW 025 16/10^{0}C Q1029=	
METAR HAAB 100400Z		
06008KT 9999 FEW 025 13/11^0 C Q1028=		

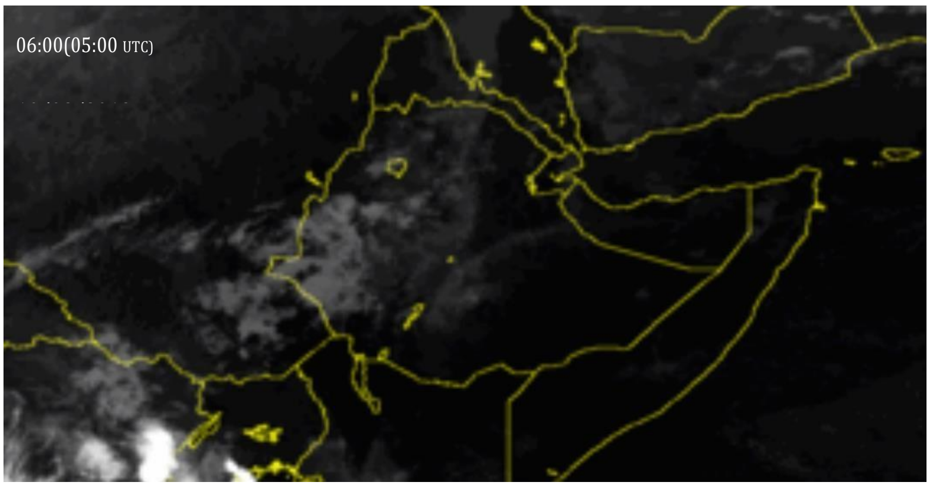


FIGURE 27: METDATA DURING THEEVENT

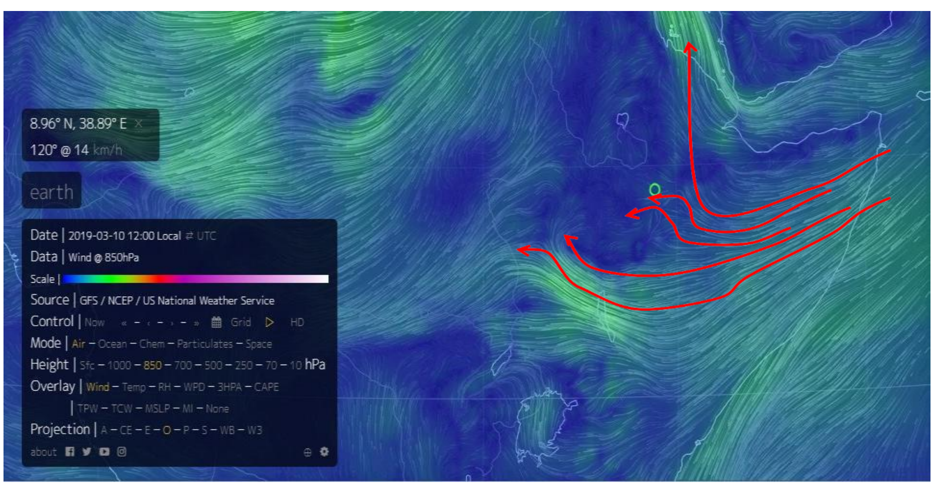


FIGURE28: WIND FROM BELOW LINK

DATE AND TIME 10/03/2019

PLACE OF ORIGIN HAAB

WSET 31 HAAA 100400Z

HAAB SIG MET 01 VALTD 100500/100900 HAAA

HAAB ADDIS ABEBA C/D TURR FCST=

TAF from Addis Ababa Bole International Air Port

TAF HAAB 092130 Z 1000/1106 09008KT 9999SCT028 SCT090 BECMG 1007/1011 12008KT BKT026=

TAF HAAB 100330Z 1006/1112 12010G20KT CAVOK BECCMG 1009/1012 16016KT BECMG 1012/1015 10012G22KT=

MET REPORT HAAB 100500Z

Wind - runway 25: 060 degrees 8 Kt, and runway 07: 050 degrees 8Kt Visibility: 10km; few cloud 750 m; temperature: 16^0C; dew point: 10^0C QNH: 1029 hPa; QFE: 776.8 hPa

MET REPORT HAAB 100530Z

Wind - runway 25: 070 degrees 10Kt, runway 07: 050 degrees, 10Kt Visibility: 10km; few cloud 750 m; temperature: 17^0C; dew point: 09^0C QNH: 1029 hPa; QFE: 777 hPa

1.8 AIDS TO NAVIGATION

Not applicable

1.9 COMMUNICATION

The Ethiopian Accident Investigation Bureau obtained VHF communications information and transcribed pertinent portions of the communications between the flight crew and air traffic control. The VHF Communication frequencies involved were: Ground - 121.29 MHz, Tower - 118.1 MHz & Departure (radar) is 119.7 MHZ.

1.9.1 ATC Communication with ET- 302

1. At 05:14 ETH-302 from stand 6 of main apron called ground control on VHF 121.9 MHZ and requested start engines and push back destination Nairobi FL 360;

2. At 05:16 ATC approved start and push back clearance for ETH-302;

3. At 05:24 ATC issued taxi clearance for ETH-302 to holding position RWY 07R-B 25R-Aand the pilot acknowledged;

4. At 05:28 Airway clearances issued by ATC to ETH 302 and released to 118.1MHZ;

5. At 05: 30 ETH-302 contacted tower 118.1MHZ and instructed to hold on alpha 07R;

6. At 05:37 ETH-302 reported to tower ready for departure;

7. At 05:37:51 ATC issued take off clearance to ET-302 and contact radar on 119.7MHZ;

8. At 05.39:17 ETH-302 contacted radar 119.7MHZ and reported SHALA 2A departure crossing 8400 climbing 320;

9. At 05:39:40 Radar controller identified ETH-302 and instructed to climb 340 able rights direct RUDOL and ETH-302 acknowledge;

10. At 05:40:14 ETH302 reported unable to maintain SHALA 1A and requested RWY heading;

11. At 05:40:20 ATC approved RWY heading;

12. AT 05:41:15 ETH-302 reported to ATC they had flight control problem and requested to maintain 14,000 and ATC approved;

13. At 05:42:32 ETH-302 requested radar control to vector to home and approved;

14. At 05:42:47 ATC instructed ETH-302 to turn right heading 260 and acknowledged;

15. At 05:44:34 ATC called ETH-302 and requested if he could make left turn, but no respond;

16, The ATC called ETH-302 repeatedly, but no response from ETH-302;

1.10 AERODROME INFORMATION

Addis Ababa aerodrome has two runways which consist of two parallel paved surfaces designated 07R/25L and 07L/25R. The elevation of the airport is 2333.5 m. The Airplane took off on runway 07R which was

3800m long and 45m wide. The runway was not grooved but visual inspection revealed a very smooth runway with proper crowning.

Airport name	Addis Ababa Bole Int. Airport
Airport identification	HAAB
Airport operator	Ethiopian Airlines Group
Certificate number Adm.	AC/01/2006 ETH/
Certificate dated	1 June 2015
Certificate effective for	2 years
Runway Direction	07R / 25L
Runway Length	3800 m
Runway Width	45 m
Surface Condition	Asphalt Concrete

The RWY has performed adequate skid resistance to ensure safe landing and takeoff for Airplane; the level of skid resistance provided by a pavement surface is expressed in terms of the surface friction value. The smaller values mean poorer friction and more slippery conditions.The runway surface condition (friction measurement or estimate of the braking action) at Airport is measured using a Mu-meter. According to the Airfield Services Division procedure the runway shall be measured by towing the Mu-meter back and forth five to ten meters from the centerline of the runway at 65 kilometers per hour.
Bole International airport RWY friction test has been done by test speed which is indicated below by friction coefficient.

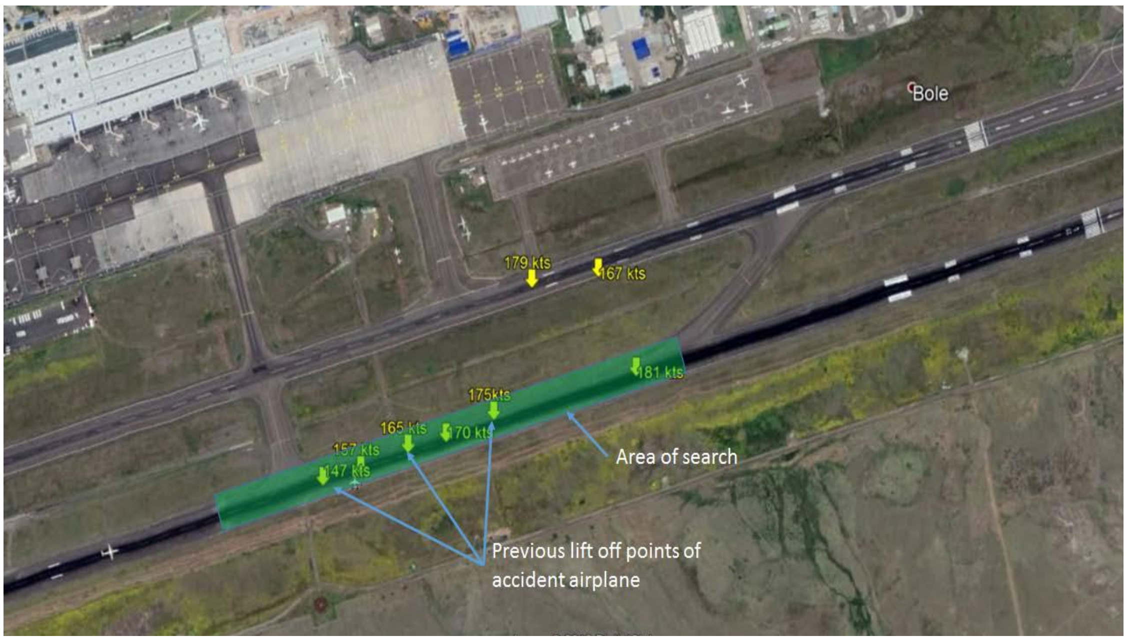
Table14: RWY FRICTION COEF. VALUE

No	RWY designation	Friction coefficient values (%)				Remarks
		A	B	C	Average	
1	RWY 07R	58	62	54	58	Medium
2	RWY 25L	66	58	67	63	Good

Measurement has been carried out on a long line on each side of the center line, approximately 3m or the distance from the center line on which most operations took place.

1.10.1 Aerodrome Inspection

The EAIB investigation, Airworthiness group chairman and team members obtained permission to walk the runway and its sides to check for airplane debris and any evidence of a bird-strike or tail strike. The Investigators walked the area of runway 07R (12,400 feet in length) highlighted in green in the picture 29 below. The length and width of the runway inspected was approximately 3,000 feet and 150ft to the left and right of the centerline. The team started the search in the vicinity of taxiway C and extended toward taxiway D as well as back towards taxiway B. Those participating in the walk searched along in the grass and the runway side where small broken rocks were. The team walked two rounds along the same area but there were no bird remains and AOA vane wreckage. The investigation team confirmed that there was no evidence of a bird and AOA vane remains in the highlighted search area. The team also noted no evidence of damage to the runway surface in this area consistent with a tail strike. FDR data shows that Left AOA deviations began when theairplane was located over taxiway D.



PICTURE: 29 AREA OF SEARCH FOR AOA VANE & BIRD REMAIN

The analysis part of Collins laboratory simulation test for the AOA vane was presented to the EAIB. Even though bird strikesmaybe one of the causes, a wide range of power quality problems and error sources that can affect an airplane's electrical and electronic systems resulting in unstable and erroneous AOA Sensor output signals were not analysed.

Despite the two fatal accidents and the electrical problems associated with the AOA Sensors, Collins Aerospace did not evaluate the electrical installation and testing procedures being performed by Boeing production.

The following partial list could have been considered in the analysis:

a. Damaged EWIS resulting in short circuits or open circuits

b. Circuit component failures and overloaded circuits resulting in changes to rated voltage, current, resistance
c. Reference carrier frequency and amplitude variations
d. Improper bonding and/or grounding
e. EMI, HIRF, Noise
f. Mechanical failures

Hence, the investigation team cannot comment and verify on the conclusions noted in Collin's report.

On both RWY sides there were stationed people who used to protect the area from Birds, whenever any wild animal or bird dies around the area they immediately collect it so as not to be attracted by other big birds or small carnivorous animals; therefore, according to their witness reports there was no bird or other remains found.

The investigation team was also appraising of the bird control program at Addis Ababa International Airport. This consists of a number of individuals stationed in the grass area between the two runways. These individuals have shotguns which are used to startle noted birds so that they avoid the area immediately adjacent to the runways.

1.10.2 RUNWAY (RWY) and TAXI- WAY (TWY) Markings and LGT

Runway LGT edge elevated bi- directional and brilliance control of combination of white and amber lights.
Threshold lights: Green light across displaced threshold
TWY markings: Centerline. Taxi holding position edge TWY designator boards
TWY LGT: Edge elevated Omni directional blue lights.

1.10.3 RWY Infrastructure

The runway, stop way and taxiway surfaces are all covered in tarmac. The aerodrome has night lighting. All of the obstacles are equipped with lighting systems. The runway has white runway lights, red runway end lights and green unidirectional threshold lights. The stop ways have red lights. Runway 25, which is equipped for instrument approaches, has centerline approach lighting over a distance. No operational anomalies were noted in the lighting either by the crew of flight MSR 851 or by the crews of having used it before and after the accident.

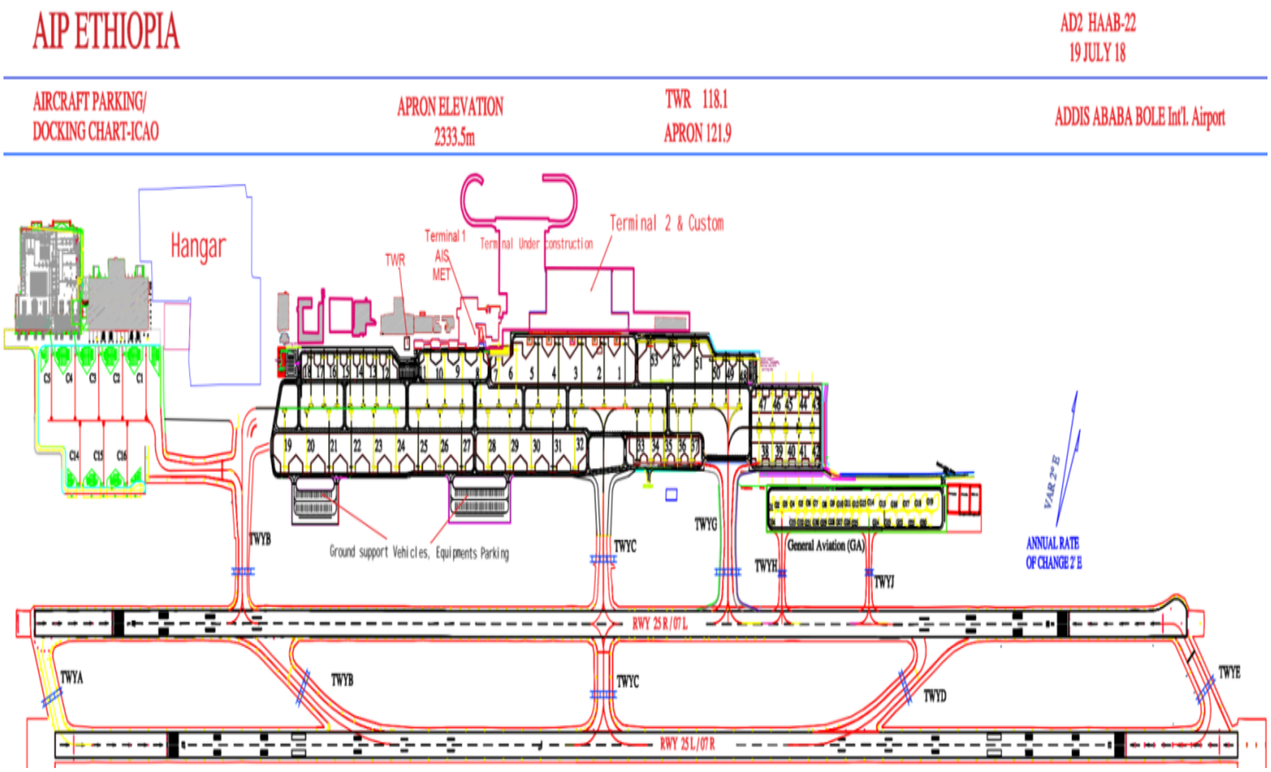


FIGURE 30: AIRPORT STRUCTURE

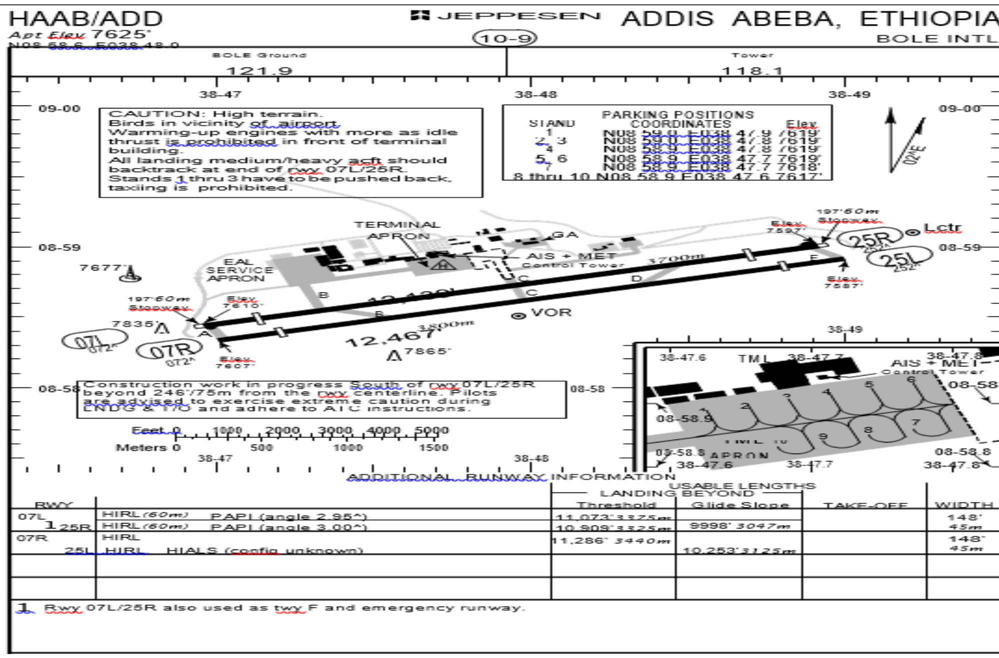


FIGURE 31: RWY & TAXI WAY LAYOUT

The Addis Ababa Bole International Airport is the major hub for Ethiopian Airlines and one of the largest airports in Africa. The ultra-modern airport terminal was inaugurated on January 21, 2003. This terminal handles all international flights with its modern facilities.

Addis Ababa Airport is the busiest airport in East Africa with a capacity of providing world class passenger and cargo services to more than 6.5 million international and domestic passengers each year.

1.11 FLIGHT RECORDERS

The Airplane was equipped with a Digital Flight Data Recorder (DFDR) and Cockpit Voice Recorder (CVR), which were located in the aft cabin and aft cargo hold (respectively) section of the Airplane.

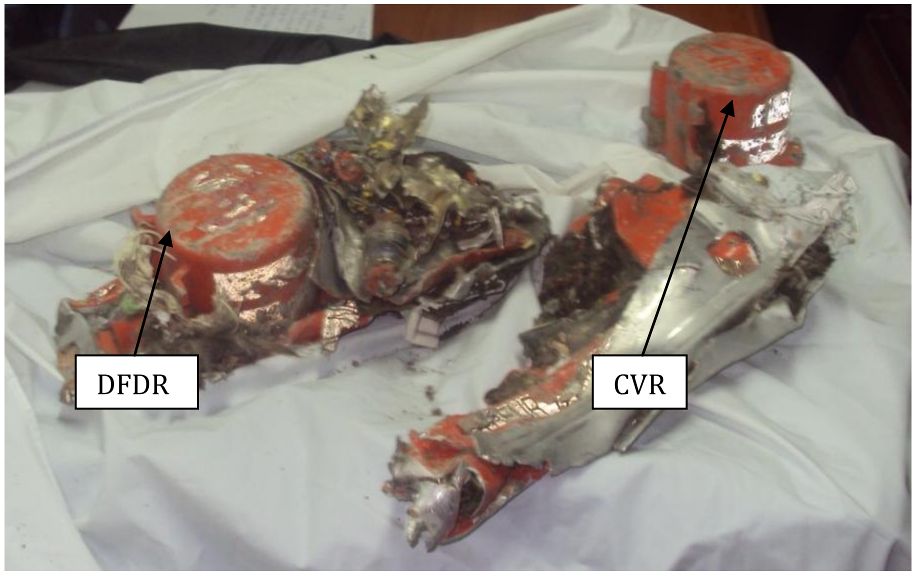


FIGURE 32: DFDR AND CVR AS DISCOVERED ON THE ACCIDENT SITE.

1.11.1 Digital Flight Data Recorder

The Airplane was equipped with a FA2100 NAND DFDR manufactured by L3-com with part number 2100-4945-22 and serial number 001217995.

On 11 March 2019, the DFDR was recovered from the accident site by the EAIB. On 12 March 2019 the DFDR chassis with the Crash Survivable Memory Unit (CSMU) attached were transported to the French BEA recorder facility for data downloading.

The delegation from Ethiopia (EAIB) arrived at the BEA facilities. The team visited the BEA facilities and an agreement was prepared to describe how the readout operations would be performed. Following the signature of the *executive technical cooperation program document*, the recorder's data recovery operations started. National Transportation Safety Board (NTSB) of the United States of America as Accredited Representatives, advisors (Boeing, FAA and EASA) participated in the operation the Ethiopian EAIB had brought a suitcase containing the equipment that was recovered on the accident site:
- A complete recorder (chassis and CSMU)
- A CSMU separated from its chassis

- A chassis without its CSMU

The information provided by the manufacture indicated that the Airplane was fitted with the following recorders.

TABLE15: FDR, CVR IDENTIFICATION

	FDR	CVR
Manufacturer	L3-com FA2100 NAND	L3-com FA2100 NAND
Part number	2100-4945-22	2100-1925-22
Serial number	001217995	001289168

The opening of the recorders and data extraction were done following BEA FA2100 NAND procedure, which is based on the *AIK Accident Investigator Procedure, FA2100 series*, Rev 7 dated 16th September 2015 published by L3 communications (reference 905-E1436-22).

FIGURE 33: DFDR IN THE SUITCASE

The memory puck was opened and the electronic board containing the memory component support was extracted. The memory board identification was P/N 205-E5458-04, S/N 001157901 and the flex identification was 024-E5675-20 REV, 1809-1.

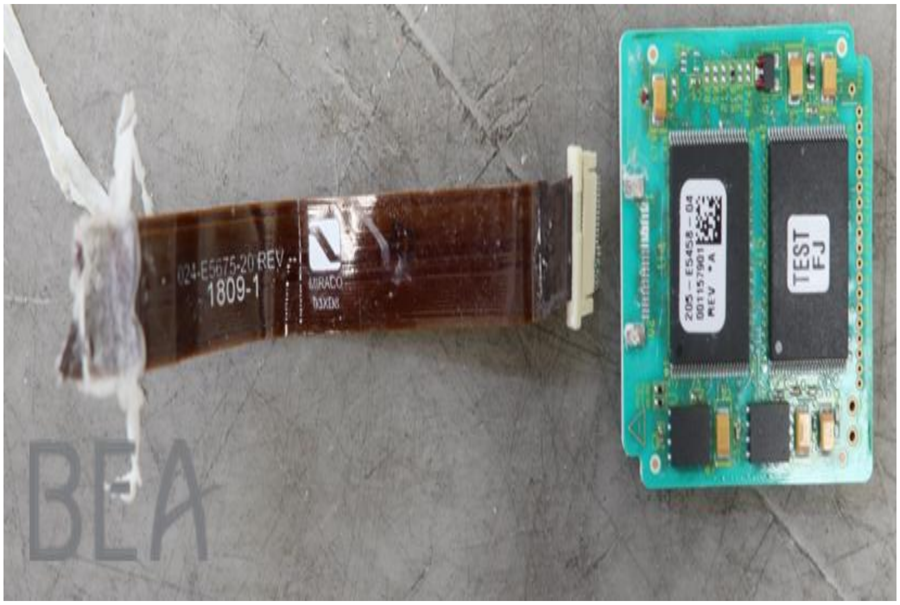


FIGURE 34: FDR MEMORY BOARD, FLEX AND CONNECTOR

The memory board was visually inspected with a Keyence microscope. Apart from the connector pads, the memory board was in good condition. There was no trace of impact. The two memory chips as well as the micro-processor were found in good condition.

The recorder read-out was performed by BEA (Bureau d'Enquête Analyses pour la sécurité de l'aviation civile) investigators for the Ethiopian Accident Investigation Bureau (EAIB) under the authority of Ethiopian investigators with the participation of the U.S National Transportation Safety Board (NTSB), The Boeing Company, U.S Federal Aviation Administration (FAA) and EASA.

The downloaded file provided more than 73hrs of valid data, including the flight of the event. The FDR data were decoded using the Boeing data frame provided by the NTSB and described in the document *Digital flight data acquisition unit 737 MAX Data frame interface control and requirements* document, reference D226A101-6, rev E dated 10th January 2019.

DFDAU INFORMATION

The validity tests and the way the DFDAU provides the invalidity information to the FDR are defined inside the appendix B of 737 MAX Data frame interface control and requirements document.

The following has to be taken into account when analyzing the recorded FDR data:

- FDAU records the invalidity pattern once 4 consecutive invalid values have been received. As a consequence, when an invalidity pattern is detected inside the recorded data, the 4 previous samples shall also be considered as invalid.
- Taking into account the invalidity pattern (Data – Error code – Data – 0), an invalidity of a parameter during less than 6 samples cannot be detected inside the recorded data. Indeed, the FDAU would transmit in this case: 4 samples of data as if they were valid, then the invalidity pattern starting with the data and then only the error code (the 6th values recorded after the start of the invalidity). For a parameter recorded each second, up to 6s of invalidity may not provide any cue inside the recorded data.

These impacts are illustrated in Fig 35 with the same parameter plotted twice (raw recorded values on the top and engineering values on the bottom).

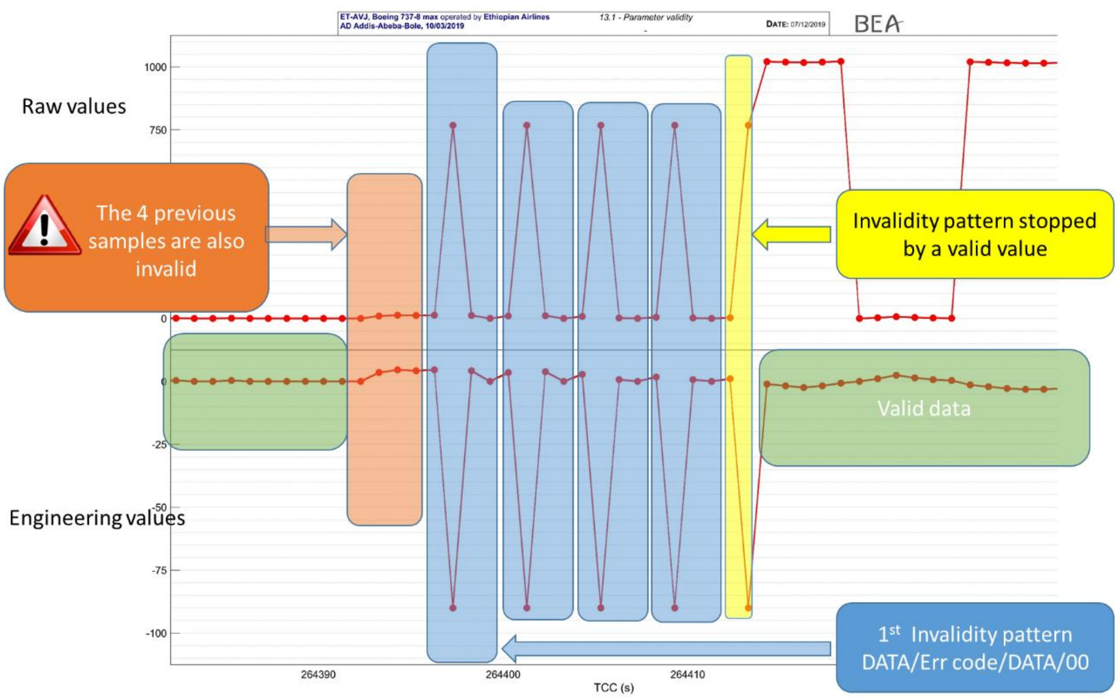


FIGURE35: ILLUSTRATION OF THE INVALIDITY RECORDING

Specific information for FDR data analysis

Stab trim cutout switches positions

No discrete parameter records the positions of the stab trim cutout switches. However, some recorded parameters provide information on these positions:

- The discrete parameter of the manual electric trim command records command (up or down) only when both stab trim cutout switches are in the normal position.
- The discrete parameter of the FCC trim command records command whatever the positions of the stab trim cutout switches are. When FCC commands are recorded, if no stabilizer motion is recorded, it means that at least one stab trim cutout switch is in the CUTOUT position.

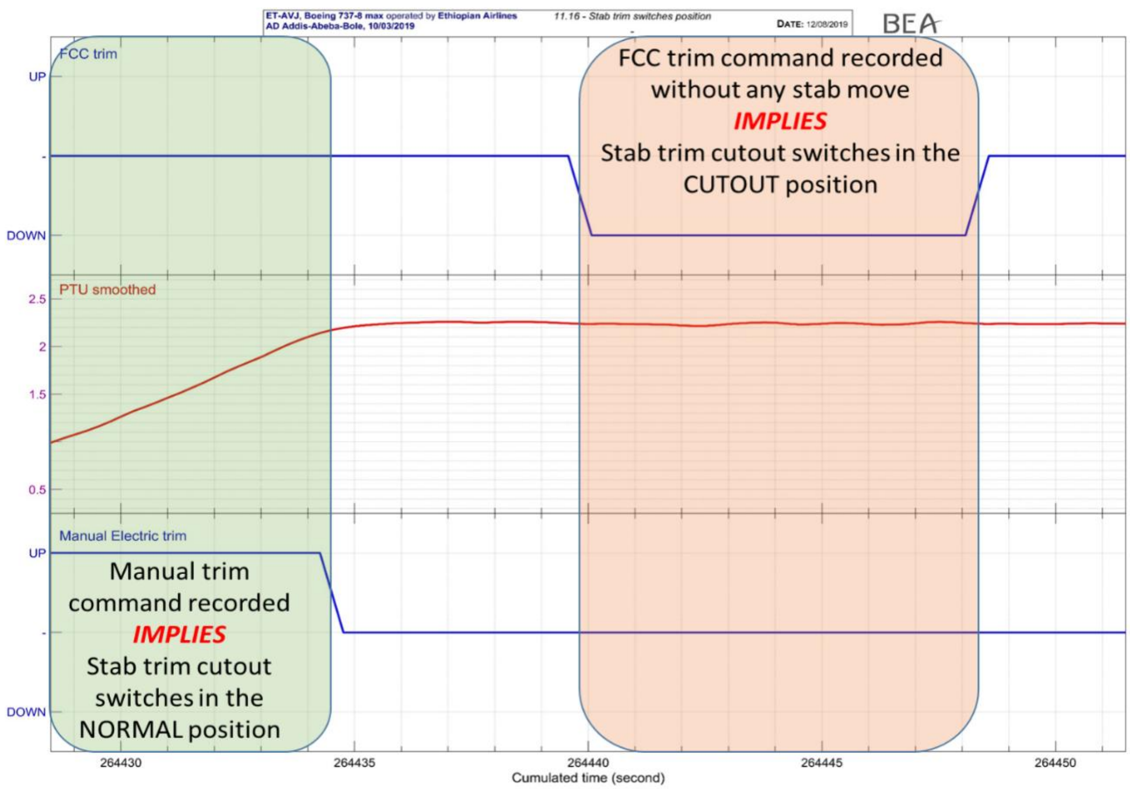


FIGURE 36: STAB TRIM CUTOUT SWITCHES POSITION

MCAS DETECTION

No discrete parameter records the MCAS activation. However, MCAS activation can be detected with the following recorded information:

1. The autopilot is not engaged
2. The flaps are retracted
3. The initial stabilizer movement is commanded by the FCC in the Airplane nose down direction
4. If stabilizer moves, the trim rate is 0.27°/sec. (The flap down trim rate is used during MCAS activations, even though flaps are up).
5. If stabilizer did not move, the FCC command shall last during a time consistent with the MCAS computed duration.
6. If a manual trim command was performed before, MCAS triggers after a delay of 5 s.

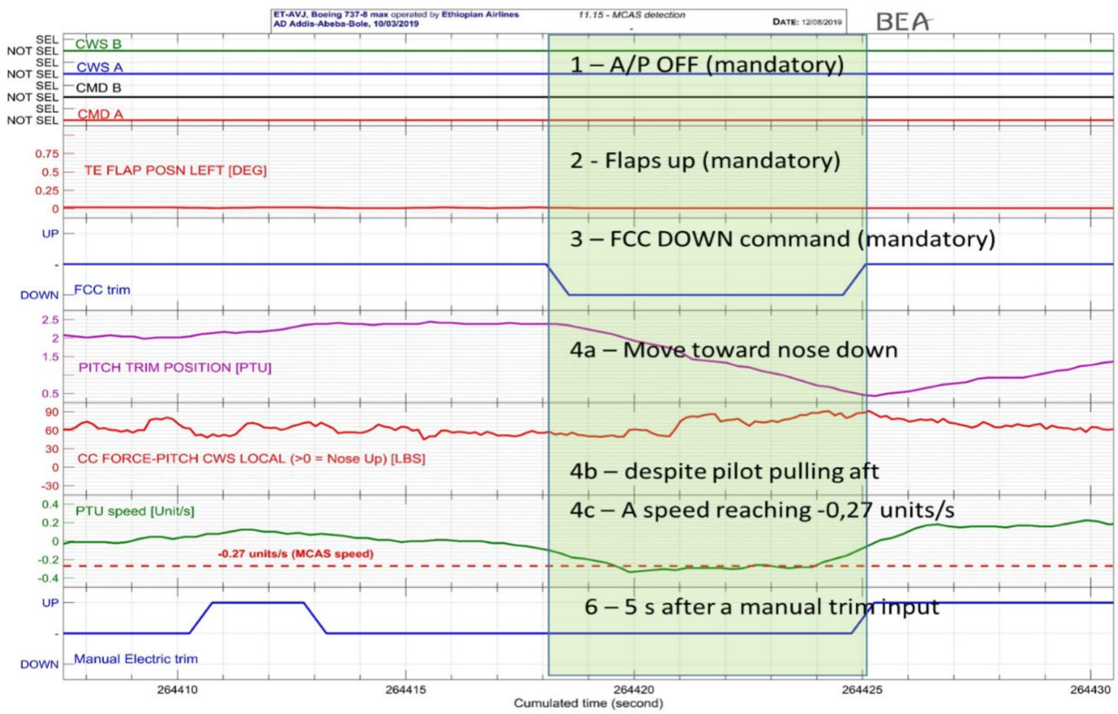


FIGURE 37: MCAS DETECTION WITH FDR DATA

1.11.2 Cockpit Voice Recorder

The Airplane was fitted with a FA2100 NAND CVR manufactured by L3 Communications with part number 2100-1925-22 and serial number 001289168.

FIGURE 38: CVR CSMU

On 11 March 2019, the CVR was recovered from the accident site by the EAIB. The CVR CSMU was transported to the BEA recorder facility for data downloading. The CMSU was found separated from the chassis during wreckage recovery. The read-out was performed by BEA under the authority of the Ethiopian Accident Investigation Bureau (EAIB), with the observation of the National Transportation Safety Board (NTSB) of United States of America.

The memory board identification was P/N 205-E5458-04, S/N 001158641 and the flex identification was 024-E5675-20 REV, 1809-1.

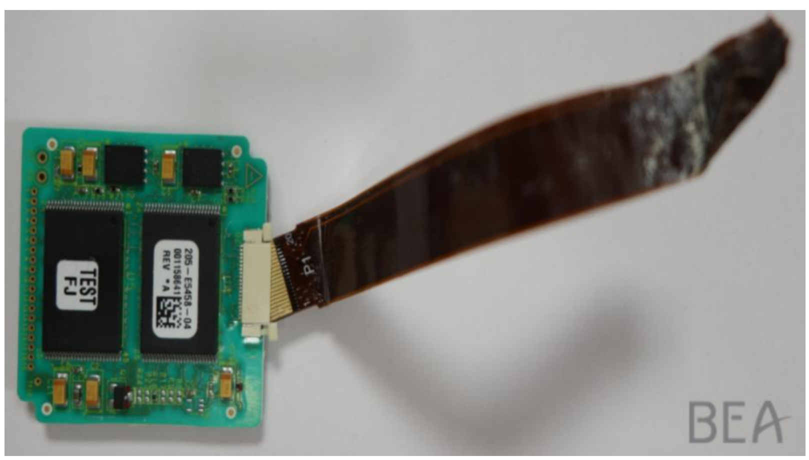


FIGURE 39: CVR MEMORY BOARD AND FLEX

The CVR memory board and flex were visually inspected with the Keyence microscope. There was no damage on the board and the connector was in good condition.
A second observation with the X-ray was made, which confirmed that the connector soldering were in good condition.

The memory unit recorded 2 hours, 4 minutes and 14 seconds of Airplane operation, which contained 2 flights including the accident flight.

1.11.3 Accident Flight CVR Transcript

TABLE16: ACCIDENT FLIGHT CVR TRANSCRIPT

Time (FDR UTC)	Captain	First-Officer	ATC, ground staff, Cabin crew, others …	Warning, sound, remarks
05:37:14	Ready for departure			
05:37:18		>Tower Ethiopian three zero two ready for departure		
05:37:20			>Please stand by	
05:37:22		>Standing by Ethiopian three zero two		
05:37:34			>three zero two clear for take-off runway zero seven right, zero eight zero ten (080/10) airborne Shala two alpha departure contact radar one nineteen seven (119.7) *MelkamMenged (bon voyage)	
05:37:42		>Airborne Shala two alpha departure contact radar one nineteen seven (119.7) Ethiopian three zero two cleared for take-off runway zero seven right		
05:37:50	Ready?			
05:37:51		Ready		
05:37:52	Stable			

05:37:57		N1 TOGA		
05:37:58	Check			
05:38:00		Take-off thrust set		
05:38:01	Cross checked			
05:38:06		Speed increasing		
05:38:07	Checked			
05:38:13	Check	Eighty knots		
05:38:14		Thrust hold		
05:38:15	Check			
05:38:32				SV : V one (V1)
05:38:33		Rotate		
05:38:41		Positive rate		
05:38:43	Gear Up			Clank sound (sound similar to gear lever moved to up)
05:38:43				Stick shaker activates
05:38:44		Gear up		
05:38:49		Master Caution, Anti-Ice		
05:38:50	*Eshi (OK)			
05:38:50				Trimwheel activation sound
05:38:51				Trim wheel activation sound
05:38:52				Trim wheel activation sound
05:38:54				Autopilot disconnect wailer (3 times)
05:38:55	Command			
05:38:58				Trim wheel activation sound
05:39:00	Command			Autopilot disconnect wailer (3 times)
05:39:02	*Yeheendetnew ? (What's going on?)			
05:39:04				Trim wheel activation sound
05:39:06	*Eshi (OK), contact radar			

05:39:08		Contacting radar		
05:39:09	Yeah			
05:39:10			(*)	
05:39:11		> Radar Ethiopian three zero two Good Morning after airborne Shala two Alpha departure crossing eight thousand four hundred climbing three two zero		
05:39:17				Trimwheel activation sound
05:39:23		Command engaged		
05:39:24	Ok, checked			
05:39:25			>Confirm calling three zero two	
05:39:27		>Affirm three zero two		
05:39:29			>Identified	
05:39:30			>Continue climb Flight Level three four zero when able right turn direct to RUDOL	
05:39:35	*Eshi (OK)			
05:39:36		>When able right turn direct RUDOL eh and eh Ethiopian three zero two		
05:39:45	Flaps up	Flaps Up		
05:39:48		(*)		
05:39:49				Sound similar to **flap** lever movement
05:39:50	*Eshi (OK) advise *aregew (go ahead) we are unable request to maintain runway heading			
05:39:55				Autopilot *disconnect* wailer (3 times)
05:39:57	Request to maintain runway heading			
05:40:01	We are having flight control problem			
05:40:02				SV : Don't Sink, don't sink

05:40:05		>Radar Ethiopian three Break, Break Radar Ethiopian three zero two, unable to maint... to Shala one Alpha		
05:40:11	Request runway heading			
05:40:13		> Request runway heading		
05:40:14			>Ethiopian three zero two approved	
05:40:16		>Approved Ethiopian three zero two		
05:40:19	*Eshi (OK), Flaps up speed			
05:40:23				SV : Don't sink, don't sink
05:40:26	*Aregew endeze (Do it like this)			
05:40:27	Trim, Trim, Trim with me, Trim with me, Trim with me, Trim ,Trim up, Trim up*kenegar kenegar (with me with me) (*Name of the First-Officer)* *Awo, Awo, aregew (Yes Yes do it)	Trim, Trim UP		SV : Don't sink, don't sink
05:40:30				Trim wheel activation sound (2 clicks)
05:40:31				SV : Don't sink, don't sink
05:40:35		Stab trim cut-out? Stab trim cut-out?		
05:40:36	*Awo awo aregew (Yes, yes, do it)			
05:40:37		Stab trim cut-out		
05:40:44	pull up, pull up	Pull up		
05:40:50	*Eshi (OK), advise we would to like maintain one four thousand. We have flight control problem			
05:40:56		>Radar Ethiopian three zero two we would like to maintain one four thousand.		

		We have flight control problem		
05:41:02			>Uh say again	
05:41:04		>We have flight control problem we like to maintain one four thousand		
05:41:08			>Approved and uh report intention	
05:41:10		>Will call you maintaining Ethiopian three zero two		
05:41:16	*Eshi (OK) Set one four thousand	Okay		
05:41:17	Set one four thousand, *awo (yes)	one four thousand set		
05:41:20				Over speed clacker started and continued until the end of flight
05:41:23	(Uh sh)			
05:41:24		One four thousand set		
05:41:25	*Speedun (the speed)			
05:41:26		OK		
05:41:28		Speed		
05:41:30	*Eshi (OK), speed, *kenegar (with me). pitch up, pitch up, pitch up, yes, yes, pitch up			
05:41:33		Pitch up?		
05:41:34	Yes, with me	Ok		
05:41:35	Yes	Pitch up?		
05:41:38	Aha continue			
05:41:46	Eh trim *yeseral? (is it functional?)			
05:41:47		*Ayseram, wey beje lemokerew? (it is not working, shall I try manually?)		
05:41:49	*Esti (Try it)			
05:41:49				Click sound (similar to manual trim wheel handle extending)

05:41:50		Trim up		
05:41:54	Eh Eh	*Ayseram (it is not working)		
05:41:56	Ok, with me, keep with me (*Name of the First-Officer)*, keep with me, keep with me	Ehh!(sound of straining)		
05:41:59	Yes			
05:42:00	We have to go up to one four thousand	Ok		
05:42:10	Request a vector to return			
05:42:12		Ok, Eh		
05:42:14		>Radar Ethiopian three zero two request vector to return to home		
05:42:20			>Eh, Confirm, eh, for hold or to come approach?	
05:42:26		>To commence approach for eh...		
05:42:27	Standby, Standby, Standby,			
05:42:28		>Standing by Ethiopian three zero two		
05:42:29	Ehhh (sound of straining)			
05:42:30			>(Turn) right turn two six zero	
05:42:34	Two six zero			
05:42:35		>Right heading two six zero Ethiopian three zero two		
05:42:38				
05:42:40		Two six zero		
05:42:41	Ok (Trink)		(*)	Sound similar to radio interference tone
05:42:42	Pitch up *kenegar (with me)			
05:42:44	*Wede (towards) one four thousand, *eshi, mendennew ? (Ok, what's it?) Master Caution?			
05:42:46		Master caution?		
05:42:47	Eha check *arge (verify)			

05:42:48				
05:42:51		Master Caution anti-ice		
05:42:54	Left alpha vane	Left alpha vane		
05:42:58				
05:43:04	Should we pitch *abren (together)? Pitch is not enough			
05:43:06	Straining sound “pitch is not enough”			
05:43:08	Put them up			
05:43:09				
05:43:10	*Eskezaw (Till then) Command *argew (put it on)			
05:43:12		Command		
05:43:12				Autopilot disconnect wailer (5 times)
05:43:14	No, no, leave it, leave it, it’s ok, it’s ok, let’s go up, let’s go up			
05:43:16	Disconnect, let’s go back right heading	*Eshi (OK)		
05:43:28	Hof (straining sound), pitch up, pitch up, PITCH UUUP!!!!			
05:43:32	Pitch up *arge (to order)			
05:43:34	PITCH (with tone of distress)			
05:43:35				SV : Terrain, Terrain, Pull Up, Pull up
05:43:36	Heh, Heh…. Pitch…Heh			
05:43:39	Eh Eh, MAYDAY MAYDAY MAYDAY (screaming sound)	(screaming sound)		

1.12 WRECKAGE AND IMPACT INFORMATION

The accident site was located near Ejere, Ethiopia with a GPS location of 8.8770 N, 39.2516 E.

The investigation team had much of the wreckage moved from the accident site to a secured location in Addis Ababa EAIB store. The wreckage pile measures approximately 5' high and about 30' in diameter. Assistance from Ethiopian Airlines recovered a number of flight control components – some are documented above during the on-site examination. Below is a detailed exam of each of the identified components.

The Airplane impacted terrain at a farm field and created a crater approximately 10 meters deep (last Airplane part found) with a hole of about 28 meters width and 40 meters length. Most of the wreckage was found buried in theground; small fragments of the Airplane were found scattered around the site in an area about 200 meters wide and 300 meters long. Damages to the Airplane were consistent with a high energy impact.

FIGURE 40: TOP VIEW OF THE CRATER

FIGURE 41: CLOSE VIEW OF THE CRATER BEFORE EXCAVATION

FIGURE 42: ACCIDENT SITE

1.12.1 Left Hand Engine (S/N602722)

The left engine core was recovered from the site and examined by the group. The engine was reportedly recovered at a depth of approximately 10 to 15 meters depth on the left side of the excavation site. The predominant feature of the deformation of the entire remaining core was axial deformation.

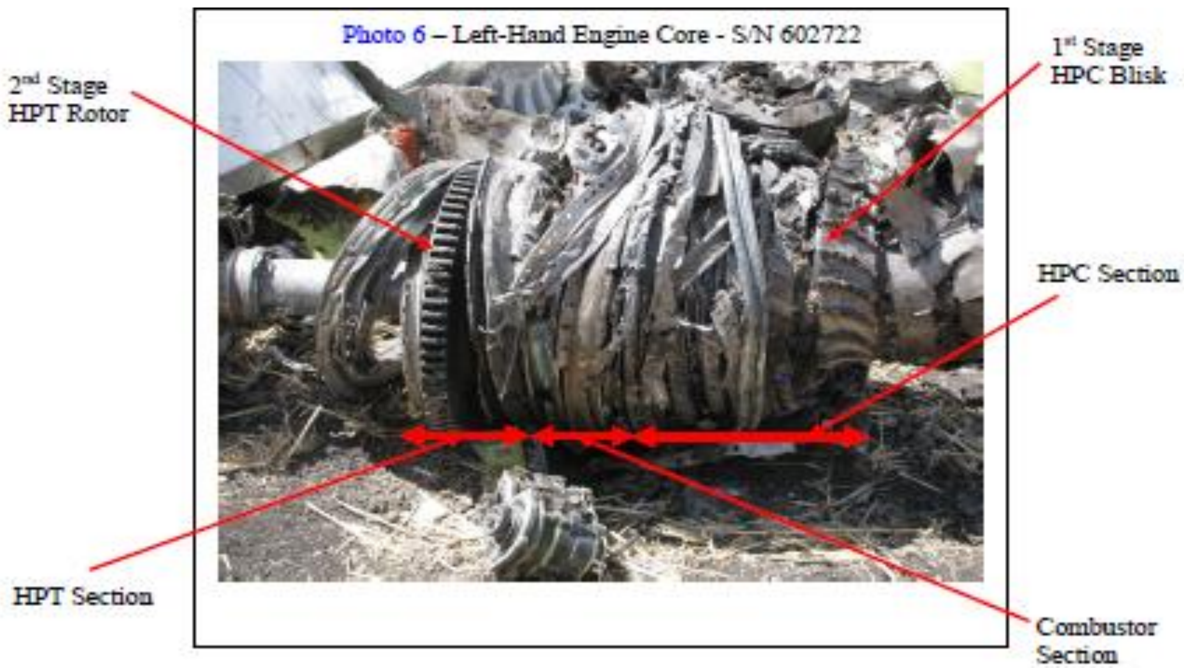


FIGURE 43: LEFT HAND ENGINE SECTION

1.12.2 Right Hand Engine (S/N602695)

The right engine core was recovered from the site and examined by the group. The recovered core of the right engine was more damaged than the left-hand engine. The engine was reportedly recovered at a depth of approximately 10 to 15 meters depth on the right side of the excavation site.

The predominant feature of the deformation of the entire remaining core was axial deformation.


FIGURE 44: R/H ENGINE - S/N 602695 – CORE FIGURE 45: - R/H ENGINE - S/N 602695 – FAN DISK

FIGURE46: R/H ENGINE - S/N 602695 – FAN DISK FIGURE47: R/H ENGINE - S/N 602695 - RETENTION LUGS – FRACTURED

1.12.3 High Pressure Compresser (HPC)

The HPC case was fractured and a portion of it remained with the core and the HPC stages were separated from the core. The 1st, 2nd and 3rd stage blisks were found together and were missing their airfoils. The 4th,

6^{th}, and the 8^{th} to 10^{th} stages were not found. The 5^{th} stage was found separately, and it was also missing its airfoils. The 7^{th} stage web was fractured circumferentially. The stator sections could not be identified.

FIGURE 48: - R/H ENGINE - S/N 602695 – HPC STAGES 1 TO 3 **FIGURES 49:- R/H ENGINE - S/N 602695 – HPC STAGE 7**

1.12.4 Combustion Section

The combustor was severely crushed and most of it was missing into pieces.

FIGURE 50: COMBUSTOR CRASHED

The Airworthiness Group comprised of members from Ethiopian CAA, Boeing, and NTSB convened at accident site, located near Ejere, Ethiopia, on March 12, 2019 to examine the Airplane wreckage with a specific focus on flight controls and the air data system components.

FIGURE51: RECOVERED WRECKAGE PILE ON THE SITE

1.12.5 Recovered Wreckage Examination

The investigation team had much of the wreckage moved from the impact site to a secured location in Addis Ababa EAIB store. The wreckage pile measures approximately 5’ high and about 30’ in diameter. Assistance from Ethiopian Airlines recovered a number of flight control components – some are documented above during the on-site examination. Below is a detailed exam of each of the identified components.

FIGURE 52: RECOVERED WRECKAGE PILE

1.12.6 High Lift Control System Components

The Airworthiness group located components from the high lift control system at the accident site and within the wreckage pile located at the Addis Ababa airport EAIB store.

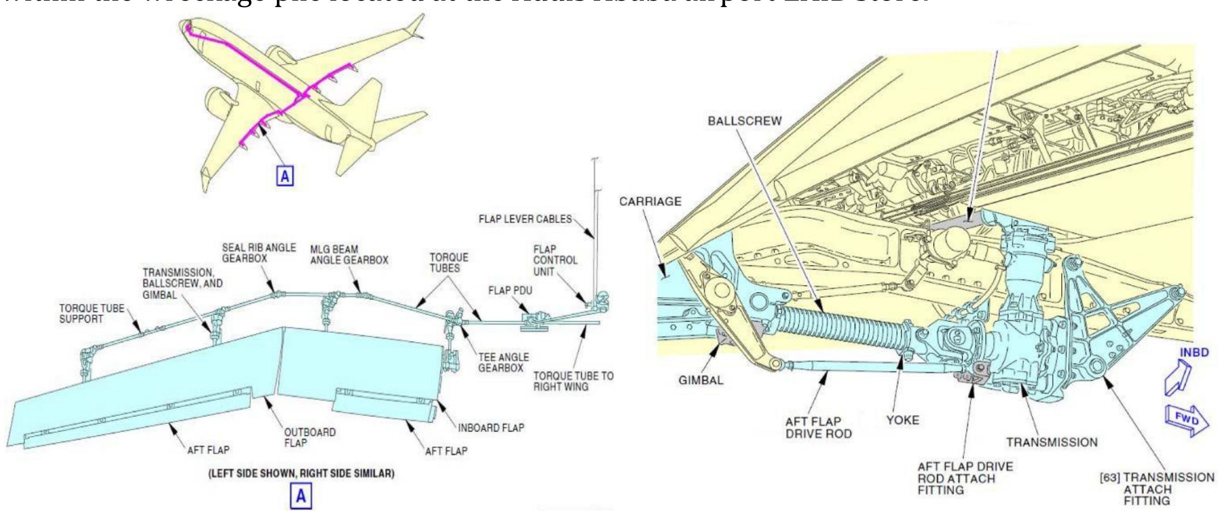


Image of the trailing edge flap system

Image of a flap transmission and ballscrew

FIGURE 53: HIGH LIFT CONTROL SYSTEM COMPONENTS

Two parts of the actuation system were located and examined at the impact site. One consists of the ballscrew, yoke, gimbal and flap transmission; the other consists of just the ball screw, yoke, and gimbal (see **Figures** respectively).

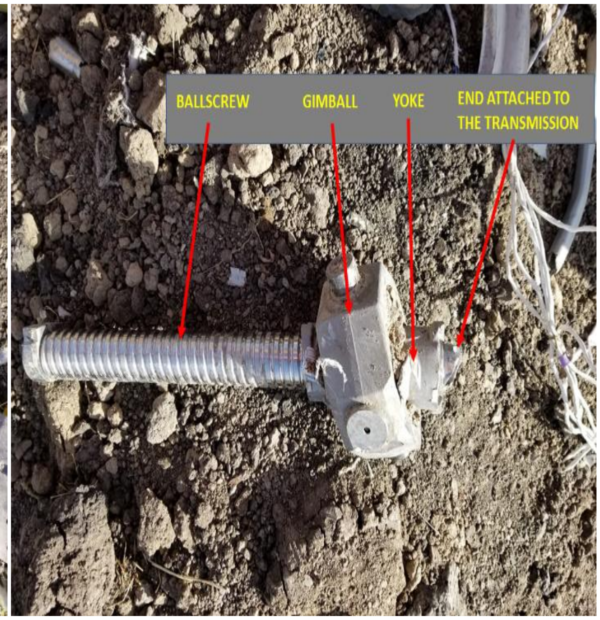


FIGURE54: FLAP TRANSMISSION & BALLSCREW FIGURE55: FLAP TRANSMISSION

The installed location of each unit has not been identified. The position of each gimbal is consistent with the flaps in the fully retracted position.

During the examination of the wreckage pile located at the Addis Ababa airport EAIB store, the Airworthiness group identified a total of 4 (including the ones identified at the impact site) trailing edge flap transmissions (there are 8 total); three of these had the ball nut and gimbal still attached.

FIGURE56: TRAILING EDGE FLAP TRANSMISSIONS AND BALL SCREWS

Again, all three were found in the fully retracted position. There was one additional transmission portion that was found as well as three ball screw segments. All examined damage appears consistent with high energy impact.

1.12.7 Leading Edge Slats Actuators

The high lift control system consists of the trailing edge flaps and the leading edge slats.

Three of the 8 leading edge slat actuators were photographed (see Figures below) at the impact site. The installed location for each actuator has not been identified. The actuator position, as photographed, is in the fully retracted position.

During the examination of the wreckage pile located at the Addis Ababa airport EAIB store the Airworthiness group identified a total of three leading edge slat actuators at the impact site. The actuator position, as photographed, was in the fully retracted position.

FIGURE 57: SLAT ACTUATOR (POSITION UNKNOWN)

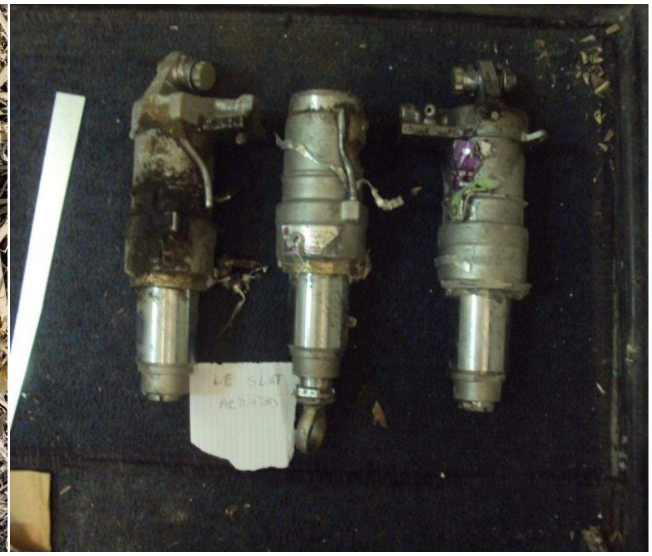


FIGURE 58: LEADING EDGE SLAT ACTUATORS

The Airworthiness group located components from the horizontal stabilizer control system at the accident site and within the wreckage pile located at the Addis Ababa EAIB store.

Most of the located components of the stabilizer trim system were located once the wreckage was transported to Bole International Airport. The only part of the stab trim system located on site was the motor housing (see above). Referencing **figure-54** above, the parts located in the wreckage pile at the airport consisted of the Primary Brake Housing (has the Lower Gimbal on it), the entire jackscrew (fractured into three pieces), and the ballnut (jammed onto the screw). Damage to the components of the stabilizer trim system is consistent with a high energy impact.

1.12.8 Stabilizer Trim Notes & Position

The figure below shows the relationship of the ballnut position along the ball screw. There is a safety rod which acts as a secondary load path should the ball screw fracture in service for any reason. It is attached to a separate set of secondary gimbals below the primary support gimbals on the primary brake housing and to the top of the ball screw. Figure 54 shows the safety rod and that it protrudes out from the ball nut. However, the fracture faces on the 5” long upper screw portion (*note the measurement in Figure 53*) match those found near the ballnut upper stop. This is consistent with the safety rod being pulled out several inches prior to final fracture.

Two parts of the control system were located and examined at the impact site. One consists of aft cable drum; the other consists of the stab trim actuator (see Figures 59 & 60 below respectively). These components do not provide any evidence of what position the horizontal stabilizer may have been at the time of impact.

FIGURE59: AFTCABLE DRUM FIGURE60: STAB TRIM ELECTRIC MOTOR HOUSING

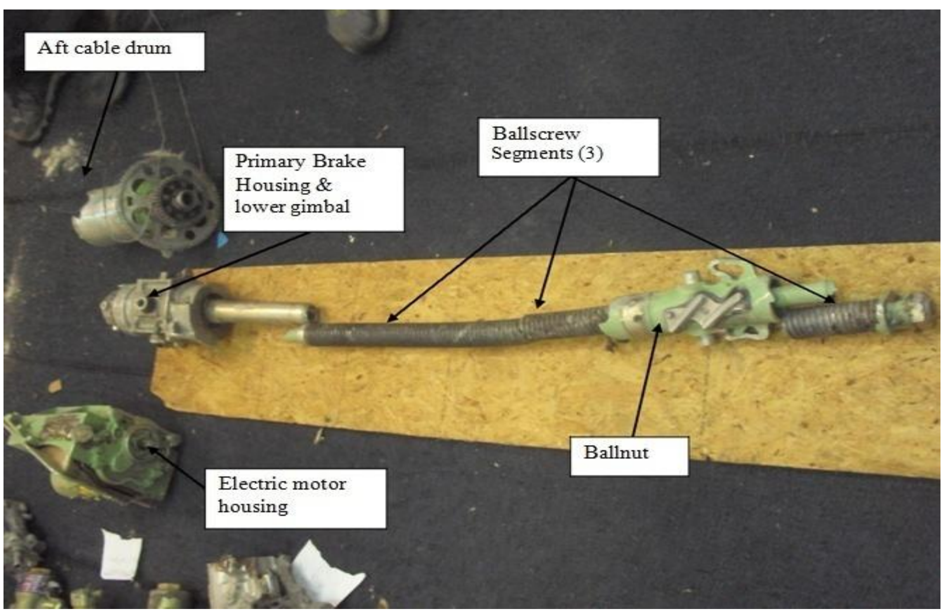


FIGURE 61: RECOVERED STABILIZER TRIM COMPONENTS

Examining the fracture surfaces, the upper screw segment fits with the fracture face just inside the ballnut giving a measurement between the stops on the ballnut and the upper ballnut stop of ~5". Referencing Boeing document D251A122 (737NG Control Position Data), this measurement equates to a stabilizer trim setting of 1.5 degrees Airplane Nose Down (AND) or an indicated position of 2.5 units of trim. Although the data is for the 737NG, the position of the MAX stab trim holds the same relationship. According to Boeing:

TABLE 17: STAB NOTES & POSITION

	Stab.Angle(deg)	Stab. Units
Airplane Nose Down (Stab Leading Edge Up) Mechanical Limit	4.71	-0.71
Main Electric Nose Down (AND) Limit with flaps down (flap not up)	4.45	-0.45
Main Electric Nose Down (AND) Limit with flaps up	0.15	3.85
Neutral Stabilizer	0	4.00
Main Electric Nose Up Limit	-10	14.00
Airplane Nose Up (Stab Leading Edge Down) Mechanical Limit	-12.40	16.40

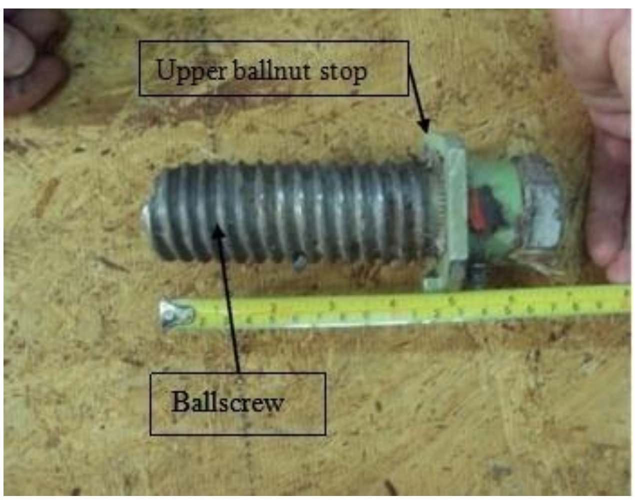


FIGURE62: UPPER BALLSCREW SEGMENT

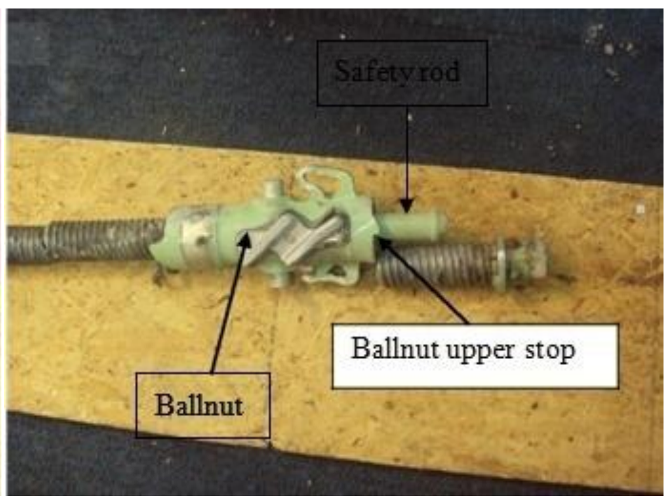


FIGURE 63: BALLNUT AND UPPER BALLSCREW SEGMENT

PITCH CONTROL SYSTEM (ELEVATOR)

The Airworthiness group located components from the elevator control system within the wreckage pile located at the Addis Ababa airport property.

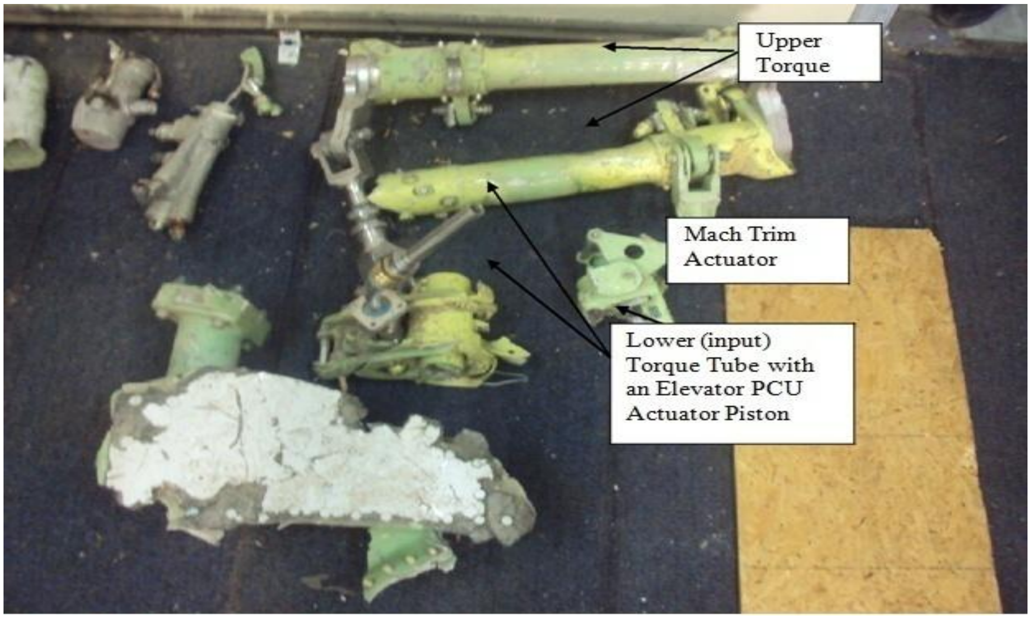


FIGURE64: ELEVATOR PCU ACTUATOR PISTON

The only components that were located for this system were the output torque tube, the mach trim actuator, a small portion of the Elevator feel and centering unit, and a small piece of the elevator input torque tube. Figure 55 above shows the recovered components of the elevator control system. Note that all components, like the lateral components show significant damage consistent with a high-energy impact. The upper torque tube was fractured in half. Only a small portion of the lower (input) torque tube was recovered along with a piston of the Elevator Power Control Unit actuator. The Mach Trim Actuator was found in the fully retracted position.

1.13 MEDICAL AND PATHOLOGICAL INFORMATION

Autopsy and body examination data made available by the Federal Police and foreign autopsy examiners. DNA analysis of all recovered human remains allowed the identification of all persons who were on board and autopsy examination concluded that the human remains were infection free.

All reports observed through clinical examinations 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 and ground impact of the airplane resulting in severe vital lesions that led to immediate death.

All 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.

1.14 FIRE

There was no evidence of fire.

1.15 SURVIVAL ASPECTS

There were no survivers

1.16 TEST AND RESEARCH

Three Major tests were conducted:-

1. Column force and manual trim force evaluation using B737-8- MAX CAE-Training Simulator at Ethiopian Airlines
2. Flight deck environment and column force evaluation using the Boeing Engineering simulator (ECAB) in Seattle
3. Manual Trim evaluation using Flight Controls Test Rig (FCTR) in Seattle

1.16.1 Simulator Assessment of Control Column and Trim Wheel Force

Upon the investigative committee decision, 3 simulation tests were conducted at a simulator facility located in Addis Ababa between July 19, 2019 and July 31, 2019. The sessions were conducted in a CAE manufactured B737 MAXlevel D full flight simulator to assess the control column forces that were present and evaluate the manual trim wheel forces that were required to operate the manual trim wheel at the time the flight crew tried to use it on the event flight. While the control column forces in the Level D simulator are certified to correctly reproduce control column forces in the actual Airplane, the same is not true for the stabilizer manual trim wheel. Post-accident testing revealed differences between Level D simulators and the actual Airplane which affect the feel of the manual trim wheel. These differences are thought to be caused by system inertia, in-flight vibrations, cable stretch, and other effects not included in the simulator model.

These assessments enabled the investigation of a conversation from the cockpit voice recorder (CVR) that took place between the captain and the first officer. Particularly:

- Conversation where the captain asks the first officer to pitch up with him at different points on the event flight

- Conversation about the use of manual trim wheel where the captain asks the first officer to trim up and the first officer replied it is not working

On all sessions carried out, the simulator was set up with the weight and C.G. values of the event flight and weather condition was set to the same condition that was present at the time of the event flight.

In session 1, a survey was conducted to analyze the relationship between number of manual trim wheel turns and corresponding trim unit change. It was noted that a change in 1 unit of trim (cockpit indication) requires about 15 turns of the manual trim wheel. This finding agrees with the information supplied by the manufacturer. The Airplane was set up to the condition with thrust and trim values of the event flight when the crew moved the stab trim cutout switches to cutout. Then the pilot occupying the captain seat tried to climb to 14,000ft by pulling on the control column to evaluate the amount of force needed. The pilot on the first officer seat then started to pull together with the other pilot and together managed to establish a pitch attitude of 5-10 degrees. The forces needed from both pilots to achieve this were considered significantly very high and unbearable for the duration held. Then the pilot attempted to control the Airplane and return for landing with elevator authority only with the trim unit set at 2.3 and trim cutout switch set to cutout while adjusting thrust manually. The attempt was unsuccessful.

On session 2, in order to qualitatively assess the force on the manual trim wheel through two turns at different speeds and trim conditions, speeds 220, 250, 300Kt and trim values 2.5, 3.5 & 4.5 were chosen respectively.

The Airplane was then trimmed for level flight at 10,000ft and the hands off trim values were noted for all three speeds.

TABLE 18: HANDS OFF TRIM VALUE

	Speed		
	220	250	300
Hands off trim value	6.8	6.2	5.3

The following qualitative definitions were agreed at the start of the session.

Assessment level[19]: A = trim wheel not movable

B = trim wheel barely movable (1 turn not completed)

[19]Assessment level

C = trim wheel moves with great difficulty (2 turns not completed)

D = trim wheel moves with some difficulty (2 turns completed)

The trim was set to 4.5 then stab trim was set to cut out. Then the pilot tried to trim the Airplane nose up with the manual trim wheel while the other pilot maintained level flight by applying force on the control column. This test was repeated for trim values 3.5 and 2.5.

The pilots took turns in evaluating the required force to turn the trim wheel. Both pilots also applied force together whenever one pilot was unable to move the wheel. The following table is a summary of the qualitative assessment

TABLE 19: QUALITATIVE ASSESSMENT OF TRIM VALUE

Trim position units	Speed		
	220	250	300
4.5	D	------	------
3.5	C	------	------
2.5	B	A	A
Hands off trim values	6.8	6.2	5.3

On session 3, the qualitative assessment of the manual trim wheel through 2 turns was repeated and the same finding was observed.
As the trim position from the event flight at the time the stab trim was in cutout and the pilots tried to use manual trim wheel was close to 2.5 units, this trim value was used to analyze the amount of miss-trim at different speeds and determine the relationship of control column force, trim wheel force and amount of mis-trim.

The following table is a comparison of the mis-trim

Mis-trim = hands off trim value – current trim

TABLE 20: MIS- TRIM EVALUATION RESULT

		Speed		
		220	250	300
Hands of trim value		6.8	6.2	5.3
	Trim value	Mis-trim value / assessment value		
	4.5	2.3 / D	1.7	0.8
	3.5	3.3 / C	2.7	1.8
	2.5	4.3 / B	3.7 /A	2.8 /A

It was observed that the greater the mis-trim value, the greater the force required by the pilot on the control column to fly level flight and consequently the greater the force required turning the manual trim wheel.

As the trim value from the event flight was around 2.5 units by the time the crew tried to use the manual trim wheel, even at a speed of 220 Kt the difficulty level of turning the manual trim wheel was level B (barely movable/ 1 turn not completed).

The number of manual trim wheel turns that needed to be applied to get the hands off trim value was calculated by multiplying the mis-trim value by 15. The following table indicates the number of manual trim wheel turns required to reach the hands off trim value from a trim value of 2.5 units at three different speeds.

TABLE21: MISTRIM EVALUATION RESULT

	Speed		
	220	250	300
Hands off trim value	6.8	6.2	5.3
Mis-trim value when trim set at 2.5	4.3	3.7	2.8
Number of manual trim wheel turns required	64.5	55.5	42

Summary of observations

1. The greater the mis-trim value, the greater the force required by the pilot on the control column to fly level flight and consequently the greater the force required to turn the manual trim wheel.

2. At a speed of 220Kt, the difficulty level of turning the manual trim wheel was found to be level B (barely movable/ 1 turn not completed) for the trim value of 2.5 units, which was the trim value on the event flight by the time the crew tried to use the manual trim wheel.

3. For all speeds higher than 220Kt and trim set at a value of 2.5 units, the difficulty level of turning the manual trim wheel was level A (trim wheel not movable).

4. It takes about 15 turns of the manual trim wheel to get a 1 unit trim change.

5. On the event flight during the time the flight crew tried to use the manual trim wheel, about 40 turns of the manual trim were required to get back to the neutral position.

1.16.2 Engineering Simulator and Flight Control Test Rig Assesments

From December 16 to 18, 2019, in support of the Ethiopian Airlines flight 302 (ET302) accident investigations, representatives from the EAIB, NTSB, BEA, FAA and Boeing, conducted test activities using a Flight Controls Test Rig (FCTR) and Boeing's engineering simulator (eCAB). Testing took place at a Boeing facility in Seattle, Washington. Key observations were made specific to human performance and operational factors of the ET302 investigation. The purpose of this document is to discuss the aspects of the findings most relevant to the flight crew actions during the accident sequence and provide a list of remaining questions based on the FCTR and ECABtesting.

The main objectives of the FCTR and ECAB simulator testing were:

• Simulate the manual trim wheel forces and experience the effort required to operate the trim wheel during specific out-of-trim conditions;

• Familiarization of B737-MAX8 cockpit aural and visual alerting resulting from failure of an angle-of-attack (AOA) sensor failure;

• Familiarization of B737-MAX8 flight profile characteristics, including unexpected MCAS activation during routine flight driven by erroneous AOA input;

• Understand human performance/operational factors related to the ET302 flight crew's response to an AOA sensor failure and subsequent MCAS activation.

TEST SCENARIOS AND PROCEDURES

Test scenarios for the ECABand Flight Controls Test Rig (FCTR) were defined as follows:

Scenario 1: (ECAB) Baseline 737-8 MAX configuration, no faults present. Scenario used to demonstrate the intended operation of MCAS during high AOA maneuvers.

Scenario 2: (FCTR) Demonstration of stabilizer manual trim wheel forces.

Scenario 3a: (ECAB) Erroneously high left AOA introduced after liftoff at 50 ft AGL; leave thrust at 94% N1; run appropriate checklists (stick-shaker, airspeed unreliable, runaway stabilizer; return to ADD with stab trim in cutout.

Scenario 3b: (ECAB) Erroneously high left AOA introduced after liftoff at 50 ft AGL; leave thrust at 94% N1; mimic ET302 crew actions (based on FDR/CVR).

Scenario 4: (ECAB) Demonstrate updated FCC Software, (P12.1.2) erroneously high left AOA introduced after liftoff at 50 ft AGL; crew actions based on input from Operations and Human Factors Groups.
For all ECAB scenarios, the following Airplane configuration was set at the start of the test:

- Lined up on HAAB runway 07R, engines running, all before takeoff checklists accomplished
- Altimeter set to read 7,625 ft. MSL (HAAB field elevation)
- Flaps: 5
- Weight: zero fuel weight 61,200 kg. / 134,923 lb.; fuel weight 10,700kg. / 23,589 lb.; takeoff gross weight 71,900 kg / 158,512 lb.
- C.G.: 23.1% MAC
- Trim: 5.6 pilot units
- Weather: clear; unlimited visibility

1.16.2.1 ECab Description and Limitations

The ECAB is a fixed-base simulator incorporating a flight deck cockpit (or “cab”) that can be configured to represent different 737MAX models: -7, -8 or -9. For the tests outlined here, itwas configured as a B737-MAX 8 (the ET302 Airplane). The simulator is equipped with anumber of actual Airplane avionics boxes (as contrasted with simulating the avionics functionswith software). Boeing provided a presentation describing the design, capabilities, and limitations of the ECAB to the group during the first day of meetings. The ECAB is pictured in **Figure 65** below.

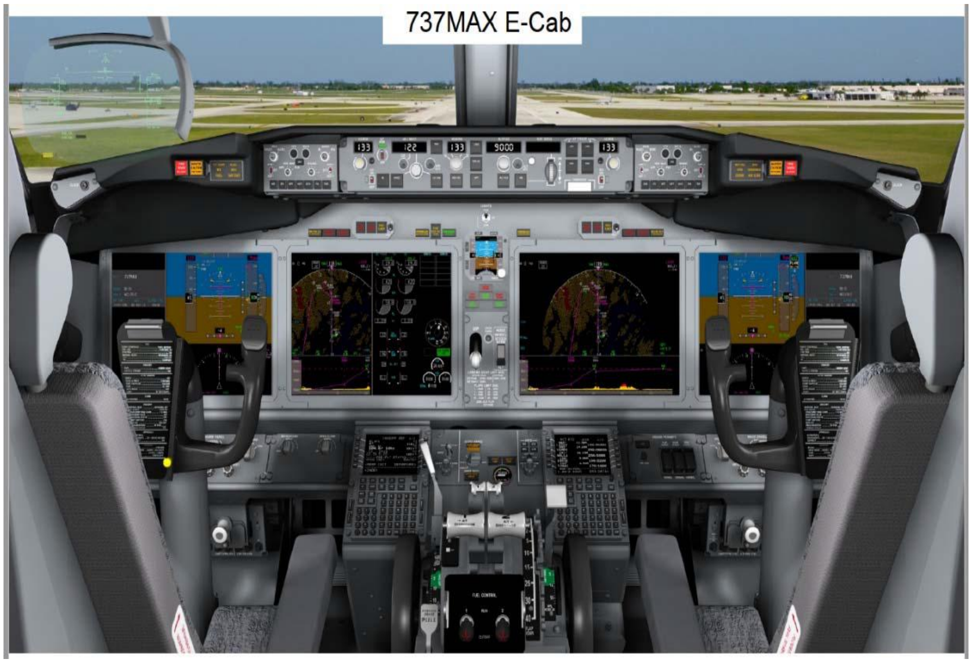


FIGURE 65: 737MAX SIMULATOR

In scenario 3b, Simulator flight crews were to reproducethe ET302 flight crew actions based on CVR and flight data recorder (FDR) data. Following stick shaker activation after takeoff, the simulator crews were instructed to attempt to engage the autopilot three times, move flaps from 5 to 0, respond to two MCAS inputs using electric nose up trim per the FDR, move STAB TRIM CUTOUT switches to CUTOUT, unsuccessfully attempt to manually trim, move CUTOUT switches back to Normal, and respond to one MCAS input using electric nose up trim per the FDR. Reproducing the control actions recorded on the FDR resulted in loss of control of the Airplane.

Finally, simulator participants were to mimic ET302 actions; however, after moving the STAB TRIM CUTOUT switches to CUTOUT, the crew was to work together to manually trim the Airplane using the trim wheel. The scenario involved both crew members each using one hand on the control column and one hand on the trim wheel. The limitations in replicating forces required moving the trim wheel in Level D simulators, noted in section B, also applied to the E-CAB; it was not able to reproduce the force that would have been required from the ET302 crew. The E-CAB was able to accurately reproduce the forces required by the crew to operate the primary flight controls via the control column.

The third demonstrated the advantage of coordinated crew efforts to both make manual trim changes via the trim wheel (as had been done in FCTR testing) and control the flight path. However, because the actual forces on the manual trim wheel experienced by the ET302 crew were not observed in the FCTR, it is unKnown if the ET302 crew could have successfully manually trimmed together, had they even considered this a technique to use.

OBSERVATIONS FROM E-CABTESTING

- When attempting to imitate the ET302 flight crew actions, the simulator crews felt it was instinctual to use as much electric trim as needed to reduce column forces in response to MCAS inputs, recognizing that a sustained input on the electric trim switch was longer than typical inputs that pilots are accustomed to making during routine operations.
- Pilot flying workload and task demand were high when attempting to maintain flight path as column force increased with MCAS activation. Simulator crews considered column forces above 60lbs to be high, and above 80lbs. It became difficult to find a neutral column and maintain level flight. For reference, after the autopilot disengagement, the ET302 captain experienced column forces on average above 90lbs. Column loads about 60-80 lbs were hard to differentiate – all are "high".
- The main goal of the scenario was to fly the Airplane per the script that would duplicate the ET302 sequence of events; little or no decision making was needed by the simulator crews. Even so, the workload appeared to be high, and it was deemed a "demanding task" by the crews to maintain flight path control;
- Participants noted the importance of mimicking the ET302 crew's actions as it allowed them to experience the time pressure the crew faced which was not as evident when reading the CVR/FDR data;
- Participants noted that the stick shaker was a distraction when managing the emergency. It's difficult to ask for help in holding column aft – that is hard to ask to share the column force. Normally only one pilot is applying force ;
- Although the accident scenario could not be perfectly replicated in the simulator due to differences in simulator crew reaction times and actions, the investigative team was able to better understand the rapid onset and complexity of the emergency and its effect on the ET302 flight crew's actions;
- A participant noted that MCAS trim is very fast; you don't realize how long you have to re-trim to get back to neutral;

1.16.2.2 FCTR Testing

FCTR Description and Limitations

The FCTR partially replicates the Boeing 737 flight deck environment, including control column and wheel, rudder pedals, and manual trim wheels, properly configured in front of two pilot seats (Figure 65). Boeing provided a presentation describing the design, capabilities, and limitations of the FCTR to the group during the meetings. The presentation notes that the FCTR correctly replicates the reach and operation of the manual trim wheel from the pilots' seats, and accounts for the kinematics (geometric constraints) of the manual trim system. The FCTR also replicates forces due to cable stretch and the inertia of masses moving within the system. The model driving the FCTR forces has been validated with flight test data at speeds up to VMO (340 KCAS).

FIGURE66: MODEL FCTR

As it is noted above the main objective of the simulator sessions was to provide a better understanding of the accident flight and observe various messages, lights, various failure modes and flight deck effects related with the event flight. It was also to understand the flight crew workload during different scenarios.

Because of limitations in reproducing trim wheel forces in Level D simulators, Boeing constructed the FCTR to replicate the forces needed to move the trim wheel in a B737MAX at various mistrim and airspeed combinations. A mistrim of -1.5 units at airspeed of 340 KCAS (VMO) was the combination that required the greatest effort to correct and was the most difficult mistrim/airspeed combination available in the FCTR1. When the ET302 crew discussed using manual trim during the accident flight, the mistrim was -2.7 units at airspeed of 340 KCAS.

Evaluating these forces was important in understanding the ET302 crew's ability to move the trim wheel. According to the cockpit voice recorder (CVR), the first officer indicated that he could not rotate the manual trim wheel. Both physical and psychological factors could influence his ability to move the wheel.
Regarding physical factors, the force required to initiate rotation of the trim wheel might have exceeded the physical capabilities of the first officer; put simply, he may not have had the strength to initiate rotation. Also, grip (overhand or underhand), seat (body) position in relation to the trim wheel, and clock-position of the handle on the wheel (which would change the direction of the force vector required to initiate or maintain rotation) could all affect how easy or difficult it was to move the manual trim wheel handle. An understanding of these physical factors was gained from the FCTR testing, as it was difficult to turn the handle at forces less than those experienced by the ET302 crew.

However, the testing did not allow the team to evaluate the control wheel forces experienced by the ET302 crew because of a lack of flight test data to validate the forces at that speed and mistrim.

Regarding psychological factors, there are several plausible explanationsfor why the flight crew was not able to move the manual trim wheels. First, the first officer's expectation of force needed to turn the wheel could have influenced his actions. Had the first officer expected the trim wheel to require less force than he encountered, it was possible that he interpreted force needed and the resistance he felt as the trim wheel being unmovable – and in the emergency he may not have had the attention resources to further diagnose why it was not moving. Further, there was no mention of high forces that may be required to trim manually in either the QRH or the Boeing FCOM bulletin issued following the Lion Air accident although the possibility is discussed in the FCTM. Excessive airloads on the stabilizer may require effort by both pilots to correct themis-trim. In extreme cases it may be necessary to aerodynamically relieve the airloads to allow manual trimming.

1.16.2.3 Trim Wheel Evaluation at the Flight Controls Test RIG (FCTR)

Multiple scenarioswere executed to run different manual trim Wheel forces for ET-302 flight conditions on ground as well as at different speeds and altitudes using Flight Controls Test Rig (FCTR).

A trim wheel evaluation was performed at the Flight Controls Test Rig (FCTR). Tests were done with Airplane on ground as well as at different speeds and altitudes with different trim settings.

It should be noted that:
- TheMaximum mistrim demonstrated on the FCTR is -1.5 units.
- 15 wheel rotations are necessary for 1 unit of trim.

- The first test was conducted with Airplane on ground at zeroKnot. Expected force on the wheel was 10 Lbs.

It was noted that the wheel was easy to operate, the FCTR matched the physical Airplane very closely and that it was qualitatively close to CAE training simulator forces. The FCTR instrumentation recorded static force of approximately 9.3 pounds.

The second test was conducted with Airplane at 12,000 ft, 250 Kt, in trim condition (expected 15 lbs force).

- It was noted that the wheel was a bit more difficult to operate but that it was still doable with one hand. It was qualitatively close to CAE training simulator forces. The FCTR instrumentation recorded static force of approximately 15 pounds.

The third test was performed at 12,000 ft, 340Kt (VMO), in trim condition (expected 21 lbs) force.

- It was noted that the trim wheel force become much more difficult to operate than in condition 2. The wheel motion became jerky, straining efforts to turn it. Impact onspeech. Qualitatively more difficult than on CAE training simulator. 15 turns would be tiring. Rig instrumentation recorded static force of 21 pounds.

The fourth test was conducted at 15,000 ft and 340Kt (VMO), -1.5 units (mis-trim)[20], expected 35 lbs force.

- It was noted that it was difficult to turn the wheel with one hand confirming the first officer's statement "it was not working" meaning "hard to move. Some participants expressed surprise at the difficulty. It was possible to turn the wheel with two hands although not convenient at all. The level of force for this condition was found to be between 30 and 40 lbs. It was agreed that difficulty would increase further outside the normal operating envelope (as in the accident case).

As noted earlier, differences between trim wheel simulations (whether Level D or FCTR)[21] and the actual airplane affect force-based comparisons between the two. Flight test data revealed that mechanical characteristics of the actual airplane (including inertia, in flight vibrations, and cable stretch) serve to increase the calculated force any specific individual pilot can apply to the manual trim wheel. Therefore these conclusions may not apply to use of the trim wheel on an actual airplane in flight.

[20]When the first officer reported that he could not move the trim-wheel, the mis-trim was about 2.5 degrees at 340 kt
[21]Differences between trim wheel simulations (whether Level D or FCTR)

OBSERVATIONS FROM FCTR TESTING

At Maximum forces experienced during testing with -1.5 units of mistrim, the trim wheel was difficult to turn by most, if not all, participants when using one hand. All participants were able to start the wheel turning, though most needed two hands to rotate the wheel completely through 360° multiple times. Using two hands (either “bicycle” technique by one participant or coordinated effort between two participants) made turning the wheel easier and resulted in greater success turning it through multiple rotations. Hand position (grabbing handle overhand or underhand), seat position, and handle location (top or bottom of wheel which would change whether the individual was pushing or pulling) could impact how easy or difficult it was to turn the wheel;

• Participants experienced variability in the force needed to turn the wheel. To get past the points in the rotation where participants found it more difficult to input the necessary force to keep the wheel moving, some felt it helped to build up rotational momentum during the easier (lower forces) portions of the rotation to assist in the more difficult (higher forces) portions of the rotation;

• The trim wheel must be rotated completely (360°) 15 times to move the stabilizer 1 unit of trim. To resolve a mistrim of -2.7 units as on ET302, the wheel would need to be rotated through 40.5 revolutions. In FCTR testing, the average force needed to turn the wheel at -1.5 units of mistrim (at 340 KCAS) was 40lbs. Participants had difficulty in initiating rotation of the wheel at this setting and found prolonged rotation fatiguing. The ET302 flight crew may have initially encountered greater force requirements due to the greater mis-trim condition on the accident flight that would have reduced after trimming.

• It was noted that the force needed to rotate the wheel during ET 302 would decrease with each rotation as the Airplane approached an in-trim condition (a dynamic not reproducible in the FCTR.). Even so, initiating rotation and continuing for 40 revolutions on the accident flight may have been difficult.

E-CABAND FCTR TEST AND RESEARCH SUMMARY

Participants made the following observations:

- As it was observed from SIM test MCAS trim is very fast; you don’t realize how long you have to re-trim to get back to neutral;
- Column loads about 60-80lbs were hard differentiate – all are “high”;
- It was difficult to ask for help in holding column aft – that was hard to ask to share the column force. Normally only one pilot is applying force;
- At high column force, relaxing column position didn’t provide much perceived relief in column force;
- 5 seconds delay after yoke trim stops, you have mentally moved on to something else – catches you off guard again;

- When column force loads is above 80 lbs, it was doable as a single pilot, but noticing the effort paid but Once column loads > 80 lbs, finding neutral position was difficult and harder to distinguish low load from zero load; workload appeared high “Demanding task” to maintain path control”. It was also confirmed that very difficult trying to turn the trim wheel as the pilot holding around 60-80 lbs column force.

It was observed that the greater the mistrim value, the greater the force required by the pilot on the control column to fly level flight and consequently the greater the force required turning the manual trim wheel.

Moreover, the trim wheel must complete 15 revolutions to move the stabilizer by 1 unit (degree) of trim. Consequently, to resolve a mistrim of -1.5°, the wheel would have to be rotated through 22.5 revolutions; but to resolve a mistrim of -2.7° it would have to be rotated through 40.5 revolutions, i.e., 80% more.

1.16.3 Angle of Attack, AOA Values

At 5 h 38 min 44 s, the LH AOA recorded values began drifting from the RH AOA recorded values; before that time, no clue of concern existed on the LH AOA recorded values.

The first decrease of AOA wasby2.6° record (1 sample) before a sudden increase to more than 60° in half of a second followed by a slower increase to 74.5°

At 5 h 38 min 48 s, a master caution triggered. From that time, the primary AOA heat LH recorded values underlined a failure of the vane heating (first recorded OFF value at 5 h 38 min 51s, sampling rate of the parameter: 0.25 Hz). The reason for the master cautionwas the anti-ice left alpha vane indication.

Note: the master caution was no longer recorded as active at 5 h 38 min 55 s.

From the CVR transcript, at 5 h 42 min 48 s, the Captain requested the recall of the master caution. At that time, master caution had only triggered once. Following the master caution recall, the crew exchanged “Master Caution Anti Ice” and “Left Alpha Vane”.

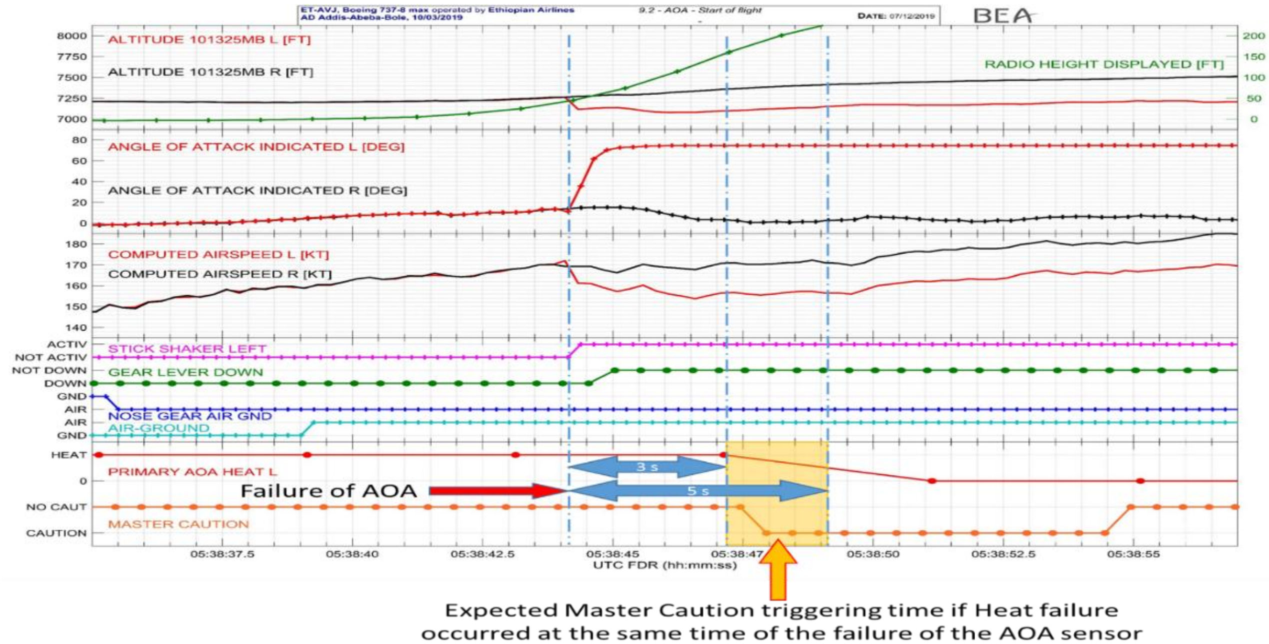


FIGURE 67: AOA VALUES DURING THE BEGINNING OF THE FLIGHT

Although the FDR does not separately record both resolvers within the LH AOA sensor, recorded ADIRU and SMYD parameters are consistent with both resolvers providing the same erroneous values. Therefore, the investigation concluded that the failure impacted the signals provided by both resolvers of the LH AOA.

According to the description provided in §1.6.3.3 it took between 3 to 5 s between the AOA heat failure and the triggering of the associated master caution. The LH AOA heat failure triggered at a time consistent with a single event leading to both heat failure and erroneous values from both resolvers at the same time.

1.16.3.1 Impact Of AOA Failure on ADIRS

Detection of the AOA failure by ADIRU

As LH AOA vane heating failure occurred, LH ADIRU continued providing its parameters without any information of failure.

LH ADIRU provided the recorded LH computed airspeed values. These recorded values never showed any invalidity pattern during the whole flight of the event. LH ADIRU provided output data without any invalidity information.

As a consequence,

- SPD flag never appeared on the PFD
- ALT flag never appeared on the PFD

During the flight of the event, the left and right recorded altitude values, the recorded CAS values and the recorded Mach numbers diverged after LH and RH AOA values divergence.

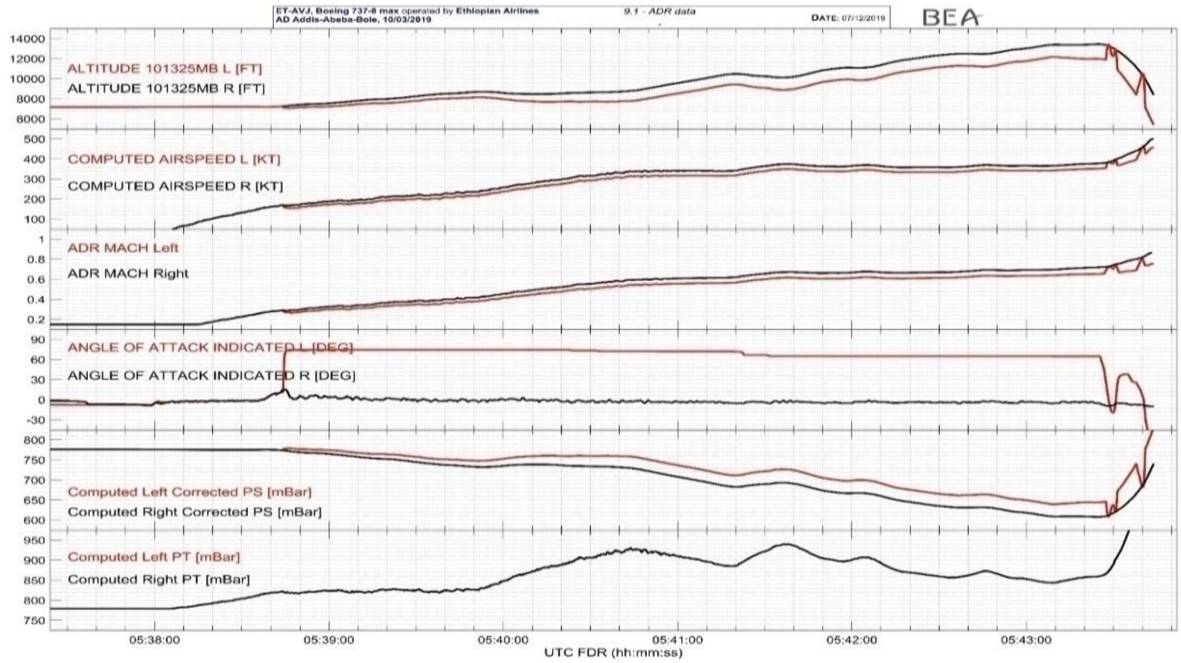


FIGURE 68: AIR DATA PARAMETERS

Although not explicitly recorded, the RH and LH computed total pressure values calculated from the recorded parameters were found to match. The differences between the recorded Mach number and between the recorded computed airspeed values were consistent with a difference in the corrected static pressure values resulting from the left ADIRU's use of the erroneous left AOA sensor data.

The Airplane manufacturer recomputed the uncorrected static pressure for both sides, with the recorded LH and RH AOA values.

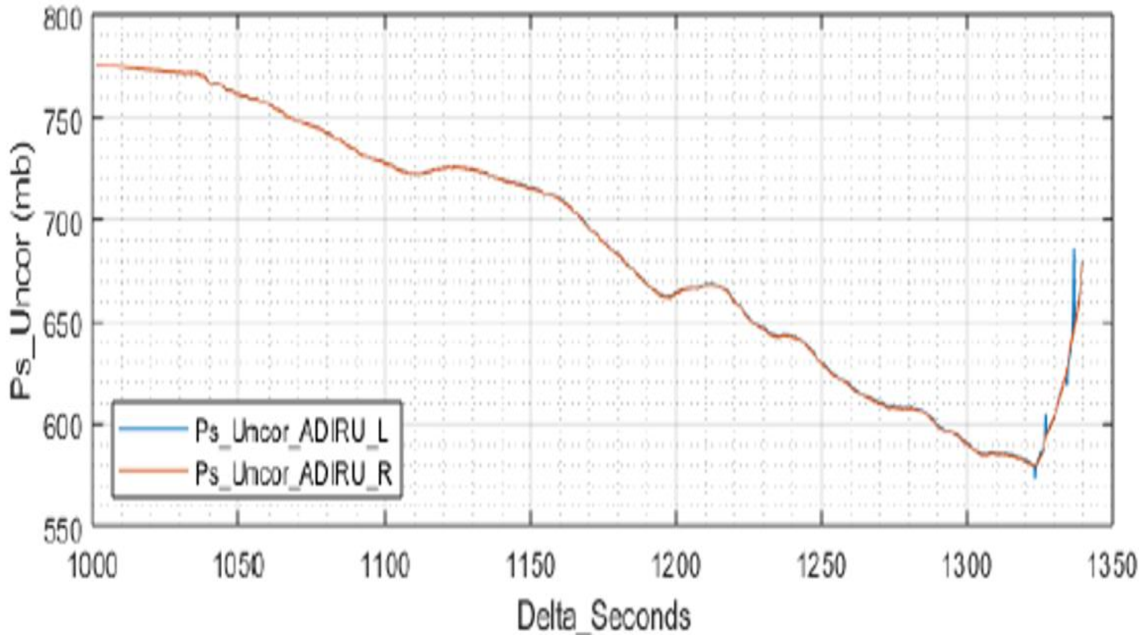


FIGURE 69: UNCORRECTED STATIC PRESSURE COMPUTED BY THE AIRPLANE MANUFACTURER

Uncorrected static pressure values from both sides were identical. The difference between the LH and RH side corrected pressure values were therefore only due to the AOA correction.

On the LH side, the erroneous LH AOA values induced corrected static pressure values greater than the true corrected static pressure values. This increase of the LH corrected pressure values induced:

- LH pressure altitude values lower than the true altitude values
- LH computed airspeed values lower than the true computed airspeed values.

The RH air data parameters were not affected.

IRS

Most of the recorded IRS parameters did not show any variation following the AOA failure. On the contrary, the computed wind, on the left side, was clearly affected by that failure.

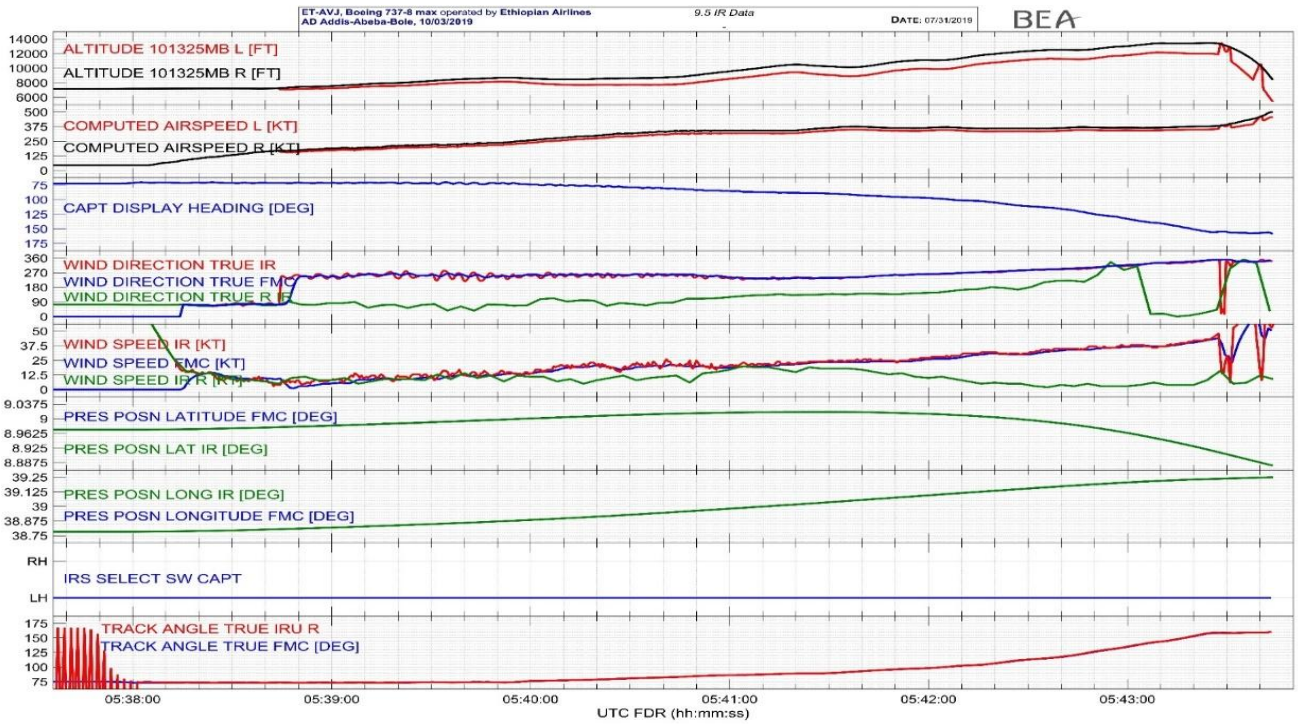


FIGURE70: IMPACT OF AOA FAILURE ON THE WIND COMPUTED VALUES

The LH IRS was selected for the flight of the event. The invalid wind computed values impacted also the FMC that smoothed the values coming from the selected IRS.

On the Captain display, the wind direction and the wind speed values were incorrect.

Note: At 5 h 39 min 52 s, the difference between the computed LH and RH TAS values reached the threshold value used by FMC to detect inconsistency before then falling below the threshold two seconds later. If these 2 samples resulted in FMC Target N1 parameters being declared invalid, it would not be immediately evident in the FDR data because of the 4 second time delay before recording an error code.

1.16.3.2 Impact of AOA Failure on Engines and A/T

IMPACT OF FAILED AOA VALUES ON FMC (ENGINE PART)

For the takeoff phase, the N1 limit mode was the TO mode and the N1 recorded values corresponded to 95% of $N1_{MAX}$. At 7,000 ft of elevation, it indicates that the take-off was performed with Max. Takeoff Thrust. Indeed, at 7,000 ft of elevation, between 15°C and 20°C, the Max. Takeoff thrust corresponds to 95% of N1.

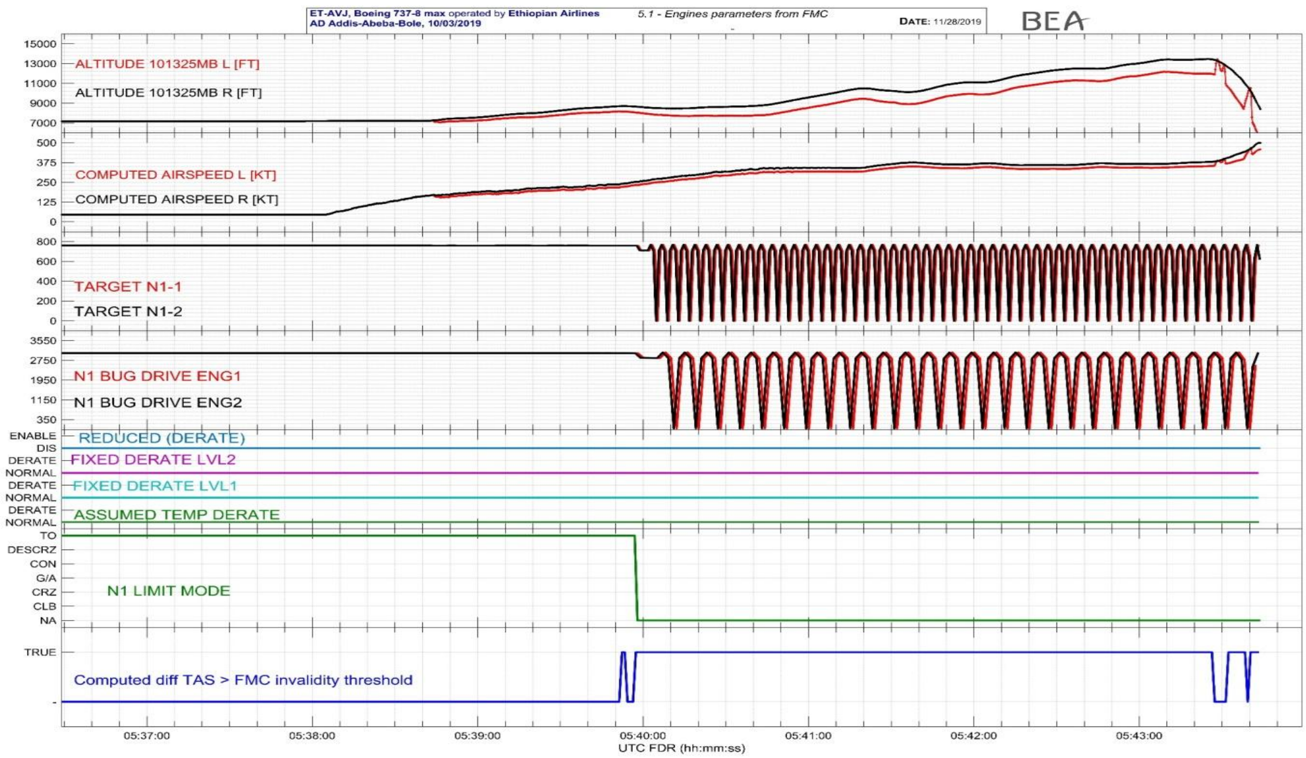


FIGURE71: FMC PARAMETERS FOR THE ENGINES

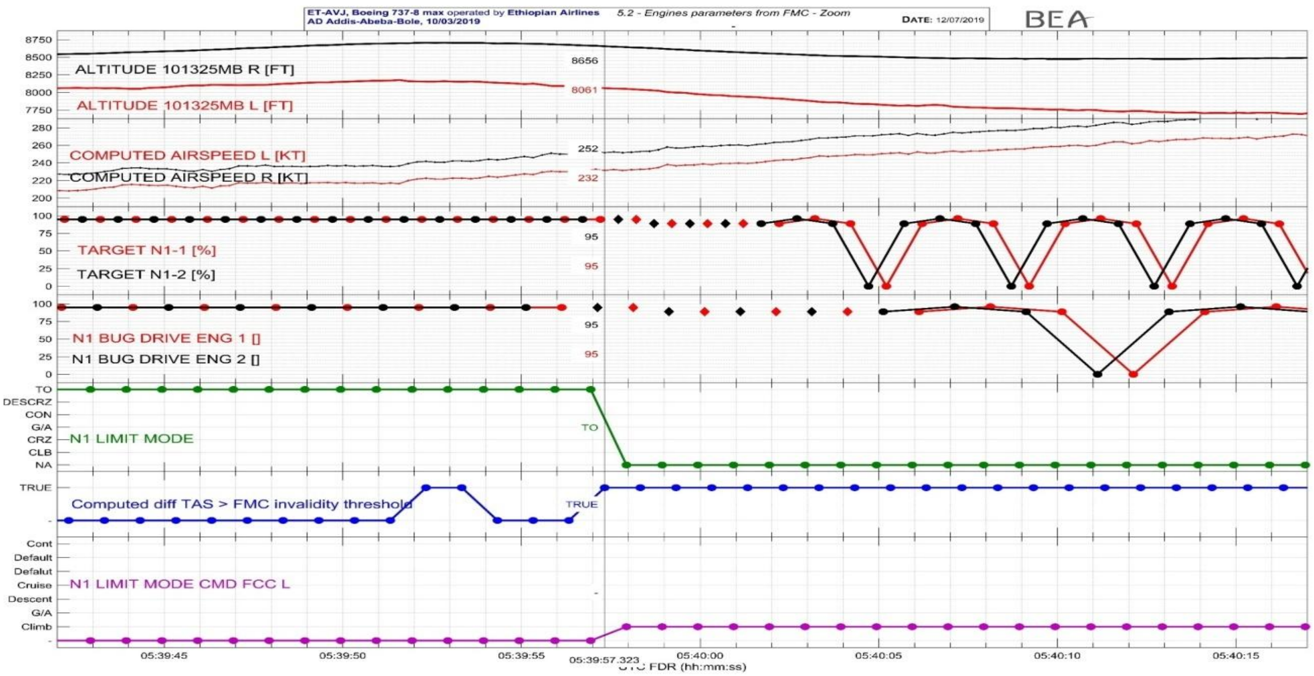


FIGURE 72: FOCUS ON INVALID N1 DATA FROM FMC

On Figure 72:

- The start of the recorded invalidity patterns was denoted by the absence of line segments between the data points.

According to the DFDAU design the four values preceding the invalidity pattern shall also be considered as invalid. They were plotted using diamond symbols. At the same time that the difference between the TAS computed on each side reached the FMC's threshold, N1 LIMIT MODE parameter (FMC) switched to "Not Available"

1.16.3.3 Impact of AOA Failed Values on Auto-Throttle (A/T)

During the whole flight of the event, A/T stayed engaged and remained in ARM mode.

At 5 h 37 min 43 s, the TRA recorded values showed an increase, from 36° to 45° in 3 s. During that move, THR TORQUE-[1/2] recorded values stayed null. That move was manually performed.

At 05 h 37 min 53 s, the TO/GA switch was pushed. A/T switched to the N1 mode. The A/T moved automatically the throttles forward *(THROTTLE RATE CMD-[1/2]* values, *THR TORQUE-[1/2]* values were positive). Once the throttles reached takeoff thrust, they remained there. As noted earlier, the normal automatic reduction to climb thrust did not occur because the LH and RH TAS diverged by more than 25Kt before the FMC sensed that the Airplane had reached the thrust reduction altitude.

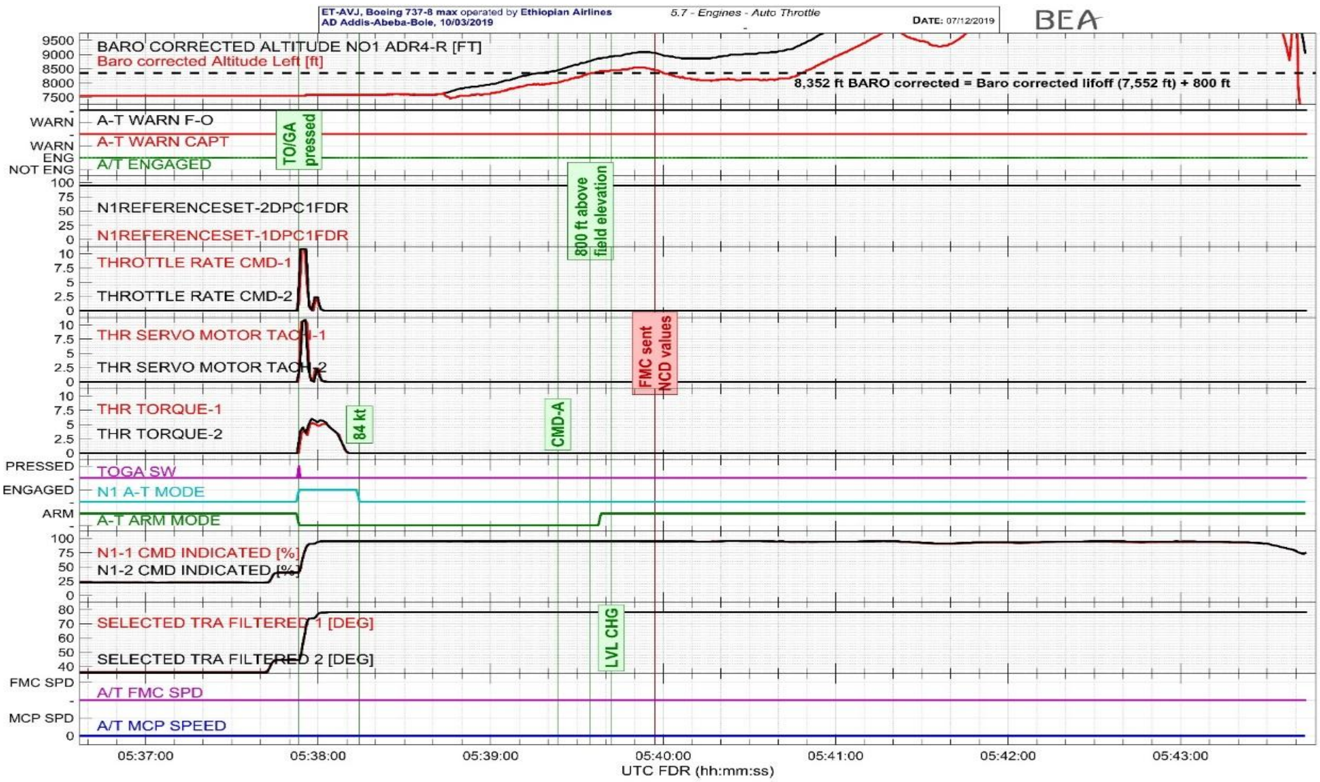


FIGURE 73: AUTO THROTTLE BEHAVIOR DURING THE FLIGHT OF THE EVENT

As expected:

- At a recorded computed airspeed of 84Kt (5 h 38 min 14 s), the A/T switched to the THR HOLD mode (no other mode recorded).
- When the Airplane altitude reached 800ft above the field elevation, computed from the LH baro corrected altitude (at 5 h 39 min 38 s, the Airplane reached a LH baro-corrected altitude of 8,416 ft), the A/T switched from THR HOLD to ARM mode.

Note: the true altitude of 800 ft above the field elevation was in fact reached at 5 h 39 min 22 s (RH baro-corrected altitude of 8,416 ft).

19s after the engagement of the ARM mode, the FMC detected the discrepancy between the LH and RH TAS values. At that time, the Airplane was descending and the Maximum height above field elevation it had reached before was 950ft (from the LH baro corrected altitude). The thrust reduction altitude was not reached at that time. The TARGET N1-[1/2] and of the N1 BUG DRIVE ENG[1/2] values transmitted by the FMC decreased to 89% (5 h 39 min 58.7 s) with the flag NCD. Due to the invalidity flag, A/T function disregarded this new target.

Note: By design, when no valid airspeed is available, the FMC changes the TARGET N1-[1/2] to the climb value. A N1 target value of 89% is consistent with a Climb phase.

Summary on A/T behavior

During the flight of the event, A/T was engaged in the automatic takeoff sequence and due to the erroneous LH AOA values:

- LH and RH TAS diverged by more than 25 Kt. From 5 h 39 min 57, the FMC did not send any valid N1 target values
- The thrust reduction altitude was reached around 5 h 39 min 28 (computed from the RH baro corrected altitude). However, the FMC used the LH baro corrected altitude values, which were lower than the true ones. The FMC did not detect the thrust reduction altitude when it was sending valid engine commands.

1.16.3.4 Impact of AOA Failure on SMYDC

Stall management

Following the increase of the left AOA values:

- the autoslat system triggered (SMYDC 1),
- the LH stick shaker engaged
- the LH elevator feel shift triggered.

At 5 h 39 min 56 s, the autoslat command ceased, the flap handle was at 0 position and flaps were moving up (flaps position lower than 1) with LH computed airspeed values reaching 230Kt and RH computed airspeed value 250Kt.

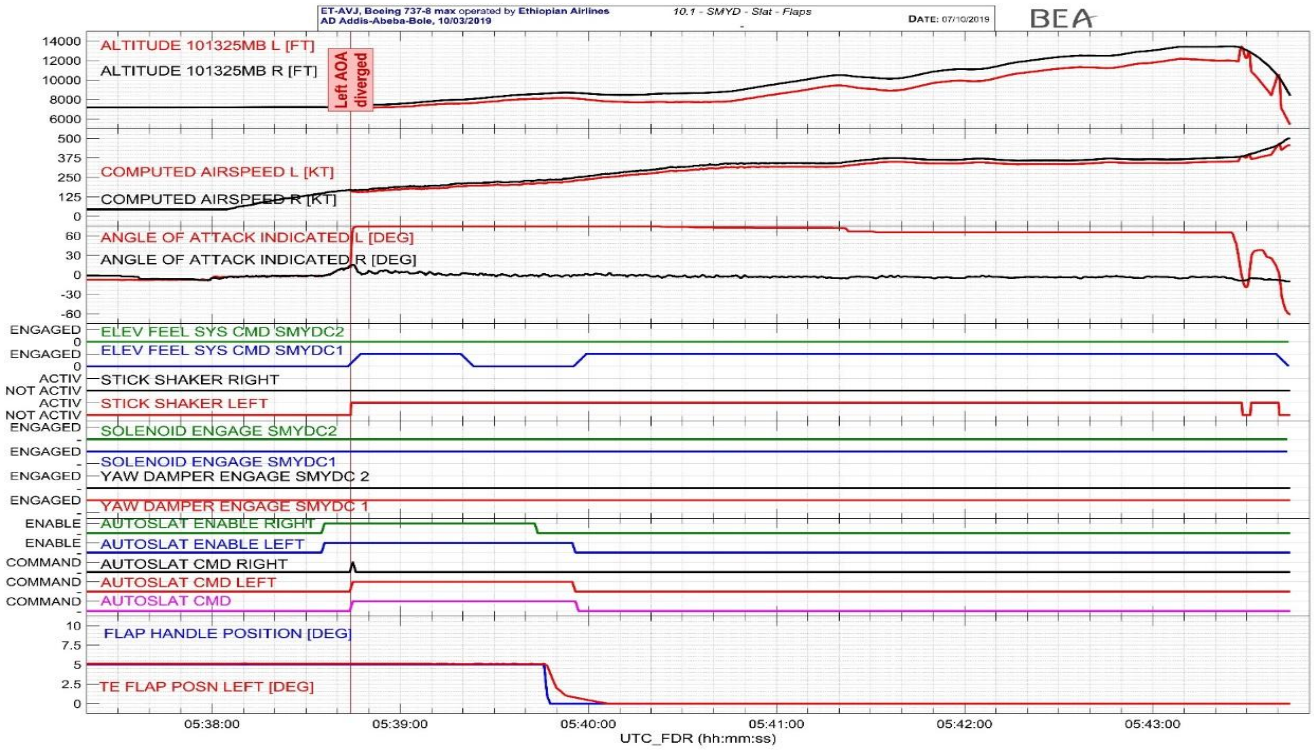


FIGURE74: AUTOSLAT, LEFT STICK SHAKER AND ELEVATOR FEEL SYSTEM

At 5h 39 min 44s SMYDC-2 disabled the RH autoslat function due to the RH computed airspeed (230Kt reached). SMYDC1 disabled the LH autoslat function 12s later due to the invalid LH computed airspeed.

SMYDC COMPUTED SPEED

From 5 h 40 min 13 s the LH FC Minimum operating speed computed by the SMYDC 1 reached values greater than VMO; 3s later the LH stick shaker speed reached values greater than VMO. The erroneous nature of these computed speeds were not detected by any computer.

From 5 h 41 min 30 s until the end of the flight by computing the equivalent Mach number, the left Stick Shaker Mach computed numbers were greater than the MMO (0.82);

At 5 h 41 min 17 s, SMYDC1 computed FC minimum operational speed values greater than High speed buffet speed values. Both values were computed by the same computer SMYDC 1.

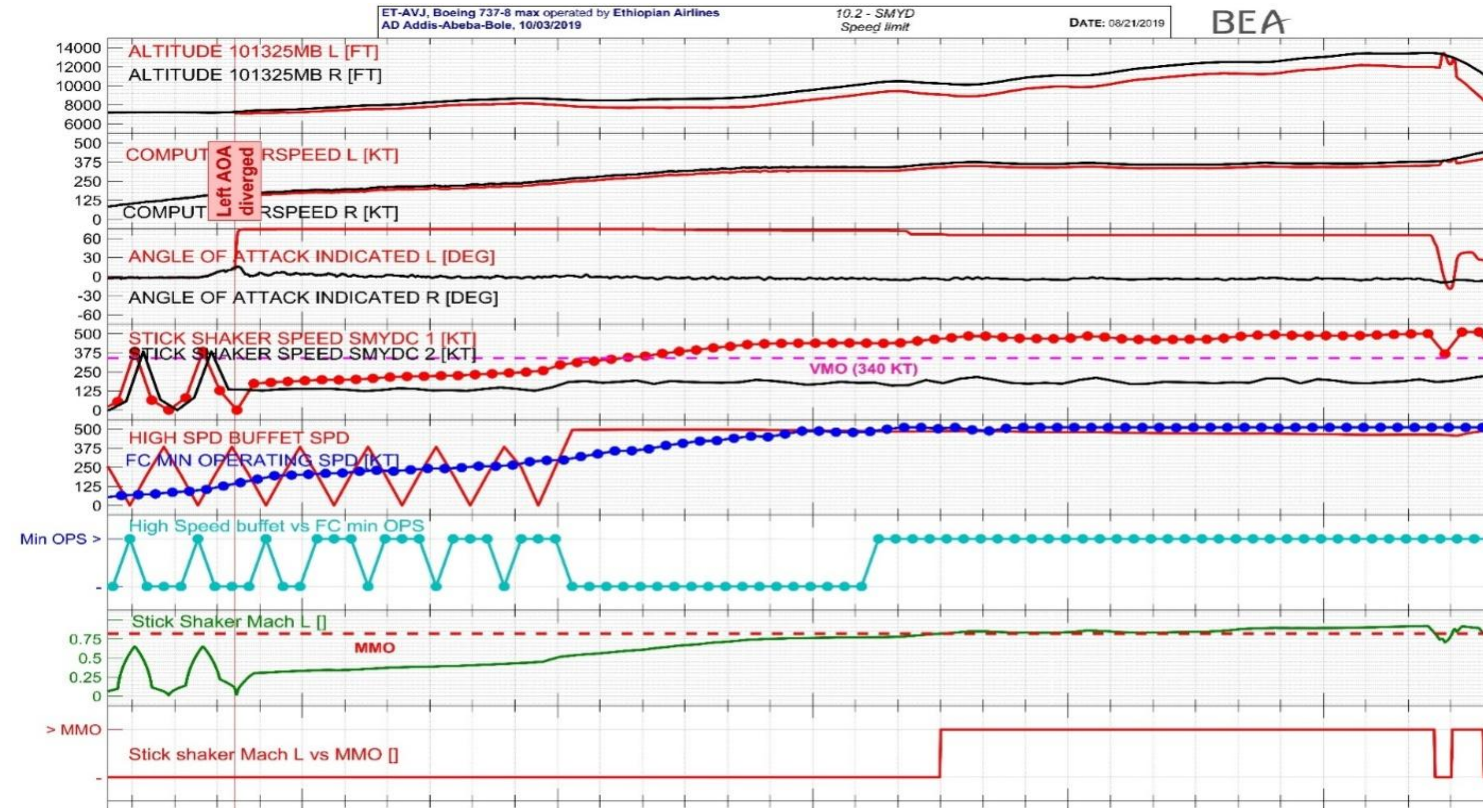


FIGURE 75: SMYD COMPUTED SPEEDS LIMITS

The speed tape of the Airplane had a range of 120Kt (60Kt above and below the actual computed airspeed). As soon as the stick shaker speed reached values higher than the actual computed airspeed plus 60Kt, red and black stripes are displayed all along the border of the speed tape.

During the flight of the event, the red and black stripes should have been displayed almost all the time from 5 h 40 min 03s until the end of the flight (parameter Full Red black Stripes).

1.16.3.5 Impact of AOA Failure on Flight Controls

STABILIZER

Stabilizer commanded moves

Takeoff was performed with a trim position set at 5.7 units.

During the beginning of the flight, several manual electrical trim inputs were recorded. These inputs reduced the force the captain needed to apply to the control column to maintain the desired path (this is the normal and intended function of stabilizer trim in manual flight). Between the liftoff and the engagement of CMD A, the stabilizer moved between 4.9 and 5.9 units. When A/P was engaged, the stabilizer was at 5.6 units.

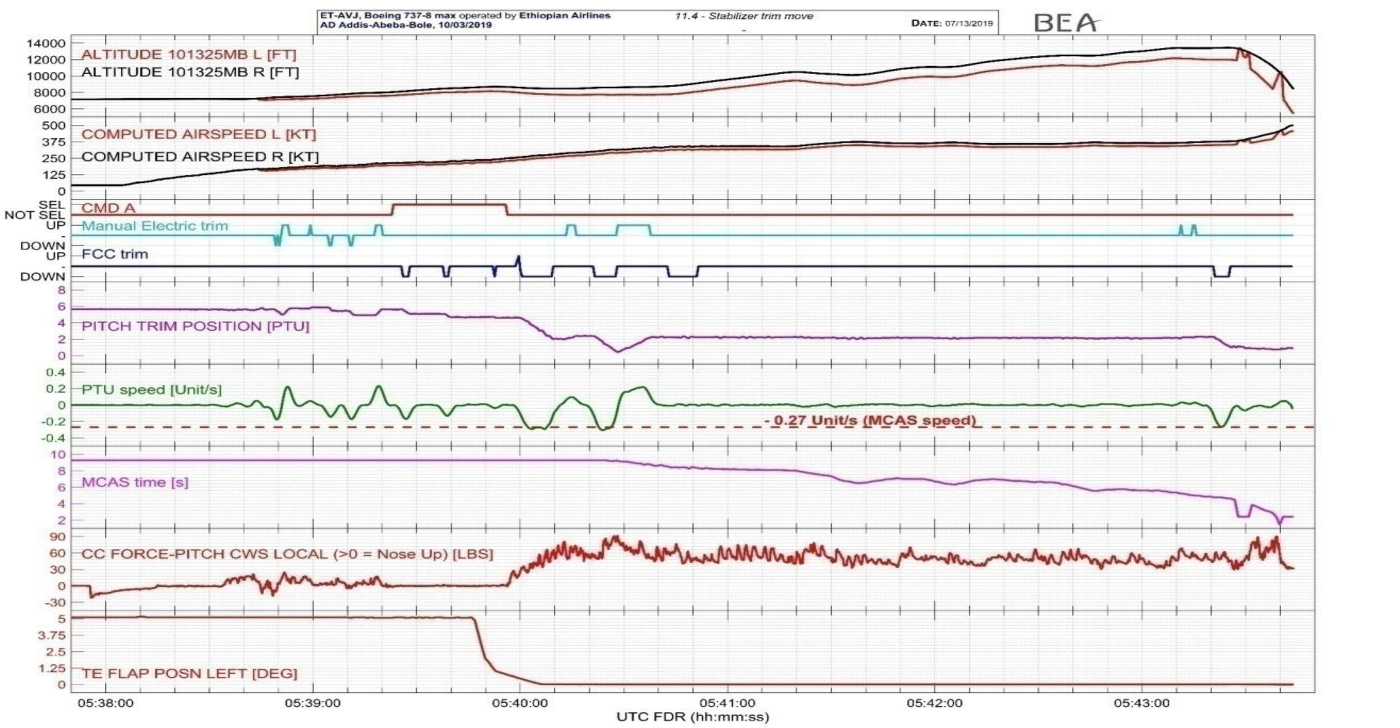


FIGURE 76: STABILIZER COMMANDED MOVES

Under A/P, 3 FCC A/P trims down commands were recorded and the stabilizer trim values decreased to 4.6 units. When A/P disengaged, one single sample of FCC trim UP was recorded (Speed Trim activation).

At 5 h 40 min 00 s, MCAS function triggered for the first time. At the end of the MCAS activation, the stabilizer position was 2.1 units.

Manual electrical trim UP input was recorded from 5 h 40 min 14 s for 2 s. The stabilizer reached a position of 2.38units.

At 5 h 40 min 21 s, MCAS triggered for the second time. At the end of the 2nd MCAS activation, the stabilizer position was 0.4 units.

Note: *The MCAS function should have commanded stabilizer move towards Airplane nose down for 9.3 s but, during that period of time, the movement of the trim towards nose down command was limited to only 7s, the MCAS command was stopped by manual electrical trim up command.*

The crew trimmed up for 9 s. The stabilizer position reached 2.3 units.

At 5 h 40 min 43s, the MCAS function triggered for the third time. The stabilizer did not move. The Stab Trim Switches were then in the CUTOUT position. As manual electrical stabilizer trim command was recorded up to 5 h 40 min 37s, the move of the switches into the CUTOUT position occurred between 5 h 40 min 38 s and 5 h 40 min 43 s.

According to the CVR transcript, the crew exchanged about the use of “stab trim cutout”. At 5 h 40 min 37 s, the Captain expressed “yes, do it”, followed by the F/O answer “Stab trim cut-out”.

Note: the investigation concluded that the F/O most likely moved the stab trim switches into the CUTOUT position at 5 h 40 min 38 s.

At the end of the flight, (at 5 h 43 min 11 s), one pulse of manual electrical stabilizer trim up command was recorded (one single sample), followed 3s later by a pulse of 2 samples. The stabilizer reached 2.3 units. At those times, both Stab Trim Cutout switches were in the NORMAL position.

The following exchanges were provided by the CVR transcript:

05:43:09 “Put Them UP”

05:43:11 “COMMAND” put it on.

***Note**: It is assumed that the Stab Trim switches were back into the normal position at around 5 h 43 min 10 s.*

At 5 h 43 min 21 s, the MCAS function activated for the 4th time.

The stabilizer position reached 1 unit. From that point until the end of the recording, no other commanded move of the stabilizer occurred.

TRIM STABILIZER FORCE

The Airplane manufacturer computed the force required on the trim wheel handle to move the stabilizer.

Taking into account the force applied on the control column, it was possible to assess that the FO was pulling the control column until 5 h 41 min 49 s

From the CVR transcript:

- At 5 h 41 min 50 s, the captain requested the F/O to try moving the trim manually.
- At 5 h 41 min 50.5 s: a sound similar to the trim wheel handle extension was detected.
- At 5 h 41 min 51 s, the first officerconfirmed “Trim up”
- At 5 h 41 min 55.5 s, the captain used an “expression of expectation”
- At 5 h 41 min 56 s, the first officer stated: “it is not working”.

The time during which the F/O tried to manually move the trim was then between 5 h 41 min 51 s and 5 h 41 min 56 s.

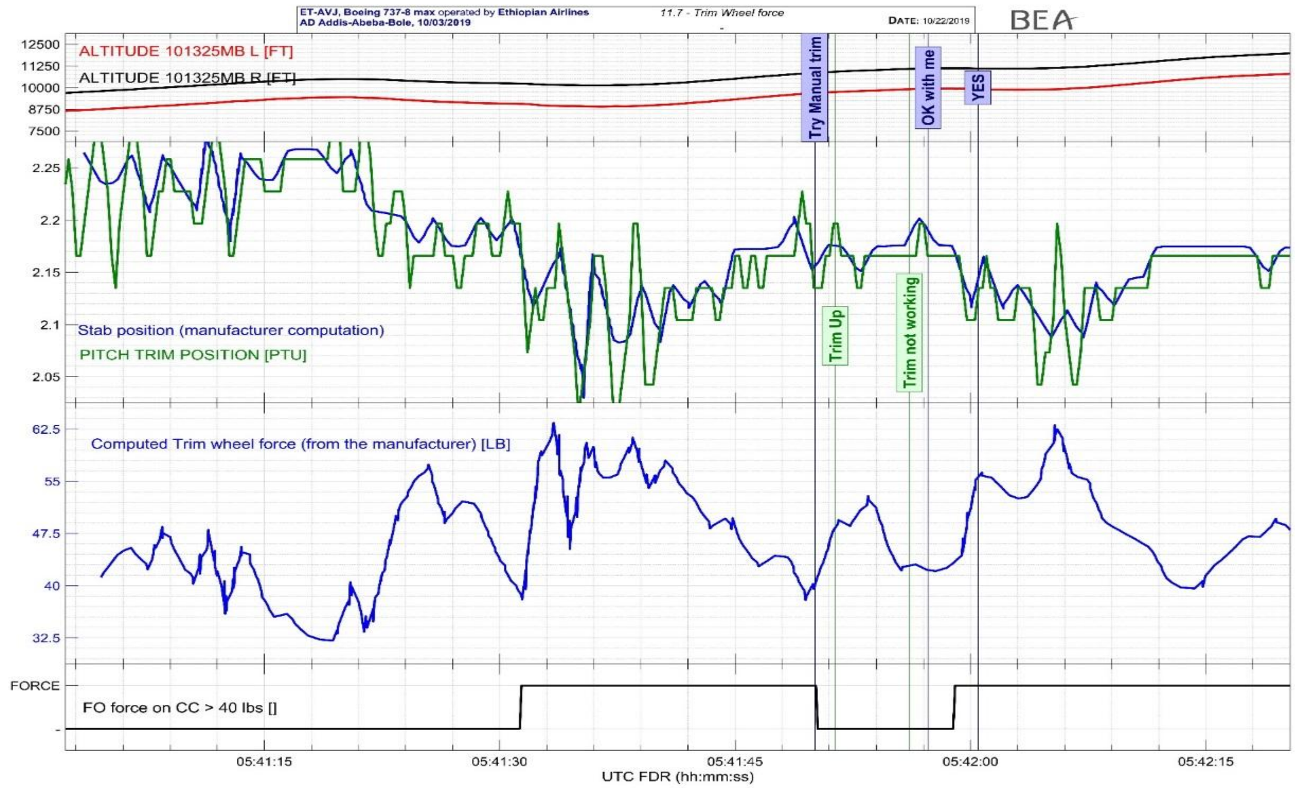


FIGURE 77: FORCE NEEDED TO MOVE THE TRIM WHEEL

By the time the FO tried to move the trim wheel manually a force between 42 lbs and 53 lbs was required according to the Airplane manufacturer computation, (see Figure 77).

Elevator feel system

Note: This part starts at the time the LH AOA sensor erroneous values.

1.16.3.6 Impact of the Elevator Feel System before the A/P Engagement

Before the A/P engagement, the recorded low force level underlined an Airplane rather properly trimmed in pitch. At that time, the stabilizer position was 5.62 units (nose up setting) and the elevators position was of 3.5° (nose down setting).

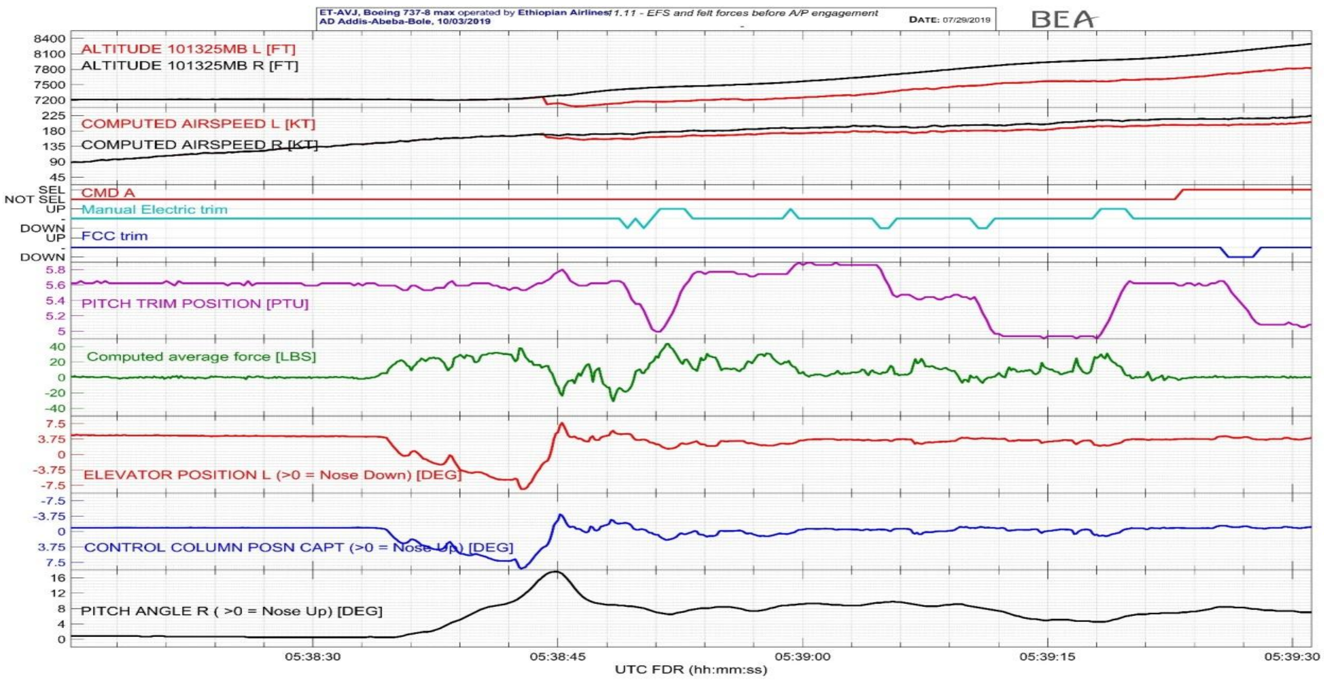


FIGURE78: FORCE BEFORE A/P ENGAGEMENT

1.16.3.7 Impact of the EFS on the Crew Feeling after the A/P Disconnection

Note1: the Airplane manufacturer computed the pressure the elevator feel system delivered during the flight of the event. After the A/P disconnection, from the end of the 1st FCC trim down command until the end of the flight, the Elevator Feel system delivered a constant pressure that was the Maximum pressure.

Note 2: the Airplane manufacturer confirmed that the FEEL DIFF PRESS master caution never triggered during the whole flight of the event. Indeed, when the conditions were met to close the feel differential pressure switch (before CMD A engaged), the duration of closure was shorter than the confirmation timer (30 s), after auto pilot disconnection, the conditions were not met anymore to close the feel differential pressure switch,

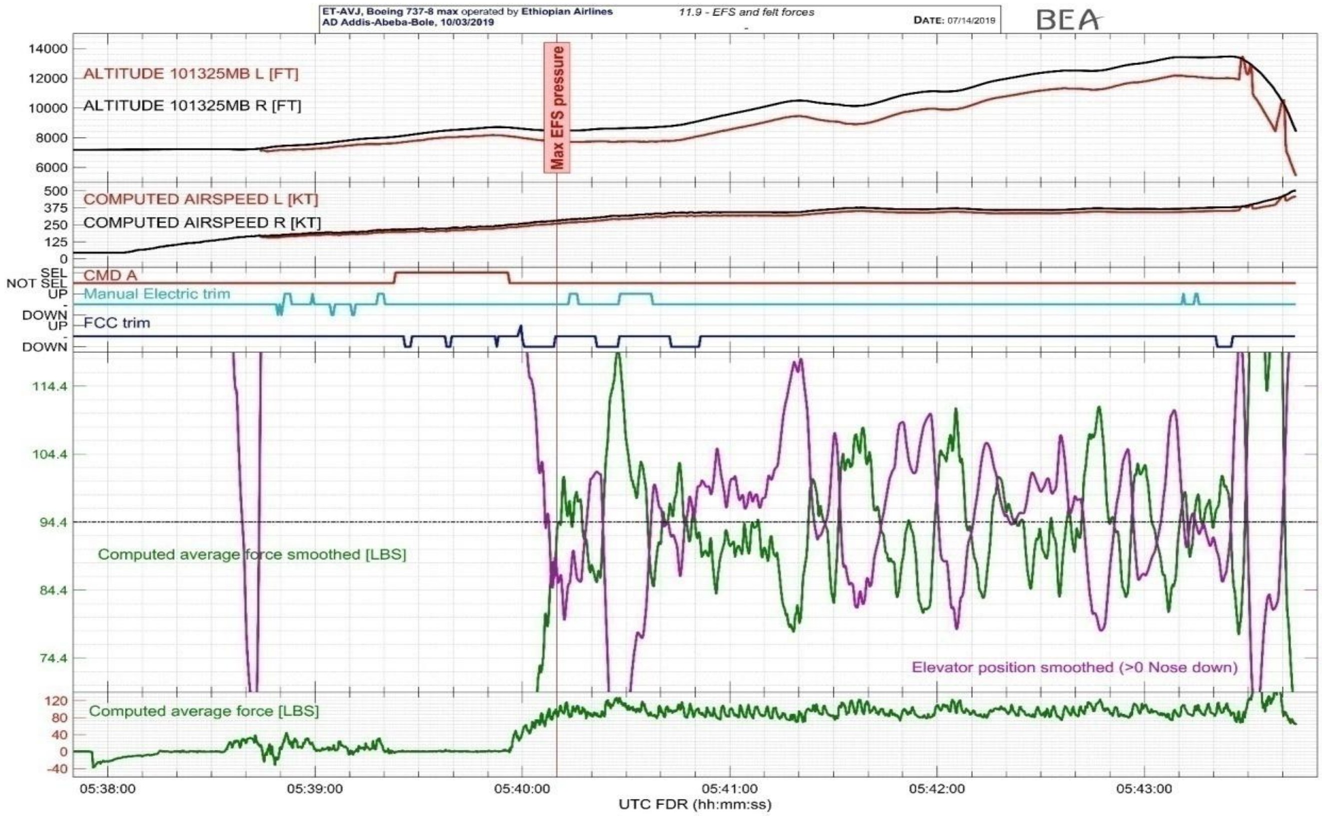


FIGURE 79: FELT FORCE AND ELEVATOR POSITION

The gradient of force felt by the crew can be illustrated by the comparison between the force applied on the control column and the position of the elevator. Note that because the flight conditions resulted in the Maximum feel pressure, the activation of EFS had no effect on these forces.

Between 5 h 40 min 10 s and 5 h 43 min 25 s, statistics were computed:

- mean values of the smoothed elevator position: -3.0°
- mean value of the smoothed computed average force: 94.4 lbs

Figure 79 shows that from 5 h 40 min 10 s until the end of the flight:

- an elevator position close to -3° required a force close to 94.4 lbs
- a decrease of the elevator position below -3° required a force greater than 94.4 lbs
- an increase of the elevator position above -3° required a force lower than 94.4 lbs
- similar elevator position required similar force values

1.16.3.8 Impact of AOA Failure on Flight Director

F/D invalidity periods

With the erroneous values of the LH AOA sensor, the RH and LH pitch F/D diverged. LH and RH pitch F/D recorded invalid patterns for the first time at 05:38:51

Then the RH pitch director did not experience invalidity pattern anymore but 3 other periods of invalidity were recorded on the LH pitch director.

Each time the LH or the RH invalidity pattern was recorded, the recorded invalidity code (NCD - No Computed Data) indicates that the pitch F/D bar was removed from the PFD (biased out of view or BOV). The F/D fail flag did not trigger during the accident flight.

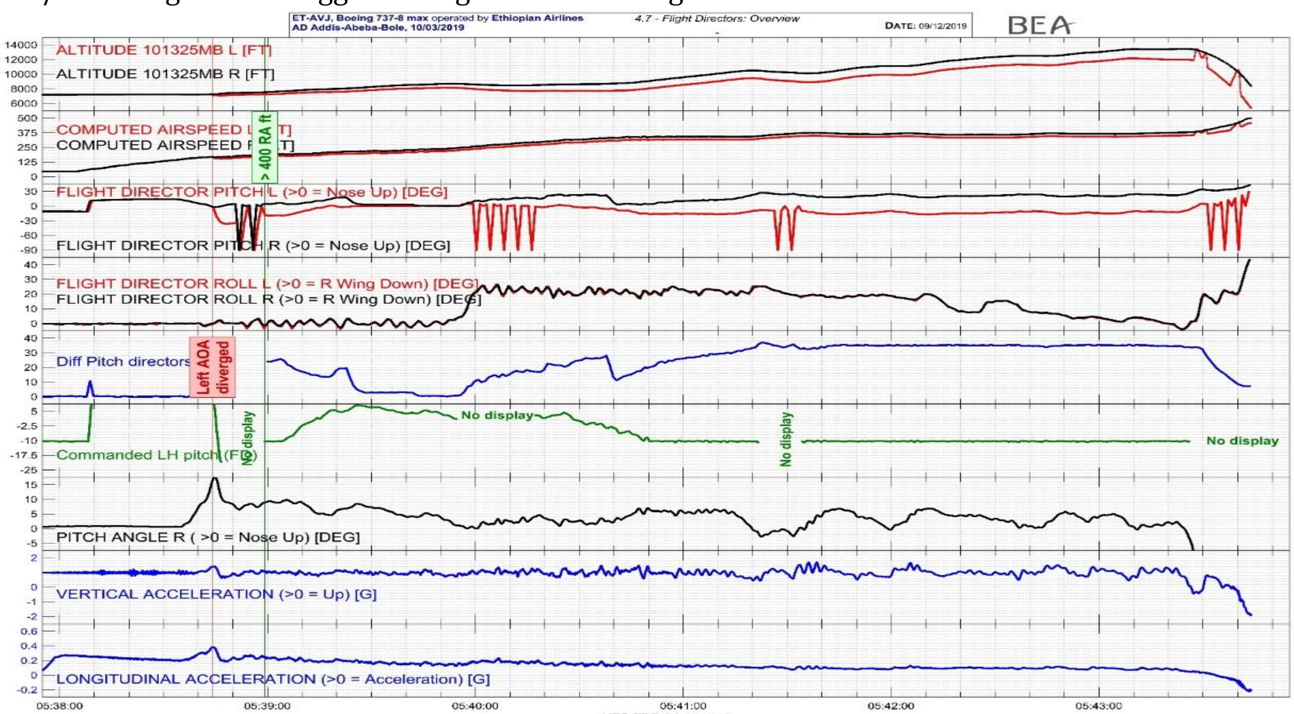


FIGURE 80: FLIGHT DIRECTOR DURING FLIGHT

1st invalidity period

At the time of the 1st invalidity, F/D was in T/O mode and the radio altitude was lower than 400 ft.

Note: *Below 400 ft, during TO mode, LH and RH pitch bars positions are compared with each other. If the difference between both pitches bars position exceeds a defined threshold, both pitch bars are BOV.*

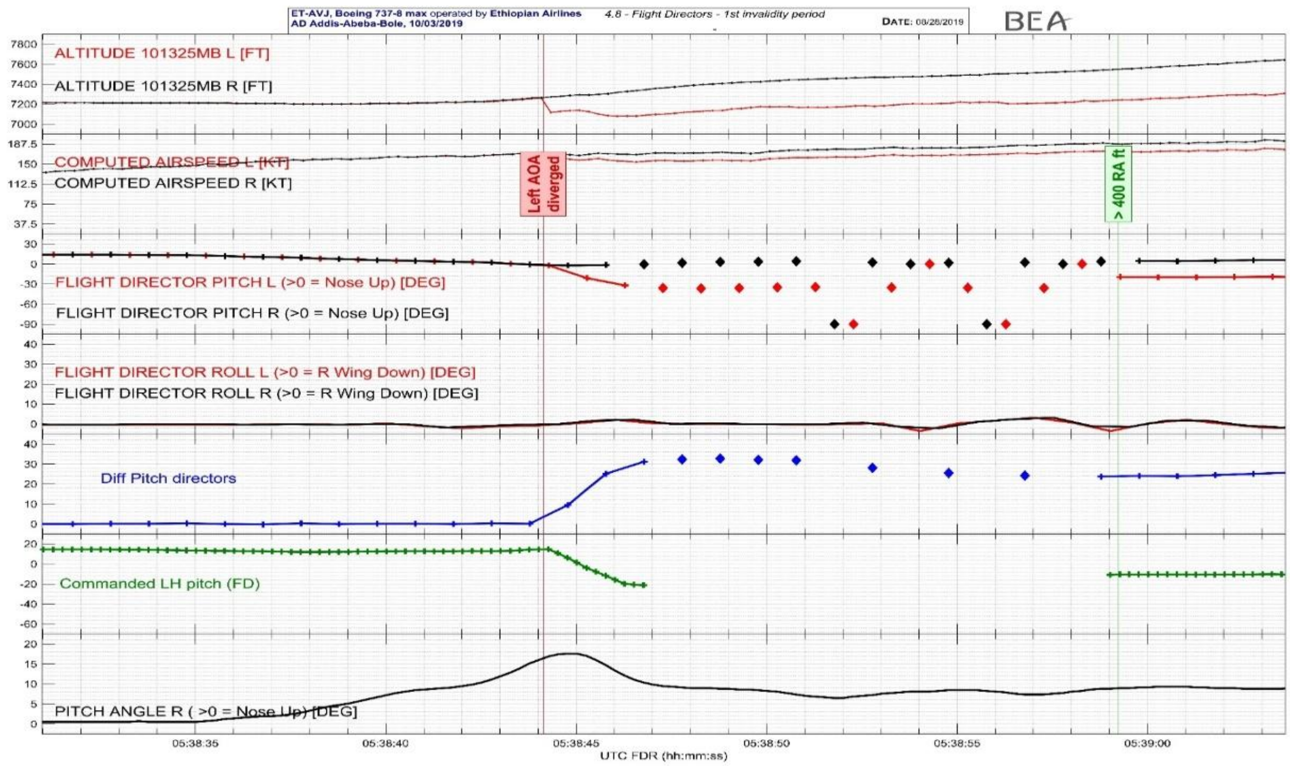


FIGURE 81: FLIGHT DIRECTORS - START OF THE FLIGHT

When the LH and RH AOA values diverged, LH pitch F/D commands recorded values quickly decreased to -32° while RH pitch F/D recorded values slightly increased to -0.4°. The difference between LH pitch F/D values and RH pitch F/D values were greater than the threshold above which FCCs comparators triggers and both F/D pitch were biased out of view.

At 5 h 38 min 59 s, the radio altitude reached values greater than 400 ft RA increasing. The F/D was displayed again as per design, the comparator function stops above 400 ft.

Note: The LH pitch F/D values were due to the erroneous LH AOA values and their impact on computed data (information sent by ADIRU 1 and SMYDC 1 to FCC A).

Other invalidity periods

During the remaining time of the flight, 3 other periods of invalidity were recorded:

- From 5 h 39 min 56 to 5 h 40 min 16 s
- From 5 h 41 min 22 to 5 h 41 min 33 s
- From 5 h 43 min 29 to the end of the flight

The computation of the LH F/D pitch behavior by the Airplane manufacturer allowed the detection of 2 other periods of invalidity, with too small a duration for the invalidity to be recorded inside the FDR data:

- From 5 h 42 min 01 for 0.5 s
- From 5 h 42 min 41 for 3 s

Each invalidity period was due to the following conditions, described in the Airplane Maintenance Manual:

- The F/D was in speed mode.
- The Airplane should have been climbing but the computed vertical speed value of the Airplane had been lower than the Climb threshold for 5 consecutive seconds.
- At the LH side the Airplane approached to stall
- LH F/D pitch commands (A/P not engaged)

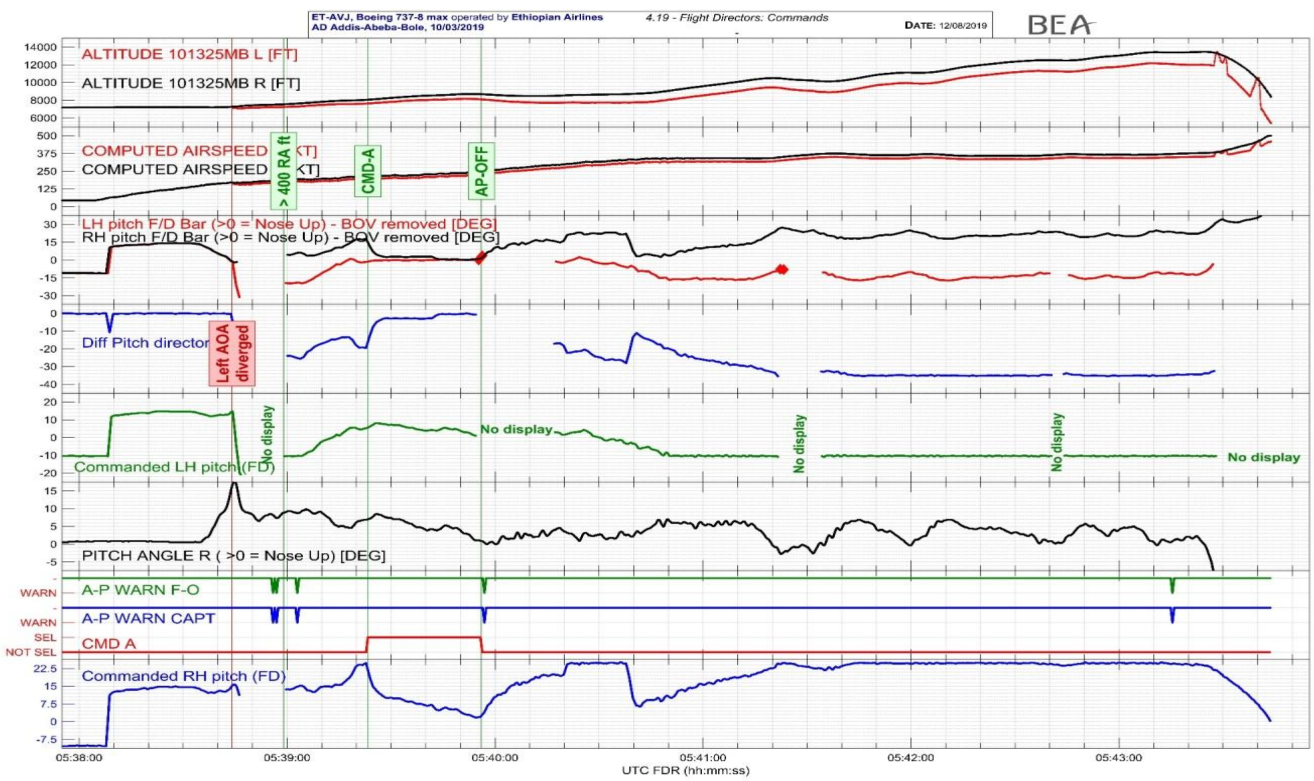


FIGURE82: PITCH F/D COMMANDS

Inside the Figure:

- the LH and RH pitch F/D bar was plotted without the period when the pitch F/D bars were BOV
- the difference between the RH and LH pitch F/D command was plotted (LH F/D bar minus RH F/D bar)
- The recorded pitch F/D parameter is the angle between the center of the PFD (the symbolic Airplane in fact) and the position of the bar. To allow a better understanding of what the pitch bar requested, commanded pitch parameters were computed. For instance, at the beginning of the takeoff phase, the pitch F/D target is -10°. Prior to rotation, the target moves to around 15°. When the rotation occurred, the Airplane pitch increased, the target pitch (commanded pitch parameters) stayed almost constant around 15°, while the recorded pitch F/D bar parameters decreased.

Note*: No anomalies were observed in the RH pitch F/D bar positions the RH pitch F/D bar positions are then considered as valid positions based the Airplane attitude, altitude, and speed engaged modes.Except under the autopilot, the LH pitch F/D bar position was at least 10° lower than the RH pitch F/D bar. The commands provided by the LH pitch F/D bar were not consistent with the true Airplane status and the engaged modes, due to the effects of the erroneous AOA on the calculation of the minimum operation speed.*

Summary of AOA impact on F/D pitch command

Once the LH AOA values diverged from the RH AOA values, the LH pitch F/D bar provided command that were not consistent with the true state of the Airplane and the engaged modes.

LH F/D pitch bar was BOV (biased out of view) 6 times. Each time, airborne systems detected an important inconsistency:

- The first instance was due to a divergence between RH and LH pitch F/D commands, when the Airplane was below 400 ft.
- The remaining instances were due to the Airplane not deserving the minimum climb rate during level change mode. During manual flight, while the crew was pulling on the column and successful in making the Airplane climb, the pitch F/D bar would appear; however, once the Airplane starts to descend then the pitch F/D bar would be removed thus causing the disappearing and reappearing behavior of the pitch F/D bar.
- Each time the LH pitch F/D bar automatically reappeared, without any crew action.The underlying cause of the anomalous LH pitch F/D behavior was confirmed to be erroneous LH AOA sensor values. Erroneous AOA results in display of the IAS DISAGREE and ALT DISAGREE alerts. The appropriate NNC for these alerts is the Airspeed Unreliable NNC, which, as a memory item, requires that the crew turn off both flight directors.

1.16.4 Airplane Behavior under CMD A

CMD AENGAGEMENT

At 5 h 39 min 23 s, CMD A engaged in HDG/VNAV modes.

Roll axis under CMD A

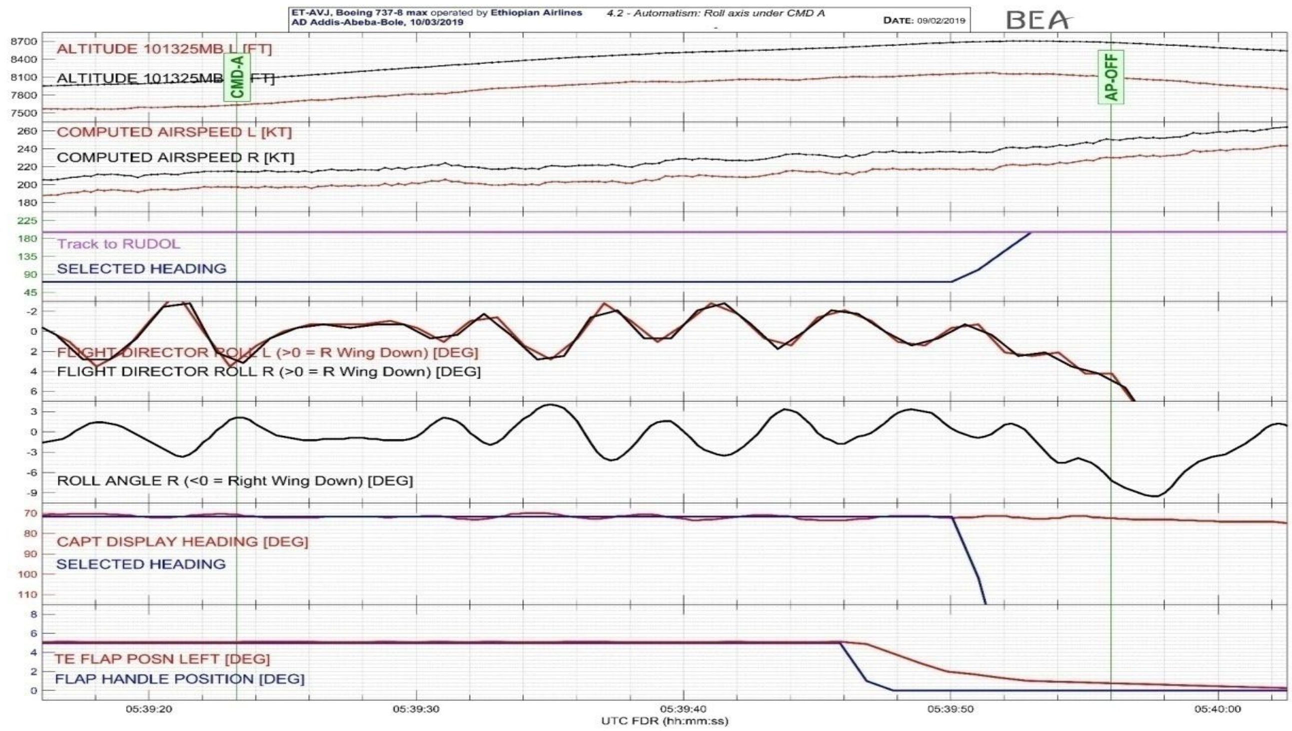


FIGURE 83: ROLL AXIS UNDER CMD A

The roll axis under CMD A behaved as expected:

- RH and LH roll F/D commands were consistent with each other.
- Under HDG mode, the heading was kept within 2° of accuracy
- At 5 h 39 min 50s the crew selected a new heading (197°) and the A/P commanded a right bank to turn towards the new selected heading. However, the A/P was disconnected and the Airplane returned to wings level prior to reaching the new selected heading.

Pitch Axis under CMD A

With the VNAV SPD mode engaged, the Airplane was expected to climb towards the target altitude of the flight plan (32,000 ft) at a speed close to the FMC target airspeed.

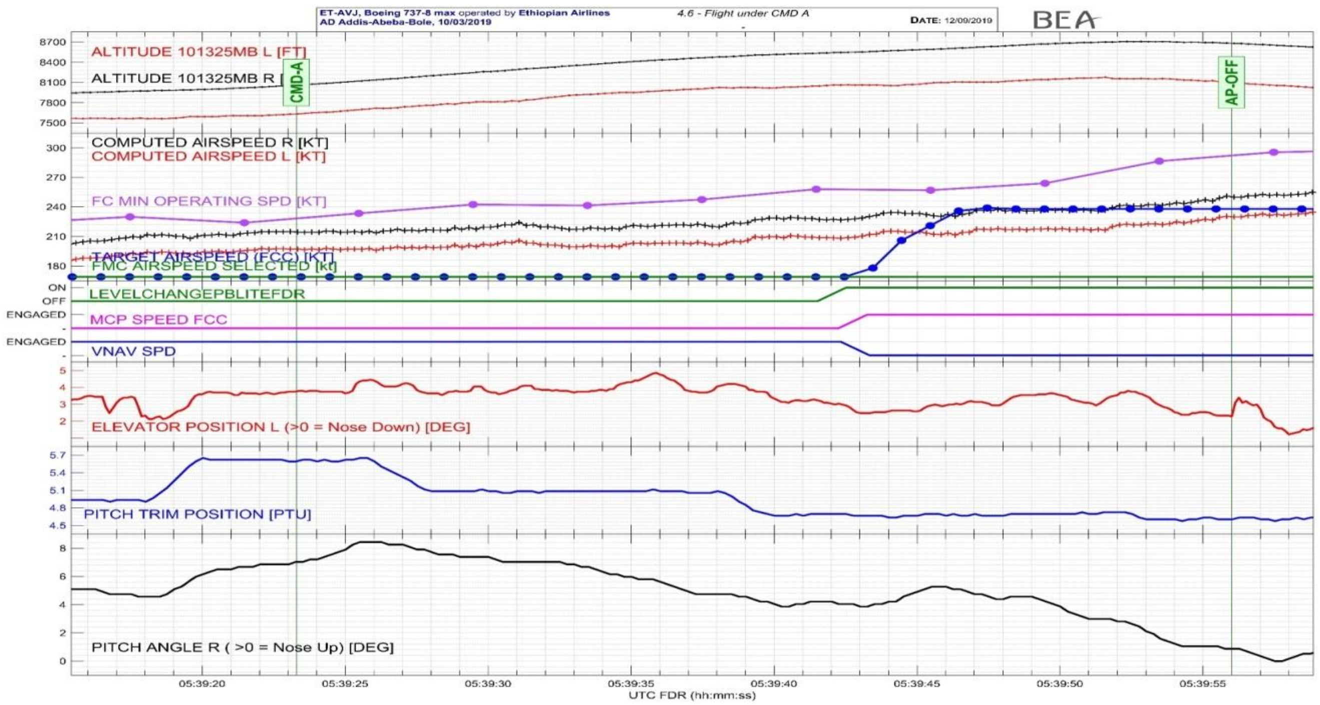


FIGURE 84: CMD A ENGAGEMENT

The longitudinal engaged mode (VNAV SPD) is a speed mode.

Note: In a speed mode, the auto throttle sets a fixed thrust for the specific phase of flight and the autopilot uses the elevators to adjust pitch angle to control the airspeed to the target airspeed, which is the higher of the Minimum Operating Speedand either, FMC speed or selected speed. At that time of the flight of the event, the erroneous the Minimum Operating Speed values computed by SMYDC 1was the higher of the two and was thus the target airspeed.

As the target airspeed used by the autopilot was higher than the current LH computed airspeed, CMD A commanded a decrease of the Airplane pitch to increase the airspeed.

As the flaps were retracted, the autopilot commanded 2 stabilizer moves towards nose down to reducethe amount of elevator deflection necessary to maintain the intended pitch angle.

The crew engaged the LVL CHG longitudinal mode (speed mode also) at 5 h 39 min 42 s and increased the target airspeed (MCP setting), reaching 238 Kt at 5 h 39 min 49 s. After a transient period due to the speed setting, the Airplane pitch continued decreasing.

CMD A DISCONNECTION

The autopilot uses a condition similar to the condition used by the pitch F/D to be BOV. In speed mode, when the autopilot is commanding a climb but the climb rate falls below a minimum threshold, the autopilot automatically disengages.

With the decrease of the pitch, the vertical speed of the Airplane decreased. Climb rate dropped below the minimum climb rate threshold and CMD A automatically disengaged.

SUMMARY OF AIRPLANE BEHAVIOR UNDER CMD A

The Airplane behaved as expected on the lateral axis.

On the longitudinal axis, the erroneous Minimum Operating Speed values computed by the SMYDC 1 (due to erroneous LH AOA values) became the target airspeed for the autopilot. As those values were greater than the current LH computed airspeed, the autopilot commanded a decrease of the Airplane pitch, leading to a stop of climbing followed by a start of descent.

At the connection of CMD A, the Airplane was climbing with a vertical speed of around 1,000 ft/min increasing, a pitch value of around 7° increasing and a stabilizer position of 5.6 units.

When CMD A automatically disconnected, the Airplane was descending with a vertical speed of around -1,400 ft/min, a pitch angle of around 1° and a stabilizer position of 4.6 units.

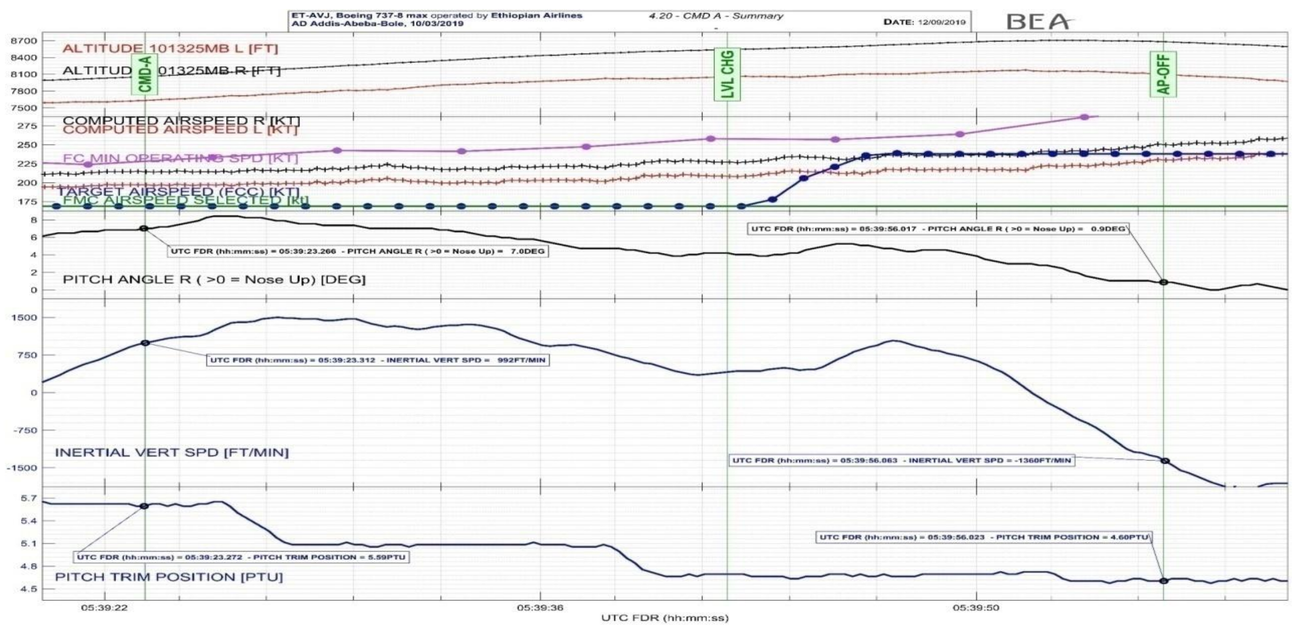


FIGURE85: CMD A - SUMMARY

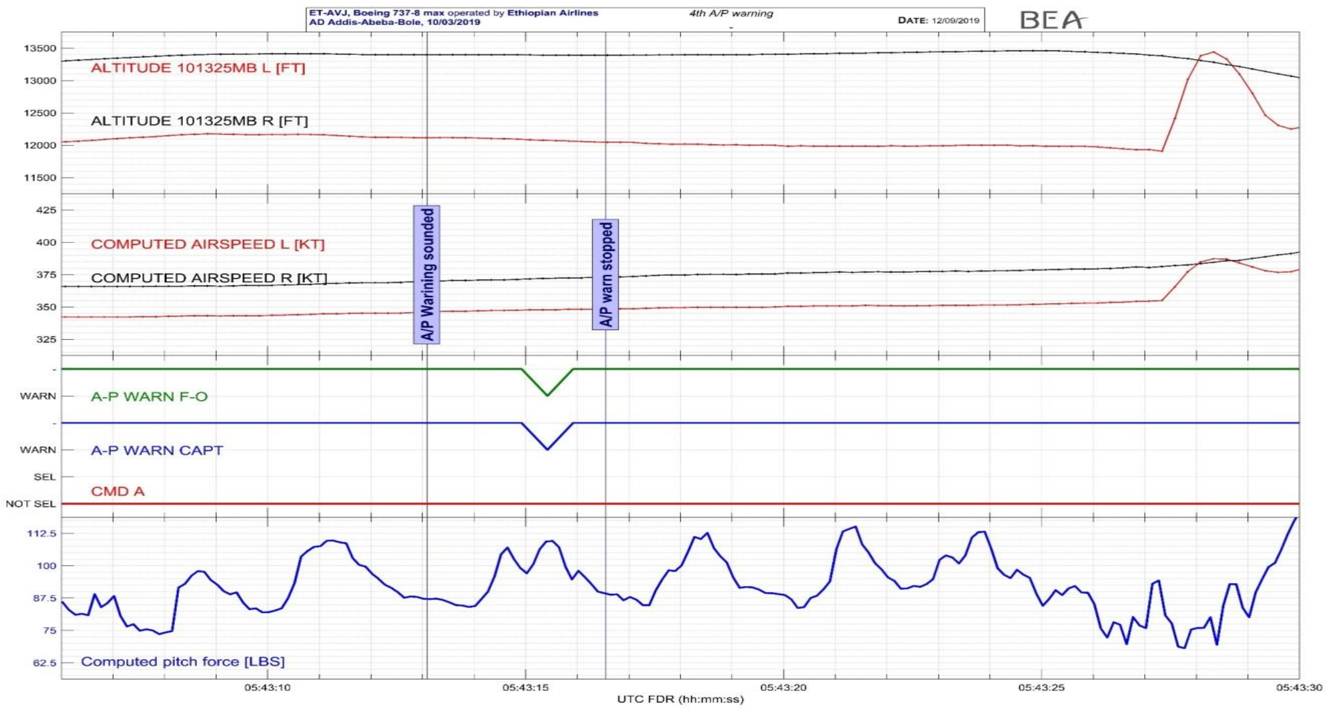


FIGURE86: A/P WARNING AT THE END OF THE FLIGHT

1.16.5 Alerts and Warning

GPWS

At 5 h 40 min 3 s, the GPWS alert 'DON'T SINK' sounded twice. The previous Maximum recorded height was 1,646 ft.

The mean vertical speed of the Airplane before the Maximum value was around 12 ft/s. An alert triggering around 1,271 ft – after 229 ft of altitude loss was consistent with the GPWS Mode 3A alert envelop shown in Figure 26.

Once the alert was engaged, it continues until inertial vertical speed becomes positive.

During all these alerts, the 'PULL UP' message should have been displayed on both PFD.

At the end of the flight, the combination of the vertical speed and the height of the Airplane made the terrain and pull up warning trigger.

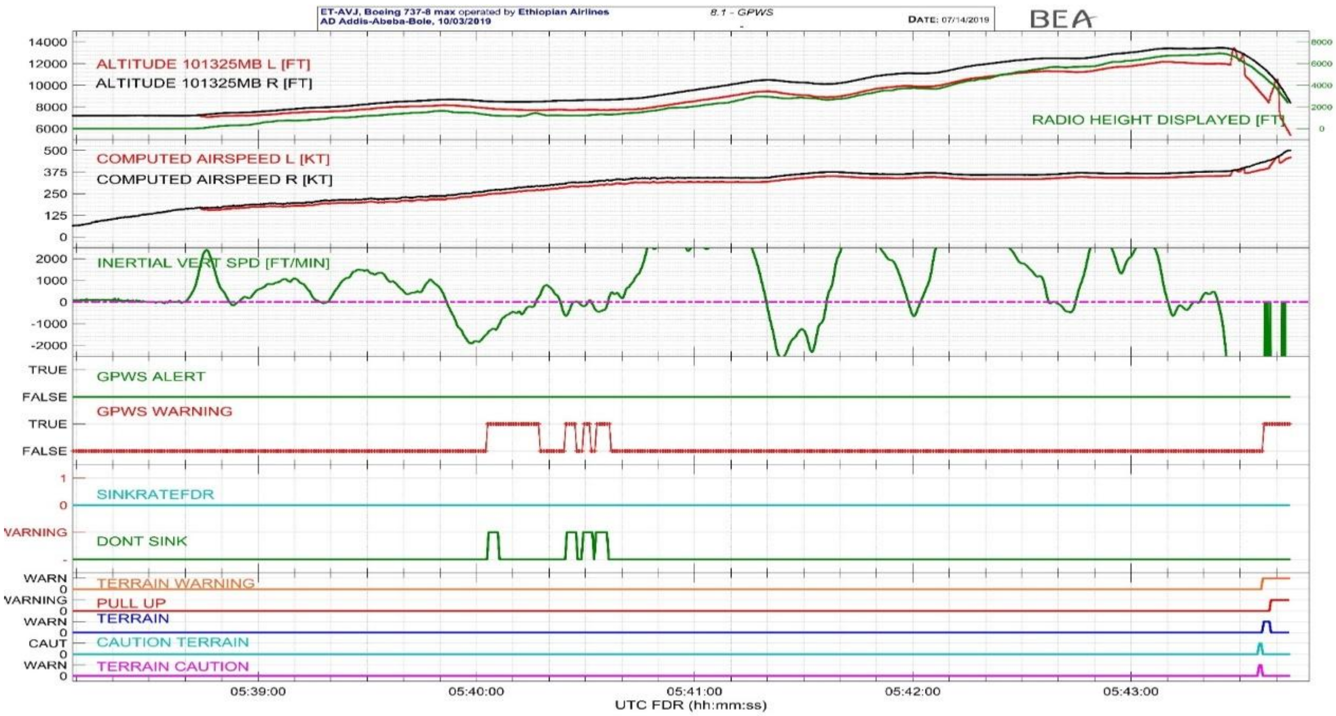


FIGURE87: GPWS ALERTS

Other alerts

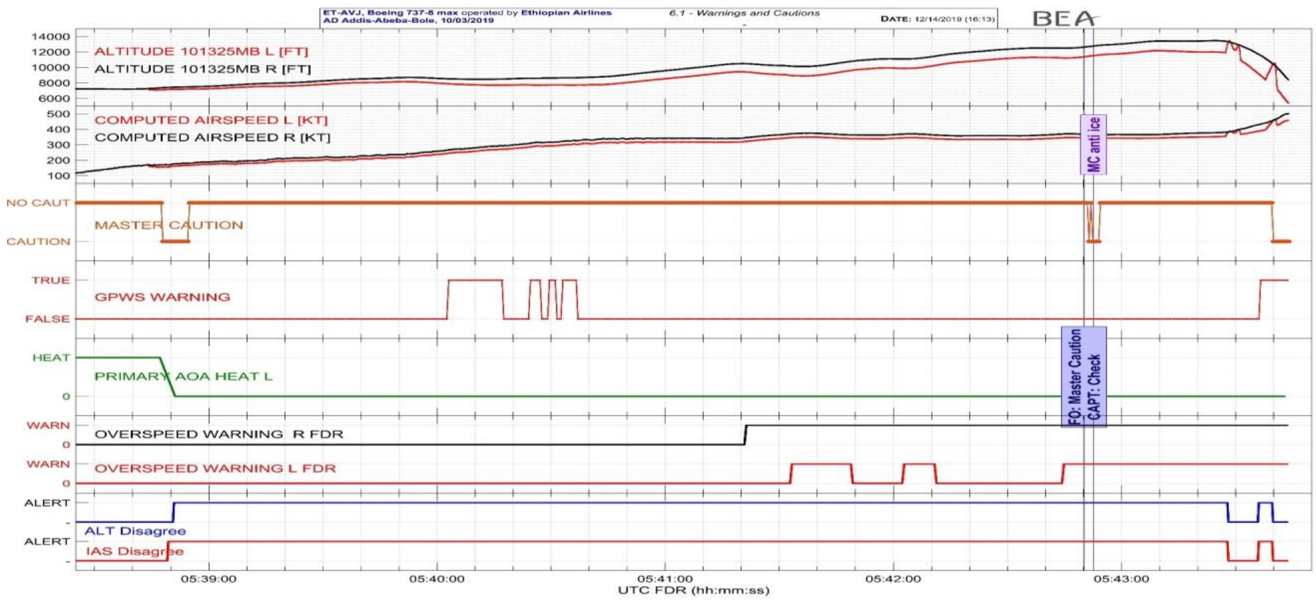


FIGURE 88: ALERTS DURING THE FLIGHT

MASTER CAUTION

The first master caution triggered at 5 h 38 min 48 s during 7s. The reason for this master caution was anti-ice left alpha vane.This caution is triggered when low current is sensed in the AOA vane internal heater circuit. At 5 h 42 min 47 s, the crew exchanged about the master caution.

Then master caution triggered a second time at 5 h 42 min 51 s during 2.5 s. The crew detected: “Master Caution/anti Ice/left Alpha Vane”.

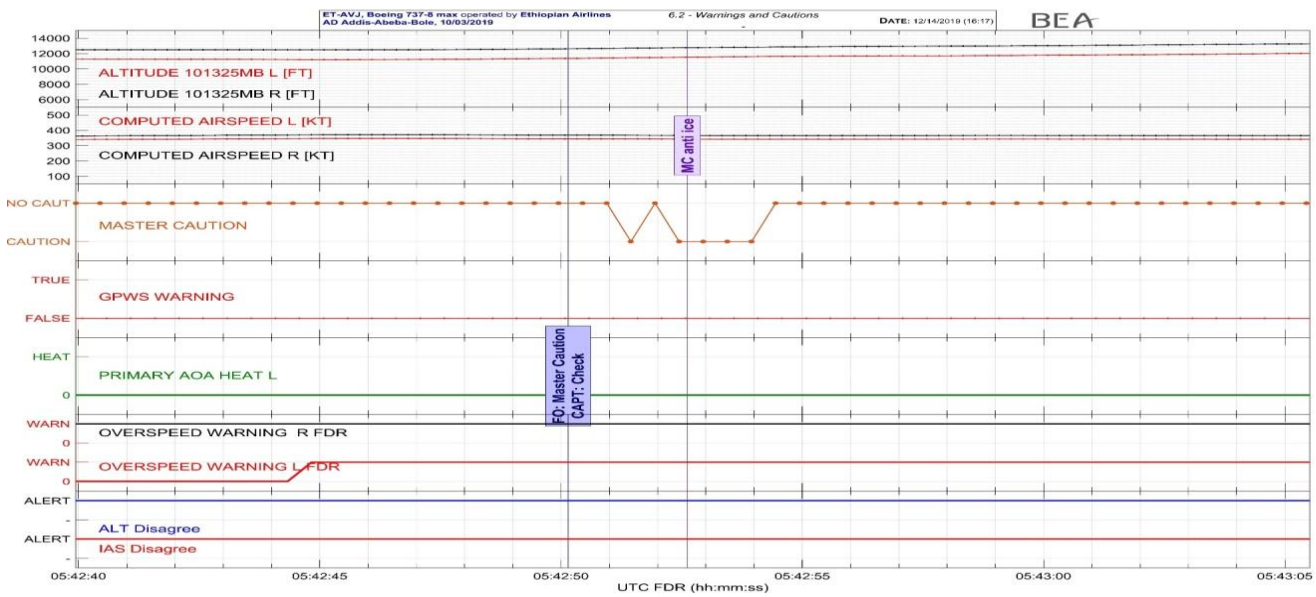


FIGURE 89: MASTER CAUTION RECALL

The third master caution triggered at 5 h 43 min 40s, but had no bearing on the sequence of events which led to the accident.

1.16.6 IAS, ALT Disagree

These alerts were not recorded in the FDR. Their time of appearance has been computed, as per computation, the IAS disagree alert should normally have triggered at 5 h 38 min 49 s, and stopped at 5 h 43 min 28 s. It might have triggered again at 5 h 43 min 36 s during 4 s. As per computation, the ALT disagree alert should have triggered at 5 h 38 min 51s and stopped at 5 h 43 min 28 s. it might have triggered again at 5 h 43 min 36s during 4s.

Over speed

Over speed warning RH side triggered at 5 h 41 min 21 s and stayed engaged until the end of the recording.

Over speed warning LH side triggered at 5 h 41 min 33 s for 15.5 s, at 5 h 42 min 02 s for 8 s and at 5 h 42 min 45 s. It stayed engaged until the end of the recording.

1.17 ORGANIZATIONAL AND MANAGEMENT INFORMATION

1.17.1 The Operator

The Ethiopian Airlines group/Operator (ETAG) has valid Air Operator Certificate (AOC) number CATO-01/270295
The Ethiopian Airlines group operates a total of 126Airplanes consisting of:

TABLE 22: AIRPLANE IN TYPE

No	Airplane type	Total
1	Airbus A350	14
2	Boeing787-8	19
3	Boeing B787-9	6
3	Boeing 767-300	6
4	Boeing777-200	16
5	Boeing777-300	4
6	Boeing B737-800	20
7	B737-700,	10
8	B737-MAX8	4
9	Q-400	27

Ethiopian Airlines (Ethiopian) is the flag carrier of Ethiopia. It commands a lion's share of the pan African network including the daily and double daily East-West flight across the continent. Ethiopian currently serves more than 100 international and 21 domestic destinations operating the newest and youngest fleet.

Ethiopian Airlines, which is owned by the government of Ethiopia, has grown over the last two decades as it has capitalized on a strategy connecting markets across the African continent with European, North& South American, , and Asian destinations via its hub in Addis Ababa.

1.17.2 Ethiopian Airlines Pilot Training School

The Pilot Training School was commissioned in 1964. The development of this training facility has made Ethiopian Airlines self-sufficient in meeting its requirements for pilots. This is accomplished through the engagement of highly qualified and experienced the Ethiopian Airlines training staff. Over the last 50 years, the Pilot training school has trained pilots for African and the Middle East countries.The pilot training and the academy programs and facilities have acquired praise from experienced American and other foreign pilots.

The Pilot Training School currently offers accredited training programs for Commercial Pilot License with Instrument and Multi-engine Rating (CPL/IR/ME) and Multi-crew Pilot License (MPL).

The Pilot Training School offers a comprehensive Commercial Pilot License with Instrument and Multi engine rating for over half a century. The school has highly experienced instructors for both flight and ground training. In addition, Ethiopian airlines have equipped it with all the necessary facilities: simulators, Airplanes (glass cockpit DA 40NG and Cessna 172) and well equipped ground classrooms and computer based training rooms. The syllabus is developed based on Ethiopian Civil Aviation Authority Regulations and ICAO requirements for Airline Transport Pilot License (ATPL), CPL and IR/ME Requirements. Moreover, due consideration is given to fulfill EASA ATPL theoretical knowledge requirements. Hence, The EASA and JAA-FCL detailed theoretical knowledge training syllabus is benchmarked for completeness and determination of scope and level of details.

Ethiopian airlines pilot training follows an integrated syllabus for the ground and flight training. The theoretical Knowledge Courses comprise a total time of 920 class hours, including 80 hours for general English and 120 hours for Aviation English course. The CPL training also trains and offers regulatory body requirements, such as the ICAO English Language Proficiency requirements that necessitate the provision of structured Aviation English Training in the Pilot Training School. It also provides rating services for ICAO Level 4 English Requirements for Pilots.

The training program guides students seamlessly from ab-initio training to airliner type rating, using simulation designed for multi-crew training. It also addresses the increased rates of loss of control in airline operations through Upset Prevention and Recovery Training (UPRT). In addition, train the trainees to combat the continuing dominance of multi-crew human factors in accidents through threat and error Management (TEM) and Crew Resource Management (CRM).

1.17.3 ETHIOPIAN MRO

Ethiopian MRO Services is a division of Ethiopian and was established in 1957 to provide MRO services for Airplanes, engines and components of Ethiopian and third party customers. The primary base of Ethiopian is at Bole International Airport, Addis Ababa, Ethiopia. The Ethiopian MRO has an advanced maintenance base, which is fully operational for Airframe maintenance up to D-Checks, Engine, Overhaul, Components repair & overhaul, Light Airplane maintenance and technical, and management assistance for other airlines. The maintenance base is certified by the US- Federal Aviation Administration (FAA).

Ethiopian MRO is utilizing **"Maintenix"**, a state of the art MRO management IT system also selected by Boeing for Gold-care program. The values of Ethiopian MRO focus on exceptional customer satisfaction.

Ethiopian MRO has the capability to perform full airframe checks, including Heavy Maintenance on Boeing and Bombardier models of Airplanes at its base station.
The base airframe maintenance comprises various dedicated shops. These include Structures shop, Interior Shops, Non-Destructive–Testing (NDT) shop, Machine Shop.
Ethiopian MRO Engine shop has full overhaul capability of **CFM56-3/7**, **PW120**, **and GTCP331-200** APU as well as modular maintenance capability for PW2000, PW4000 engines supported by various repair shops.
In support of its engine overhaul facility, Ethiopian is utilizing a fully equipped with up to 100,000 pound jet engine test cell and two modern turboprop engine test beds.

The base station also has different mechanical and avionics shops with a repair capability of components on Boeing and Bombardier model of Airplanes. These include Pneumatic, Hydraulic, Fuel, Wheels & Brakes, Electrical, Communication & Navigation and Instrument shops.Ethiopian MRO provides Engineering support to Ethiopian Flight and third party customers.

1.17.4 OPERATION MANUAL (OM)-PART A

1.17.4.1 Captain Duty and Responsibility

Some of the Captain responsibilities according to the Operation Manual (OM)-part A subchapter 1.5, is directly and specifically responsible for, and is the final authority as to, the operation of the Airplane. Therefore, the Captain is responsible for ensuring the Airplane is in condition for safe flight and must discontinue the flight when un-airworthy mechanical, electrical, or structural conditions occur.
In regards with defect report, the OM-part A section 1.5 part 6.1 and 6.2 described that Captain has the following responsibility:

a. Conducting safe, efficient and secured flight in compliance with appropriate ATC and government rules, regulations, policies and procedures specified in the company Flight Operations Manual System.

b. The safety of all passengers, crew members, mail and cargo onboard when the doors are closed.

c. The operation and safety of the Airplane , its proper servicing, and the maintenance of airworthiness from the moment the Airplane is ready to move for the purpose of taking-off until the moment it finally comes to rest at the end of the flight and the engine(s) are shut down.

d. Cooperating with the flight dispatcher in accordance with policies and procedures specified in the flight operations manual and shall have final authority for decisions regarding airworthiness of the Airplane and flight planning.

e. Delegating his responsibility for the safety & security of the Airplane and its cargo as well as the passengers while on the ground to the company's representatives or to specific crew members.

f. Ensuring that standard and emergency procedures and regulations are known and adhered to by all crew members in the air and on the ground, including adherence to the prescribed cockpit checklist.

g. Coordinating the duties of the respective crew members in flight and on the ground to ensure that the provisions outlined herein are complied with;

h. Familiarizing himself with the records of First Officers and trainees and for giving them the fullest possible benefit of his experience in order to improve their proficiency and bring them up to a standard within their category. This shall include giving permission to first officers to perform takeoffs and landings considering operational capabilities and requirements. Whenever a First Officer performs takeoffs or landings, the Captain shall be prepared to take control immediately when such actions become necessary. The PF shall not allow the First Officer to taxi the Airplane during ground maneuver.

I. Acting within regulations in the best interest of Ethiopian at all times and taking into account all Known factors.

j. maintaining a proper liaison with supervisory staff at all stations in order to ensure an efficient and punctual operation.

k. monitor, check and verify the navigational performance, maintaining a particular RNP and accuracy of the present position of the Airplane during all phases of flight, after prolonged in-flight operations and before commencing approaches, by using the FMS RNP/ANP alerts or a VOR/DME distance and bearing against FMS fix distance/bearing of the same station.

l. the PIC ensures the continuous operation of the recorders such that for the flight recorder, the Airplane begins its takeoff roll until it has completed the landing roll and for the cockpit voice recorder, the initiation of the pre-start checklist until the end of securing Airplane checklist. (ECARAS8.5.1.24)

Note: flight crews are required to make the proper operational tests before every flight.

m. decide whether or not to accept an Airplane with defects allowed by the CDL or MEL.

n. ensure that the pre-flight inspection has been completed.

O. ensure the proper implementation and application of the manufacturer provided procedures and checklists approved for use by Ethiopian.

p. ensure that the Airplane carries sufficient required fuel, oil and additional fuel if operationally required. (FOM 2.12)

q. the pilot to whom conduct of the flight has been delegated shall, in an emergency situation that requires immediate decision and action, take any action he considers necessary under the circumstances in such cases he may deviate from rules, operational procedures and methods in the interest of safety to FOM 1.5 (6.5).

r. the captain is responsible for the safety of his Airplane and its contents throughout the time he is in command.

Emergency Authority of the Captain

ETH FOM 6.5, 1-4 describes that:

- The captain is permitted to deviate from prescribed rules, regulations, minimums, company policy and procedures as required for safety of flight considerations in emergencies. An Airplane in distress has the right-of-way over all other air traffic. Air traffic control should be kept informed of deviations from clearances of flight plans and will give priority to an Airplane that has declared an emergency.
- Dumping fuel to meet LGW limitations is an option of the captain's emergency authority.The captain may exercise his emergency authority to exceed the Maximum LGW if the landing is necessary as the result of an incident or a mechanical irregularity and he determines that such a landing would be safer than dumping fuel.
- In an emergency arising during flight time the captain shall keep the appropriate air traffic control or services facility and flight control fully informed of the progress of the flight.
- Whenever emergency authority is exercised, the captain shall submit a written report of any deviation to the VP flight operations within 2 days after the flight is completed.

1.17.4.2 The First Officer is Responsible For

a. attending pre-departure briefings, be fully aware of the intended flight planned route, contents of dispatch releases sheet, meteorology forecast conditions, NOTAMS and any other evaluation data.

b. is responsible for the completion of the required forms like load sheet, trim sheet and fuel sheet etc. during unassisted revenue departure

c. performing checks and drills, normal and emergency, in the manner prescribed by current flight operations manual.

d. monitoring the execution of emergency checklist actions whenever possible.

e.conducting radio communications, recording flight progress and importantcommunications

f. keeping the captain informed of NAV aid and communication frequency changes, ensuring that all facilities are properly identified.

g. monitoring the flight at all times, checking that correct procedures and techniques are being followed. in particular he must advise the captain clearly and concisely if and when, the Airplane departs significantly from its intended flight path e.g. climbing through a cleared altitude on departure, or going below glide slope on ILS approach, or whenever he considers that a hazardous situation is developing.

h. complete a periodic crosscheck of instrument indications of both captain and first officer instrument panels.

i. monitor, check and verify the navigational performance, maintaining a particular RNP and accuracy of present position of the Airplane during all phases of flight, after prolonged in-flight operations and before commencing approaches, by using the FMS RNP/ANP alerts or a VOR/DME distance and bearing against FMS fix distance/bearing of the same station.

j. monitor destination, destination alternate and en-route alternate(s)weather information while en-route.

k. carry out any other duties required by the captain.

l. record any system or component malfunction in the Airplane maintenance logbook (AML) when instructed by the captain.

m. maintain competency at all times to carry out basic navigation procedures using conventional methods.

n. the assume command of the Airplane while in flight in the event of incapacitation of the captain and take over the responsibilities implied.

o. first officer is not allowed to taxi an Airplane under any circumstances.

p. carry out his duties as defined in this manual and/or other relevant manuals and instructions and in conformity with legal requirements.

q. check and compute the take-off and landing weights, and pass the correct v speeds.

r. assist the captain in conducting a safe and efficient operation of the Airplane . Maintain a special relationship with.

1.17.5 Ethiopian Airlines Flight Crew Operations Manual (FCOM)

Normal Procedure Chapter, Section 21 “Amplified Procedures” section “Preliminary Pre flight Captain or First Officer” included in part: …

Maintenance documents…………………..Check

MAINT light………………..Verify extinguished

Pilot Flying

The following request calls are made by the Pilot Flying (PF):

1. Configuration requests
2. Thrust requests
3. MCP requests
4. Checklist requests

Decision calls are made by the PF. They are in effect statements of intention. The compulsory calls are listed below. It must be appreciated that any other decision calls can be made by the PF if he thinks that the information is important and enhances CRM. This becomes particularly relevant during non- normal procedures.

MACH AIRSPEED WARNING

TEST switches ....Push, one at a timeVerify that the clacker sounds.

STALL WARNING TEST switches…………… Push and hold, one at a timeVerify that each control column vibrates when the respective switch is pushed.

Note: The stall warning test requires that AC transfer busses are powered for up to 4 minutes.

Note: With hydraulic power off, the leading edge flaps can droop enough to cause an asymmetry signal, resulting in a failure of the stall warning system test. Should this occur, obtain a clearance to pressurize the hydraulic system, place the "B" system electric pump ON and retract the flaps. When flaps are retracted repeat the test. At the completion of the test, turn the "B" system electric pump "OFF"

Pilot Monitoring

The Pilot Monitoring (PM) will make all the following calls:

1. Altitude calls
2. Speed calls
3. Approach Parameter Deviation calls
4. Instrument calls
5. Lighting calls

If a call is valid and understood, it is acknowledged by the corresponding crewmember with the appropriate response. This does not apply to the V1 and VR calls as the response is a standard action. If a standard call or FMA call is responded to by another standard call or FMA call, the response "CHECK" is omitted. Calls made by the auto-callout system are not to be made by the PM unless the system is inoperative or fails to make the call.

1.17.6 Approach to Stall or Stall Recovery

An approach to a stall is a controlled flight maneuver; a stall is an out-of-control, but recoverable, condition. However, the recovery maneuver is the same for either an approach to stall or a fully developed stall.

A stall warning should be readily identifiable by the pilot, either by an artificial indication (stick shaker) or natural indication (initial buffet). During the initial stages of a stall, local airflow separation results in buffeting, giving a natural warning of an approach to stall. Stick shaker operation will usually precede initial buffet as a stall warning indication. In some cases, near cruise altitude and cruise Mach, the stick shaker may be simultaneous with the initial buffet.

Do all recoveries from approach to stall as if an actual stall has occurred. Immediately do the following at the first indication of stall (buffet or stick shaker).

If the Airplane is stalled, the recommended steps are to hold the control column firmly, disengage the autopilot and auto throttle, then smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops

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

TABLE23: STALL RECOVERY PROCEDURE

Pilot Flying	Pilot Monitoring
•Initiate the recovery: •Hold the control column firmly. •Disengage auto pilot and auto throttle. •Smoothly apply nose down elevator to reduce the angle of attack until buffet or stick shaker stops. Nose down stabilizer trim can be needed*.	•Monitor altitude and airspeed. •Verify all needed actions have been done and callout any omissions. •Callout 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 speed brakes. •Do not change gear or flap configuration, except •During lift off, if flaps are up, callforflaps1.	•Monitor altitude and airspeed. •Verify all needed actions have been done and callout any omissions. •Callout any trend toward terrain contact •Settle FLAP lever as directed.
• Complete the recovery: •Check air speed and adjust thrust as needed. •Establish pitch attitude. •Return to the desired flight path. •Re-engage the autopilot and authotrottle if desired.	•Monitor altitude and airspeed. •Verify all needed actions have been done and callout any omissions. •Callout any trend toward terrain contact

WARNING:*If the control column does not provide the needed response, stabilizer trim can be needed. Excessive use of pitch trim can aggravate the condition, or can result in loss of control or in high structural loads.

WARNING: **Excessive use of pitch trim or rudder can aggravate the condition, or can result in loss of control or in high structural loads.

1.17.7 Airspeed Unreliable

MAX FCTM 8.19 non normal operation describes that;
Unreliable airspeed indications can result from blocking or freezing of the pitot/static system or a severely damaged or missing radome. When the ram air inlet to the pitot head is blocked, pressure in the probe is released through the drain holes and the airspeed slowly drops to zero. If the ram air inlet and the probe drain holes are both blocked, pressure trapped within the system reacts unpredictably.
The pressure may increase through expansion, decrease through contraction, or remain constant. In all cases, the airspeed indications would be abnormal. This could mean increasing indicated airspeed in climb, decreasing indicated airspeed in descent, or unpredictable indicated airspeed in cruise.
Increased reliance on automation has de-emphasized the practice of setting known pitch attitudes and thrust settings. However, should an airspeed unreliable incident occur, the flight crew should be familiar with the approximate pitch attitude and thrust setting for each phase of flight. This familiarity can be gained by noting the pitch attitude and thrust setting occasionally during normal flight. Any significant change in body attitude from the attitude normally required to maintain a particular airspeed or Mach number should alert the flight crew to a potential airspeed problem.
If abnormal airspeed is recognized, immediately set the target pitch attitude and thrust setting for the Airplane configuration from the Airspeed Unreliable memory items. When Airplane control is established, accomplish the Airspeed Unreliable NNC. The crew should alert ATC if unable to maintain assigned altitude or if altitude indications are unreliable.
Memory items for target pitch and thrust must be accomplished as soon as it is suspected that airspeed indications are incorrect. The intent of having memorized pitch and thrust settings is to quickly put the Airplane in a safe regime until theAirspeed Unreliable checklist can be referenced. The following assumptions and requirements were used in developing these memory items:

- The memorized settings are calculated to work for all model/engine combinations, at all weights and at all altitudes.
- The flaps up settings will be sufficient such that the actual airspeed remains above stick shaker and below overspeed.
- The flaps extended settings will be sufficient such that the actual airspeed remains above stick shaker and below the flap placard limit.
- The settings are biased toward a higher airspeed as it is better to be at a high energy state than a low energy state.
- These memorized settings are to allow time to stabilize the Airplane, remain within the flight envelope without overspeed or stall, and then continue with reference to the checklist.

Settings are provided for flight with and without flaps extended. The crew should use the setting for the condition they are in to keep the Airplane safe while accessing the checklist. The memorized pitch and thrust setting for the current configuration (flapsextended/flaps up) should be applied immediately with the following considerations: The flaps extended pitch and thrust settings will result in a climb. The flaps up pitch and thrust settings will result in a slight climb at light weights and low altitudes, and a slight descent at heavy weights and high altitudes.

At light weight and low altitude, the true airspeed will be higher than normal, but within the flight envelope. At heavy weight and high altitude, the same settings will result in airspeed lower than normal cruise but within the flight envelope.

The goal of these pitch and thrust settings is to maintain the Airplane safely within the flight envelope, not to maintain a specific climb or level flight. The current flap position should be maintained until the memory pitch and thrust settings have been set and the Airplane stabilized. If further flap extension/flap retraction is required refer to PI-QRH Airspeed Unreliable table.

In order to determine if a reliable source of indicated airspeed is available, the Airspeed Unreliable checklist says "When in trim and stabilized, cross check the captain, first officer and standby airspeed indicators." The intent of this statement is for the pilot flying to set the pitch attitude and thrust setting from the PI-QRH Flight with Unreliable Airspeed table and allow the Airplane to stabilize before comparing the airspeed indications to those shown in the table.

The Airplane is considered stabilized when the thrust and pitch have been set, and the pitch is trimmed with no further trim movement needed to maintain the pitch setting. This is not an instantaneous process, and must be complete before comparing indicated and expected airspeeds for accurate results.

If it is determined that none of the airspeed indicators are reliable, the PI-QRH tables should be used for the remainder of the flight. Flight crews need to ensure they are using the table and values appropriate for phase of flight and Airplane configuration.

• When changing phase of flight or Airplane configuration, make initial thrust change, set pitch attitude, configure the Airplane as needed, then recheck thrust and pitch, and trim as needed. Do not change configuration until the Airplane is trimmed and stabilized at the current configuration.

If the flight crew is aware of the problem, flight without the benefit of valid airspeed information can be safely conducted and should present little difficulty.

Early recognition of erroneous airspeed indications requires familiarity with the interrelationship of attitude, thrust setting, and airspeed. A delay in recognition could result in loss of Airplane control. Ground speed information is available from the FMC and on the instrument displays. These indications can be used as a crosscheck. Many air traffic control radars can also measure ground speed.

For Airplanes equipped with an Angle of Attack (AOA) indicator, maintain the analog needle at approximately the three o'clock position. This approximates a safe maneuver speed or approach speed for the existing Airplane configuration

1.17.8 Quick Reference Handbook (QRH)

The Ethiopian 737 Flight Crew Operations Manual, Checklist instructions, Chapter NC Section 2, dated February 21, 2019, stated in part, the following:
The non-normal checklists chapter contains checklists used by the flight crew to manage non–normal situation.
Most checklists correspond to a light, alert or other indication. In most cases, the MASTER CAUTION and system annunciator lights also illuminate to indicate the non-normal conditions.

All checklists have condition statements. The condition statement briefly describes the situation that caused the light, alert or other indication. Un-annunciated checklists also have condition statements to help in understanding the reason for the checklists.
Some checklists have objective statements. The objective statement briefly describes the expected result of doing the checklist or briefly describes the reason for steps in the check list.
Check lists can have both memory and reference items. Memory items are critical steps that must be done before reading the checklist. The last memory item is followed by a dashed horizontal line. Reference items are actions to be done while reading the checklist.
Some checklists have additional information at the end of the checklist. The additional information provides data the crew may wish to consider. The additional information does not need to be read.
Checklists that need a quick response are listed in the Quick Action Index which is also available on the QRH cover page. In each system section, Quick Action Index checklists are listed first, followed by checklists that are not in the Quick Action Index. The titles of Quick Action Index checklists are printed in bold type. Checklist titles in upper case (such as AUTO BRAKE DISARM) are annunciated by a light, alert, or other indication. Checklist titles in upper and lower case (such as Window Damage) are not annunciated.

Non-Normal Situation Guideline

When a non-normal situation occurs, the following guidelines apply:
• Non-normal recognition: The crewmember recognizing the malfunction calls it out clearly and precisely
• maintain Airplane control: It is mandatory that the Pilot Flying (PF) fly the Airplane while the Pilot Monitoring (PM) accomplishes the NNC. Maximum use of the auto flight system is recommended to reduce crew workload

• analyze the situation: NNCs should be accomplished only after the malfunctioning system has been positively identified. Review all caution and warning lights to positively identify the malfunctioning system(s).
•Take the proper action: Although some in-flight non-normal situations require immediate corrective action, difficulties can be compounded by the rate the PF issues commands and the speed of execution by the PM. Commands must be clear and concise, allowing time for acknowledgment of each command prior to issuing further commands. The PF must exercise positive control by allowing time for acknowledgment and execution. The other crewmembers must be certain their reports to the PF are clear and concise, neither exaggerating nor understating the nature of the non-normal situation. This eliminates confusion and ensures efficient, effective, and expeditious handling of the non-normal situation
•Evaluate the need to land: If the NNC directs the crew to plan to land at the nearest suitable airport, or if the situation is so identified in the QRH section CI.2, (Checklist Instructions, and Non-Normal Checklists), diversion to the nearest airport where a safe landing can be accomplished is required. If the NNC or the Checklist Instructions do not direct landing at the nearest suitable airport, the pilot must determine if continued flight to destination may compromise safety.

Non-Normal Checklist Operation

Non–normal checklists start with steps to correct the situation. If needed, information for planning the rest of the flight is included. When special items are needed to configure the Airplane for landing, the items are included in the Deferred Items section of the checklist. Flight patterns for some engine-out situations are located in the Maneuvers chapter and show the sequence of configuration changes.
While every attempt is made to supply needed non–normal checklists, it is not possible to develop checklists for all conceivable situations. In some smoke, fire or fumes situations, the flight crew may need to move between the Smoke, Fire or Fumes checklist and the Smoke or Fumes Removal checklist. In some multiple failure situations, the flight crew may need to combine the elements of more than one checklist. In all situations, the captain must assess the situation and use good judgment to determine the safest course of action.
It should be noted that, in determining the safest course of action, troubleshooting, i.e., taking steps beyond published non-normal checklist steps, may cause further loss of system function or system failure. Troubleshooting should only be considered when completion of the published non-normal checklist results in an unacceptable situation.
These situations include, but are not limited to, conditions where:

- the non–normal checklist includes the item “Plan to land at the nearest suitable airport.”
- fire or smoke continues

- only one AC power source remains (engine or APU generator)
- only one hydraulic system remains (the standby system is considered a hydraulic system)
- any other situation determined by the flight crew to have a significant adverse effect on safety if the flight is continued.

Non–normal checklists also assume:

- During engine start and before takeoff, the associated non–normal checklist is done if a non-normal situation is identified. After completion of the checklist, the Dispatch Deviations Guide or operator equivalent is consulted to determine if Minimum Equipment List dispatch relief is available.
- System controls are in the normal configuration for the phase of flight before the start of the non–normal checklist.
- If the MASTER CAUTION and system annunciator lights illuminate, all related amber lights are reviewed to assist in recognizing the cause(s) of the alert.
- Aural alerts are silenced and the master caution system is reset by the flight crew as soon as the cause of the alert is recognized.
- Indicator lights are tested to verify suspected faults.
- In flight, reset of a tripped circuit breaker is not recommended. However, a tripped circuit breaker may be reset once, after a short cooling period (approximately 2 minutes), if in the judgment of the captain, the situation resulting from the circuit breaker trip has a significant adverse effect on safety. On the ground, flight crew reset of a tripped circuit breaker should only be done after maintenance has determined that it is safe to reset the circuit breaker.
- Flight crew cycling (pulling and resetting) of a circuit breaker to clear a non-normal condition is not recommended, unless directed by a non-normal checklist.

Non–Normal Checklist Use

Non–normal checklist use starts when the Airplane flight path and configuration are correctly established. Only a few situations need an immediate response (such as CABIN ALTITUDE WARNING or Rapid Depressurization). Usually, time is available to assess the situation before corrective action is started. All actions must then be coordinated under the captain's supervision and done in a deliberate, systematic manner. Flight path control must never be compromised.

When a non–normal situation occurs, at the direction of the pilot flying, both crewmembers do all memory items in their areas of responsibility without delay. The pilot flying calls for the checklist when:

- the flight path is under control
- the Airplane is not in a critical phase of flight (such as takeoff or landing)

- all memory items are complete.

The pilot monitoring reads aloud:

- the checklist title
- the Airplane effectively (if applicable) as needed to verify the correct checklist
- as much of the condition statement as needed to verify that the correct checklist has been selected
- as much of the objective statement (if applicable) as needed to understand the expected result of doing the checklist.

The pilot flying does not need to repeat this information but must acKnowledge that the information was heard and understood.

For checklists with memory items, the pilot monitoring first verifies that each memory item has been done. The checklist is normally read aloud during this verification. The pilot flying does not need to respond except for items that are not in agreement with the checklist. The item numbers do not need to be read….

Non-memory items are called reference items. The pilot monitoring reads aloud the reference items, including:

- the precaution (if any)
- the response or action
- any amplifying information.

The pilot flying does not need to repeat this information but must acknowledge that the information was heard and understood. The item numbers do not need to be read.

With the Airplane in flight or in motion on the ground the pilot flying and the pilot monitoring take action based on each crewmember's Areas of Responsibility. After moving the control, the crewmember taking the action also states the checklist response.

The pilot flying may also direct reference checklists to be done by memory if no hazard is created by such action, or if the situation does not allow reference to the checklist.

Each checklist has a checklist complete symbol at the end. The following symbol indicates that the checklist is complete:

■ ■ ■ ■

After completion of each non–normal checklist, the pilot monitoring states "___ CHECKLIST COMPLETE.

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Quick Action Index

Runaway Stabilizer

Condition: Uncommanded stabilizer trim movement occurs continuously.

1 Control column. . . . . Hold firmly

2 Autopilot (if engaged) . . . . .Disengage

Do **not** re-engage the autopilot.

Control airplane pitch attitude manually with control column and main electric trim as needed.

3 Autothrottle (if engaged). . . . . .Disengage

Do **not** re-engage the autothrottle.

4 **If** the runaway **stops** after the autopilot is disengaged:

■ ■ ■ ■

5 **If** the runaway **continues** after the autopilot is disengaged:

STAB TRIM CUTOUT
switches (both) . . . . CUTOUT

If the runaway **continues**:

Stabilizer
trim wheel . . . . Grasp and hold

- -

6 Stabilizer. Trim manually

7 Anticipate trim requirements.

8 **Checklist Complete Except Deferred Items**

▼ Continued on next page ▼

737 Flight Crew Operations Manual

IAS DISAGREE

Condition: The IAS DISAGREE alert indicates the captain's and first officer's airspeed indications disagree.

▶▶ Go to the Airspeed Unreliable checklist on page 10.1

737 Flight Crew Operations Manual

Airspeed Unreliable

Condition: Airspeed or Mach indications are suspected to be unreliable. (Items which might indicate unreliable airspeed are listed in the Additional Information section.)

Objective: To identify a reliable airspeed indication, if possible, or to continue the flight using the Flight With Unreliable Airspeed table in the Performance Inflight chapter.

1 Autopilot (if engaged) . . . . .Disengage

2 Autothrottle (if engaged). . . . . .Disengage

3 F/D switches (both) . . . . OFF

4 Set the following gear up pitch attitude and thrust:

Flaps extended . . . . 10° and 80% N1

Flaps up . . . . 4° and 75% N1

- -

5 PROBE HEAT switches. . . . . Check ON

6 The following are **reliable:**

Attitude

N1

Ground speed

Radio altitude

Note: Stick shaker, overspeed warning and AIRSPEED LOW alerts may sound erroneously or simultaneously.

Note: The Flight Path Vector and Pitch Limit Indicator may be unreliable.

7 Refer to the Flight With Unreliable Airspeed table in the Performance Inflight chapter and set the pitch attitude and thrust setting for the current airplane configuration and phase of flight.

▼ Continued on next page ▼

▼Airspeed Unreliable continued▼

8 When in trim and stabilized, cross check the captain, first officer and standby airspeed indicators. An airspeed indication that differs by more than 20 knots or 0.03 Mach from the airspeed shown in the table should be considered **unreliable.**

9 Choose one:

- ◆Reliable airspeed indication can be **determined:**

  Use the most reliable airspeed source for the remainder of the flight.

  ►►Go to step 10

- ◆Reliable airspeed indication can **not** be determined:

  ►►Go to step 14

10 Choose one:

- ◆**Captain's or First Officer's** airspeed indication is **reliable:**

  ►►Go to step 11

- ◆**Only** the **standby airspeed** indication is **reliable:**

  Note: Do not use the autopilot, autothrottle, or flight directors.

  Do not use TO/GA for a go-around or missed approach.

  ►►Go to step 17

11 Flight director switch (reliable side) . . . . .ON

12 Autopilot (reliable side) . . . . .Engage

13 ALT selector switch . . . .(1 or 2) Select reliable side

Note: Do not use the autothrottle.

►►Go to step 17

14 Set pitch attitude and thrust from the Flight With Unreliable Airspeed table in the Performance Inflight chapter for the airplane configuration and phase of flight, as needed.

▼Airspeed Unreliable continued▼

8 When in trim and stabilized, cross check the captain, first officer and standby airspeed indicators. An airspeed indication that differs by more than 20 knots or 0.03 Mach from the airspeed shown in the table should be considered **unreliable.**

9 Choose one:

◆Reliable airspeed indication can be **determined:**

Use the most reliable airspeed source for the remainder of the flight.

►►Go to step 10

◆Reliable airspeed indication can **not** be determined:

►►Go to step 14

10 Choose one:

◆**Captain's or First Officer's** airspeed indication is **reliable:**

►►Go to step 11

◆**Only** the **standby airspeed** indication is **reliable:**

Note: Do not use the autopilot, autothrottle, or flight directors.

Do not use TO/GA for a go-around or missed approach.

►►Go to step 17

11 Flight director switch (reliable side) . . . . ON

12 Autopilot (reliable side) . . . . Engage

13 ALT selector switch . . . . (1 or 2) Select reliable side

Note: Do not use the autothrottle.

►►Go to step 17

14 Set pitch attitude and thrust from the Flight With Unreliable Airspeed table in the Performance Inflight chapter for the airplane configuration and phase of flight, as needed.

▼Airspeed Unreliable continued▼

15 Check the Non-Normal Configuration Landing Distance table in the Advisory Information section of the Performance Inflight chapter.

Note: Maintain visual conditions if possible.

Establish landing configuration early.

Radio altitude reference is available below 2,500 feet.

Use electronic and visual glideslope indicators, where available, for approach and landing.

Do not use the the autopilot, autothrottle, or flight directors.

Do not use TO/GA for a go-around or missed approach.

16 Transponder mode selector . . . . TA

17 Choose one:

◆Altitude is **reliable:**

■ ■ ■ ■

◆Altitude is **unreliable:**

Transponder mode selector . . . . ALT OFF

■ ■ ■ ■

Additional Information

One or more of the following may be evidence of unreliable airspeed or Mach indications:

- Speed/altitude information not consistent with pitch attitude and thrust setting
- SPD failure flag
- SPD LIM failure flag
- IAS DISAGREE alert
- Blank or fluctuating airspeed display
- Variation between captain and first officer airspeed displays
- Radome damage or loss
- Overspeed warning
- Simultaneous overspeed and stall warnings.

737 Flight Crew Operations Manual

ALT DISAGREE

Condition: The ALT DISAGREE alert indicates the captain's and first officer's altitude indications disagree by more than 200 feet.

1 Check all altimeters are set to correct barometric setting for phase of flight.

2 Choose one:

◆ALT DISAGREE alert **extinguishes:**

Continue normal operation.

■ ■ ■ ■

◆ALT DISAGREE alert **stays illuminated:**

►►**Go to step 3**

3 Airplane does not meet RVSM airspace requirements.

4 Standby altimeter is available.

5 Do **not** use the flight path vector.

6 Maintain visual conditions if possible.

7 Choose one:

◆A **reliable altitude** can be determined:

Transponder selector . . . . .Select reliable side

►►**Go to step 8**

◆A reliable altitude **cannot** be determined:

Transponder mode selector . . . . ALT OFF

AOA DISAGREE

Condition: The AOA DISAGREE alert indicates the left and right angle of attack vanes disagree.

1 Airspeed errors and the IAS DISAGREE alert may occur.

2 Altimeter errors and the ALT DISAGREE alert may occur.

■ ■ ■ ■

Display Failure

Condition: A display unit in the MAX display system is failed.

1 Choose one:

◆ **Outboard** display unit is failed:

► ► **Go to step 2**

◆ **Inboard** display unit is failed:

► ► **Go to step 4**

2 PFD/MFD selector (affected side) . . . . INBD

3 ENG TFR switch . . . . .As needed

■ ■ ■ ■

4 PFD/MFD selector (affected side) . . . . NORM or OUTBD as needed

5 ENG TFR switch . . . . .As needed

Note: The transfer of engine indications is only available when the PFD/MFD selector on the failed side is selected to OUTBD.

■ ■ ■ ■

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1.17.9 Safety Management System

The operator shall develop an SMS implementation plan, formally endorsed by the organization that defines the organization's approach to the management of safety in a manner that meets the organization's safety objectives.

Safety Management System Standard for Airplane Operator

ICAO Annex 19 subchapter 4 requires Airplane operator to establish Safety Management System (SMS) as systematic approach to manage safety and designed to continuously improve safety performance through: the identification of hazards, the collection and analysis of safety data and safety information, and the continuous assessment of safety risks. Appendix 2 of this Annex described the minimum requirement for SMS framework which must comprise the four components, combined with the twelve elements comprise the ICAO SMS framework, are as follows:

1. Safety policy and objectives
   - Management commitment and responsibility
   - Safety accountabilities
   - Appointment of key safety personnel
   - Coordination of emergency response planning
   - SMS documentation
2. Safety risk management
   - Hazard identification
   - Risk assessment and mitigation
3. Safety assurance
   - Safety performance monitoring and measurement
   - The management of change
   - Continuous improvement of the SMS
4. Safety promotion
   - Training and education
   - Safety communication

Ethiopian SMS, REV 09.01 indicating that:

Ethiopian operational safety reporting systems provide operational personnel with a means of proactive and reactive method to report safety hazards or any other safety concerns so that they may be brought to the attention of responsible operational managers. Data gathered from voluntary /confidential and non-punitive and mandatory reporting is only used to identify system vulnerabilities and develop effective mitigation and implementation measures to address the consequences of those threats, errors and hazards occurrences relevant to the aviation safety.

1.17.9.1 Hazard Identification as Part of Safety Risk Management

Safety reporting system is one of the main internal sources within Airplane operator to identify hazard, especially a voluntary safety reporting system. Personnel at all levels and across all disciplines are encouraged to identify and report hazards and other safety issues through their safety reporting systems.
Safety reporting systems should be readily accessible to all personnel. A paper-based, web-based or desktop form can be used depending on the situation. Having multiple entry methods available maximizes the likelihood of staff engagement. Everyone should be made aware of the benefits of safety reporting and what should be reported.
Safety risk management requires the service provider to develop and maintain a formal process to identify hazards that may contribute to aviation safety-related occurrences. Hazards may exist in ongoing aviation activities or be inadvertently introduced into an operation whenever changes are introduced to the aviation system. In this case, hazard identification is an integral part of the change management processes as described in SMS framework element 3.2 – *The management of change*.

The service provider shall develop and maintain a formal process that ensures that hazards in operations are identified. Hazard identification shall be based on a combination of reactive, proactive and predictive methods of safety data collection.

Hazard identification is the first step of Safety Risk Management (SRM), the ICAO Annex 19 Appendix 2, described that Airplane operator must develop and maintain a process that ensures that hazards associated with flight operations are identified based on a combination of reactive, proactive and predictive methods of safety data collection.
The ICAO Document 9859 provided guidelines to develop SMS within organization including Airplane operator. The subchapter 2.5.2.10 of the document describes two main methodologies for identifying hazards, as follows:

a) Reactive, which involves analysis of past outcomes or events. Hazards are identified through investigation of safety occurrences. Incidents and accidents are an indication of system deficiencies and therefore can be used to determine which hazard(s) contributed to the event.
b) Proactive, which involves collecting safety data of lower consequence events or process performance and analyzing the safety information or frequency of occurrence to determine if a hazard could lead to an accident or incident. The safety information for proactive hazard identification primarily comes from flight data analysis (FDA) programs, safety reporting systems and the safety assurance function.

a. organizational safety policies and safety objectives;

b. organizational roles and responsibilities related to safety;

c. basic SRM principles;

d. safety reportingsystems;

e. the organization’s SMS processes and procedures; and

f. humanfactors.

1.17.10 FLIGHT CREW TRAINING MANUAL (FCTM)

The Flight Crew Training Manual, Chapter 3 “Takeoff and Initial Climb” stated in part, the following:

Rotation and Liftoff All Engines

Takeoff speeds are established based on minimum control speed, stall speed, and tail clearance margins. Shorter- bodied Airplanes are normally governed by stall speed margin while longer-bodied Airplanes arenormally limited by tail clearance margin. When a smooth continuous rotation is initiated at VR, tail clearancemargin is assured because computed takeoff speeds depicted in the PI Chapter of the FCOM, airport analysis, orFMC, are developed to provide adequate tail clearance.

Above 80 Kt, relax the forward control column pressure to the neutral position. For optimum takeoff andinitial climb performance, initiate a smooth continuous rotation at VR toward 15° of pitch attitude. However, takeoffs at low thrust setting (low excess energy) will result in a lower initial pitch attitude target to achieve the desired climb speed.

The use of stabilizer trim during rotation is not recommended. After liftoff, use the attitude indicator, or indications on the PFD or HUD (HUD equipped Airplane s), as the primary pitch reference. The flight director, in conjunction with indicated airspeed and other flight instruments is used to maintain the proper vertical flight path.

Note: *The flight director pitch command is not used for rotation.*

With a consistent rotation technique, where the pilot uses approximately equal control forces and similar visual cues, the resultant rotation rate differs slightly depending upon Airplane body length.

Note: *Do not adjust takeoff speeds or control forces to compensate for increased body length.*

Using the technique above, resultant rotation rates vary from 2° to 3° per second with rates being lowest on longer Airplane s. Liftoff attitude is achieved in approximately 3 to 4 seconds depending on Airplane weight and thrust setting.

OVERSPEED

VMO/MMO is the Airplane Maximum certified operating speed and should not be exceeded intentionally. However, crews can occasionally experience an inadvertent over speed. Airplane has been flight tested beyond VMO/MMO to ensure smooth pilot inputs will return the Airplane safely to the normal flight envelope.
At high altitude, wind speed or direction changes may lead to overspeed events. Although autothrottle logic provides for more aggressive control of speed as theAirplane approaches VMO or MMO, there are some conditions that are beyond the capability of the autothrottle system to prevent short term overspeeds.

When correcting an overspeed during cruise at high altitude, avoid reducing thrust to idle which results in slow engine acceleration back to cruise thrust and may result in over-controlling the airspeed or a loss of altitude. If autothrottle corrections are not satisfactory, leave the autopilot engaged; deploy partialSpeedbrakes slowly until a noticeable reduction in airspeed is achieved. When the airspeed is below VMO/MMO, retract the speedbrakes at the same rate as they were deployed. The thrust levers can be expected to advance slowly to achieve cruise airspeed; if not, they should be pushed up more rapidly.

When encountering an inadvertent overspeed condition, crews should leave theautopilot engaged and use the speedbrakes as needed unless it is apparent that theautopilot is not correcting the overspeed. However, if manual inputs are required, disengage the autopilot. Be aware that disengaging the autopilot to avoid or reducethe severity of an inadvertent overspeed may result in an abrupt pitch change.

Initiating Takeoff Roll

Auto throttle and flight director use is recommended for all takeoffs. However, do not follow FD commands until after liftoff.

A rolling takeoff is recommended for setting takeoff thrust. It expedites the takeoff and reduces the risk of foreign object damage or engine surge/stall due to a tail wind or cross wind. Flight test and analysis prove that the change in takeoff roll distance due to the rolling takeoff is negligible when compared to a standing takeoff.
Rolling takeoffs are accomplished in two ways:

- if cleared for takeoff before or while entering the runway, maintain normal taxi speed.

When the Airplane is aligned with the runway centerline ensure the nose wheel steering wheel is released and apply takeoff thrust by advancing the thrust levers to just above idle (40%N1).
Allow the engines to stabilize momentarily then promptly advance the thrust levers to takeoff thrust (auto throttle TO/GA). There is no need to stop the Airplane before increasing thrust.

• if holding in position on the runway, ensure the nose wheel steering wheel is released, release brakes, then apply takeoff thrust as described above.

Rotation and Liftoff - All Engines

Takeoff speeds are established based on minimum control speed, stall speed, and tail clearance margins. Shorter-bodied Airplane is normally governed by stall speed margin while longer-bodied Airplanes arenormally limited by tail clearance margin. When a smooth continuous rotation is initiated at VR, tail clearancemargin is assured because computed takeoff speeds depicted in the PI Chapter of the FCOM, airport analysis, or FMC, are developed to provide adequate tail clearance.Above 80Kt, relax the forward control column pressure to the neutral position. For optimum takeoff and initial climb performance; initiate a smooth continuous rotation at VR toward 15° of pitch attitude. However, takeoffs at low thrust setting (low excess energy) will result in a lower initial pitch attitude target to achieve the desired climb speed.
The use of stabilizer trim during rotation is not recommended. After liftoff, use the attitude indicator, or indications on the PFD or HUD (HUD equipped Airplane s), as the primary pitch reference. The flight director, in conjunction with indicated airspeed and other flight instruments is used to maintain the proper vertical flight path.

1.17.11 TRAINING AND EDUCATION AS PART OF SAFETY PROMOTION

According to ICAO Annex 19 Appendix2, Airplane operator must develop and maintain safety training program which ensures personnel are trained and competent to perform their SMS duties. The ICAO Document 9859 subchapter 9.6.4 described personnel who are trained and competent to perform their SMS duties, regardless of their level in the organization, is an indication of management's commitment to an effective SMS. The provision of training to appropriate staff, regardless of their level in the organization, is an indication of management‘s commitment to an effective SMS. Safety training and education curricula should consist of the following:

a. Organizational safety policies, goals & objectives;

b. Organizational safety roles and responsibilities related to safety;

c. Basic safety risk management principles;

d. Safety reporting systems;

e. Safety management support;

f. Lines of communication for dissemination of safety information;

g. A validation process that measures the effectiveness of training;

h. Recurrent training requirements;

1.17.11.1 Flight Crew Records

a) The flight crew certifications, qualifications, training and currency requirements shall be recorded and retained at the training department. The crew scheduling shall ensure that each flight crew member prior to being assigned to duty, are qualified and current in accordance with the below listed items, and the flight crew members shall not accept a flight if not qualified for duty in accordance with the requirements as listed below.

- Licenses/certification (entire period of employment);
- Specific qualification (LVP, RVSM, EDTO etc.);
- Equipment qualification (TCAS/ACAS, GPWS/EGPWS);
- Initial training, route training, route check, recurrent training, Proficiency check, line check and checking results;
- Type(s) of qualification (entire period of employment);
- CRM/Human Factor training;
- DangerousGoods training;

b) The training record copies sent to Ethiopian Civil Aviation Authority shall be used as the back up until the digitalized soft record maintenance project is completed.

c) It is the responsibility of Training Department and Manager Crew Scheduling to maintain and control records of:

Type(s) of qualification

- Recency of experience
- Medical status
- Right seat qualification
- Airport and route competence
- Instructor/Examiner/ Check Airman qualification
- Flight time, duty time and rest time

d) Manager Crew Scheduling shall ensure that there is a due date alert system to be utilized by each Scheduler before scheduling any crew member for a flight duty especially when dual qualification applies for a particular flight crew member. He shall also, in close cooperation with each respective Chief Pilot, plan the renewal of all re- currency requirements.

e) Flight Operations shall ensure that at least the following records are kept for 18 months for each flight crew member: (ECARAS 8.12.1.15)

- The start, duration and end of each flight duty period
- Rest periods
- Flight time

f) The data in the Crew Management System (CMS) as well as the backup digital file in the Information Service department shall serve as the overall back up for these files.

The ADs, Bulletins and MOMs were released through the logipad system which the pilots are required to upload as a standard procedure before going for flight. The company has got a checking system who did and who didn't. Pilots are required to update their digital updated charts and performance data by their LOGIPAD and this was done at least every 7 days.

During initial and proficiency training, crew used to take the stick shaker activation, IAS Disagree, Stabilizer Runaway, use of trim wheel, reaction to multiple non-normal, task prioritize and CRM training. In the proficiency check the crew has taken training using a simulator and found satisfactory. These trainings were incorporated in FCTM, AMP, QRH, and FOTPM.

1.17.11.2 Flight Crew Training Programme

*ECARAS part 8 article 8.10.1.9 specifies that a*n operator shall establish and maintain ground and flight training program, approved by the authority which insures that all flight crew members are adequately trained to perform their assigned duties. The operator shall receive written approval from the Authority before that revision can be used. The training program shall:

1. Include ground and flight training facilities and properly qualified instructors as determined by the Authority;
2. Consist of ground and flight training for the type(s) of Airplane on which the flight crew member serves;
3. include proper flight crew coordination and training for all types of emergency and abnormal situations or procedures caused by engine, transmission, rotor, airframe or systems malfunctions, fire or other abnormalities;
4. include training in Knowledge and skills related to the visual and instrument flight procedures for the intended area of operation, human performance and threat and error management, the transport of dangerous goods and, where applicable, procedures specific to the environment in which the Airplane is to be operated;
5. Ensure that all flight crew members know the functions for which they are responsible and the relation of these functions to the functions of other crew members, particularly in regard to abnormal or emergency procedures;

6. shall include Knowledge and skills related to the operational use of head-up display and/or enhanced vision systems for those Airplane so equipped; and
7. Be given on a recurrent basis, as determined by the State of the Operator and shall include an examination to determine competence.

TRAINING PROGRAM APPROVAL

a. Each AOC holder shall ensure that all operations personnel are properly instructed in their duties and responsibilities and the relationship of such duties to the operation as a whole.
b. Each AOC holder shall have a training program manual approved by the Authority containing the general training, checking, and record keeping policies.
c. Each AOC holder shall have approval of the Authority prior to using a training curriculum for the purpose of qualifying a crewmember, or person performing operational control functions, for duties in commercial air transport.
d. Each AOC holder shall submit to the Authority any revision to an approved training program, and shall receive written approval from the Authority before that revision can be used.

1.17.12 TYPE RATING RECURRENT TRAINING AND CHECKING

1.17.12.1 Type Ratings

ECARASpart two articles 2.3.2.4 states that:

a. The type rating shall be endorsed on the license as a rating, including any limitations.

b. A pilot seeking an Airplane type rating to be added on a pilot license shall:

1. Hold or concurrently obtain an instrument rating that is appropriate to the Airplane category, classor type rating sought;
2. Have an endorsement in his or her logbook or training record from an authorized instructor that the applicant has gained, under appropriate supervision, experience in the applicable type of Airplane and/or flight simulator in the following:

i. Normal flight procedures and maneuvers during all phases of flight

ii. Abnormal and emergency procedures and maneuvers in the event of failures and malfunctions of equipment, such as power plant, systems and airframe;

iii. Where applicable, instrument procedures, including instrument approach, missed approach and landing procedures under normal, abnormal and emergency conditions,including simulated engine failure;

iv. Procedures for crew incapacitation and crew coordination including allocation of pilot tasks; crew cooperation and use of checklists;

3. Pass the required skill test at the ATPL level, applying crew resource management concepts, applicable to the Airplane category, class and type rating being sought;

I.Applicants seeking a private or commercial license in an Airplane that requires a type ratingshall also completes the applicable portions of either the PPL or CPL skill test inconjunction with the ATPL skill test.

4. Perform the skill test under instrument flight rules unless the Airplane used for the skill test is not capable of the instrument maneuvers and procedures required for the skill test in which case the applicant may:

i. Obtain a type rating limited to "VFR only," and

ii. Remove the "VFR only" limitation for each Airplane type in which the applicant demonstrates compliance with the ATPL skill test under instrument conditions.

c. Privileges. Subject to compliance with the requirements specified in this Part, the privileges of the holder of a type rating are to act as a pilot on the type of Airplane specified in the rating. When a type rating is issued limiting the privileges to act as co-pilot or limiting the privileges to act as pilot only during the cruise phase of flight, such limitation shall be endorsed on the rating.

d. Validity: Subject to compliance with the requirements in this Part, the validity period of a type rating is1 calendar year.

e. Renewal. For the renewal of a type rating, the pilot shall:

1. Within the three months immediately preceding the expire date, complete a proficiency check: in the areas of operation listed in the skill test for the appropriate category, type and if applicable class of Airplane;
2. Have completed 10 route sectors within the 3 months preceding the expiry date; and
3. If a pilot takes the proficiency check required in this section in the calendar month before or the calendar month after the month in which it is due, the pilot is considered to have taken it in the month in which it was due for the purpose of computing when the next proficiency check is due.

f. Re-issue. If the type rating has been expired the applicant shall:

1. Have received refresher training from an authorized instructor with an endorsement that the person is prepared for the required skill test; and
2. Pass the required skill test for the appropriate category, type and if applicable class of Airplane.

1.17.12.2 Recurrent Training

a. Each AOC holder shall establish a recurrent training programfor all flight crew members inthe AOC holder's Operations Manual and shall have it approved by the Authority.

b. Each flight crew member shall undergo recurrent training relevant to the type or variant of Airplane on which he or she is certified to operate and for the crew member position involved.

c. Each AOC holder shall have all recurrent training conducted by suitably qualified personnel.

d. Each AOC holder shall ensure that flight crew member recurrent ground training includes CRM, Airplane systems and limitations, takeoff and landing, dangerous goods, etc.

a. Crew resource management:

1. Decision-making skills
2. Briefings and developing open communication.
3. Inquiry, advocacy, and assertion training.
4. Workload management
5. Situational awareness

The operator has got training manual which is approved by Ethiopian Civil Aviation Authority. According to this manual the accident pilot and first officer has taken the type rating, recurrent training, the line check and proficiency check as it is clearly put in the Ethiopian civil aviation Rules and standards(ECARAS) Part 2,part 8 and part 9 and the operation training manual of the company.

Ethiopian Civil Aviation Authority based on ICAO Doc 8335, Manuals of procedures for operation inspection, Certification and continued surveillance conducts an oversight of the operator using inspector procedure hand book and audit policy manual for the compliance of ECARAS part 2, part 8 and part 9. Ref Operation Inspector Handbook chapter 1-06 Annual Inspection Program, chapter 4-08 training program Inspections, chapter 4-07 Training and Qualification Record inspection

On the accident Airplane PF simulator proficiency check was conducted on October 1, 2018 and line check was also performed on 30 November 2018; the FO last proficiency check was December 3, 2018.

Flight Operations Accident Crew Trainings

TABLE24: PF & FO PROFICIENCY TRAINING

Captain	Type of Training check	Date
	Stick shaker activation	01.04.2018
	IAS Disagree	30.09.2018
	Runaway Stabilizer	21.10.2017
	Use of Trim wheel	21.10.2018
	Reaction to multiple non-normal	03.12.2018
	Task prioritization	17.11.2018
	MOM	15.11.2018

TABLE 25: FO PROFICIENCY TRAINING

First officer	Type of Training check	Date
	Stick shaker activation	03.12.2018
	IAS Disagree	08.12.2018
	Runaway Stabilizer	28.11.2018
	Use of Trim wheel	28.11.2018
	Reaction to multiple non-normal	01.04.2018
	Task prioritization	10.12.2018
	MOM	15.11.2018

Flight operations revise the seasonal recurrent training/check syllabus to include RUNAWAY STABILIZER Non-normal procedure practice and ensured that all crew members have received the AD and OMB by uploading them on Logipad. Furthermore, the documents were also sent to each B737 flight crew by email.

1.17.12.3 ECAA Action Upon Receipt of the FAA'S AD

Monitoring Airworthiness Directives Compliance (ECAA CHAPTER 2-60):

All Airplanes that operate in Ethiopia were manufactured and/or certificated in another State. In order to continue to maintain such Airplane (registered in Ethiopia) at a level of airworthiness equivalent to that achieved in the State in which the Type certificate for the Airplane was issued, the ECAA will obtain all airworthiness directives, service bulletins, etc., issued by the type certification authority, by the manufacturer or, by the airworthiness authority of any other State in which the same type of Airplane are registered, where such information pertains to the continuing airworthiness and the prevention and remedying of recurring defects in Airplane and their equipment.

Upon registration of an Airplane in Ethiopia, the Authority will notify the State of Design of the Airplane of the registration in Ethiopia, and request that the Authority receives any and all airworthiness directives addressing that Airplane, airframe, Airplane engine, propeller, appliance, or component part and any requirements for the establishment of specific continuing airworthiness programs.
ECARAS 5.5.1.2 (d) states that the Authority may issue Airworthiness Directives when it determines that an airframe or aeronautical product has exhibited an unsafe condition and this condition is likely to exist or to develop in other products of the same type design. However, until such time that an appropriate engineering division is established, the Authority will not develop its Airworthiness Directives.
With this consideration whenever the State of Design considers that a condition in an Airplane , airframe, Airplane engine, propeller, appliance, or component part is unsafe as shown by the issuance of an airworthiness directive by that State, such directive shall apply to Ethiopian registered civil Airplanes of the type identified in that airworthiness directive". In general, Airworthiness Directives issued by FAA, EASA or

both are automatically applicable to all Ethiopian registered Airplanes.

Airworthiness Directives issued by the State of Manufacture/Design of the Airplane are mandatory for Ethiopia registered Airplane. Ethiopia does not issue its own Airworthiness Directives. No person may operate any Ethiopia registered civil Airplane to which the measures of ECARAS 5.4.1.10 apply, except in accordance with the applicable airworthiness directives and service bulletins.

1.17.13 Federal Aviation Administration (FAA) Airplane Certification

The Federal Aviation Administration (FAA) is responsible for prescribing minimum standards required in the interest of safety for the design, material, construction, quality of work, and performance of the Airplane, Airplane engines, and propellers (Ref. 49USC44701). Product certification is a regulatory process administered by the FAA to ensure that an Airplane manufacturer's product conforms with Federal Aviation Regulations (FAR). Successful completion of the certification process enables the FAA to issue a Type Certificate (TC) or an Amended Type Certificate. To obtain a TC or an Amended Type Certificate, the manufacturer must demonstrate to the FAA that the Airplane or product being submitted for approval complies with all applicable regulations. The FAA determines whether or not the applicant has met its responsibility to show compliance to the applicable regulations.
The Federal regulations that apply to type certification of transport-category Airplanes are 14 CFR Part 21, 25, 26, 33, 34, and 36. The Part 25 regulations are those concerned with the airworthiness standards for transport-category Airplanes and are organized into sub parts A through G. These regulations represent the minimum standards for airworthiness; an applicant's design may exceed these standards and the applicant's tests and analyses may be more extensive than required by regulation. The specific applicable regulatory requirements and how compliance will be demonstrated is documented in an FAA approved certification plan.

CERTIFICATION GUIDANCE

FAA Order 8110.4C, titled "Type Certification", prescribes the responsibilities and procedures the FAA must follow to certify new civil Airplane , Airplane engines, and propellers, or changes thereto, as required by 14 of the CFR Part 21. This order is primarily written for internal use by the FAA, its designees, and delegated organizations. The order provides procedures and policy for the type certification of products and, unless stated otherwise, the type certification process in this order applies to all U.S. TCs, including amended TCs and Supplement Type Certificate (STCs).

1.17.13.1 Type Certification Process

FAA Order 8110.4C contains section that presents a high-level flow diagram of the certification events that typically make up the life cycle an Airplane. The diagram is meant to explain the type certification process, not to dictate precisely how the project should flow. Although the model shows the proper sequence of events for certificating a product, the various aspects of the project generally progress through the process at different times and at different rates. The model divides the product's type certification life cycle into phases based on the FAA and Industry Guide to Product Certification. For each of the certification events identified on the flow diagram, the Order also provides information describing each event identifiesexpectations and develops specific interface procedures between the applicant and the FAA.

During a meeting with the NTSB, the FAA provided a high-level overview of the certification process for an amended type design program. The listed documents indicate detail changes to be presented for FAA certification as compared to type certificated baseline airplanea Certification Project Notification (CPN), a Program Notification Letter (PNL) and a Master Certification Plan (MCP). These documents detail the changes and identify the regulatory requirements and policies that are applicable; they also identify areas of change associated with the FAA airworthiness directives. As part of the overview, the FAA provided a high-level flow diagram of the certification events that contained similar information as the diagram within Order 8110.4c. The following figure shows the FAA certification process.

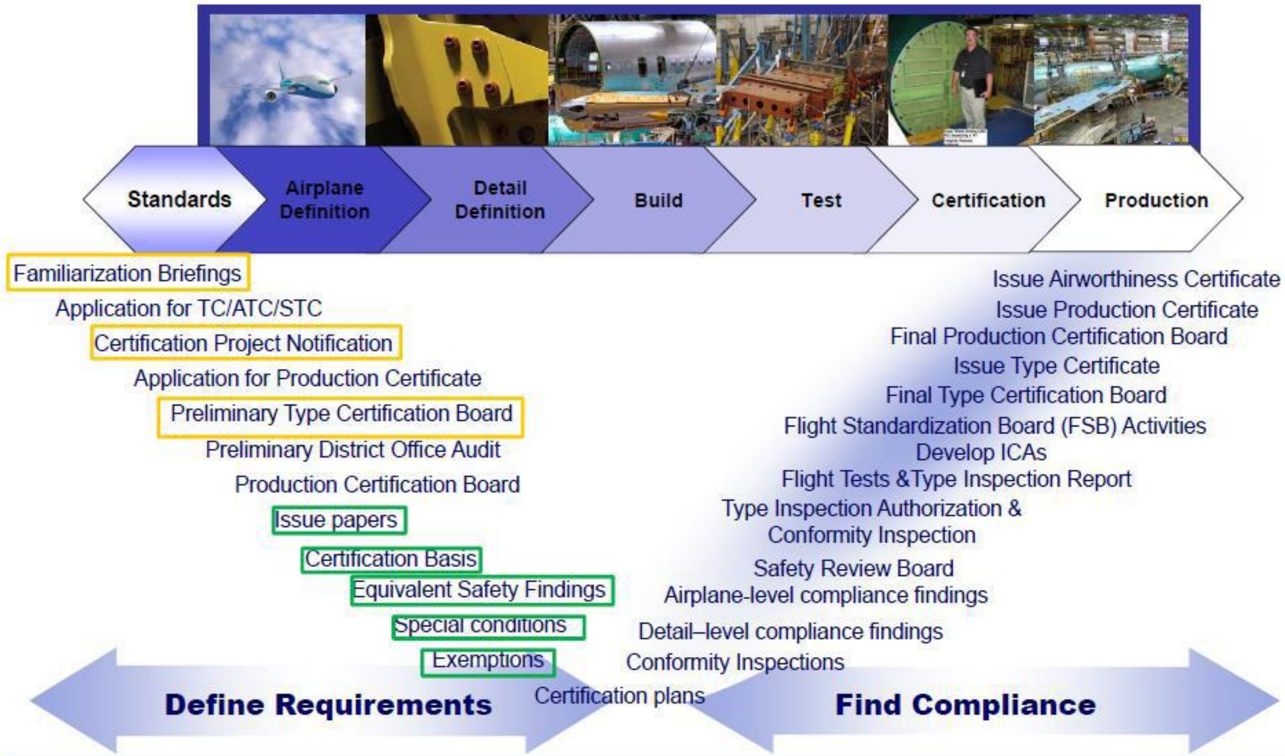

FIGURE 90: DIAGRAM OF FAA CERTIFICATION PROCESS

1.17.13.2 FAA Certification Office

The FAA has 10 Airplane Certification Offices (ACO) which are responsible for approving the design certification of Airplane, Airplane engines, propellers, and replacement parts for those products. There are also specialized certification offices which include the Engine Certification Office (ECO), the Military Certification Office (MCO), the Boeing Aviation Safety Oversight Office (BASOO), and the Delegation Systems Certification Office (DSCO). FAA's BASOO responsibilities include oversight of Boeing's Organization Designation Authorization (ODA), involvement in certification of safety critical areas as well as novel and unusual designs and assisting foreign Civil Aviation Authorities (CAAs) in validation of Boeing products. The BASOO was responsible for the certification oversight and approval for the Boeing 737-8 (MAX).

CERTIFICATION BASIS

According to Type Certificate Data Sheet[22] (TCDS) A16WE, revision 64, dated October 10, 2018, Boeing applied for a transport category amended type certificate (ATC) for the 737-8 Airplane on June 30, 2012. The ATC was approved on March 8, 2017. The Boeing 737-8 Airplane was added as the most recent model in a series of derivative models (or "changed aeronauticalproducts") that were approved and added to the Boeing type certificate (TC), originally issued for the Boeing 737-100 on December 15, 1967.

The applicable certification basis for the 737-8 Airplane is Title 14, Code of Federal Regulations (14 CFR) part 25 as amended by Amendments 25-0 through 25-137, plus amendment 25-141 with exceptions permitted by 14 CFR 21.101.

These security features must be in consideration in any subsequent type design change, modification, or repair to ensure the level of safety designed into the Boeing 737-8 (MAX) and 737-9 is maintained.

1.17.13.3 Certification Basis for Changed Aviation Products

The certification basis for changed aeronautical products allows an Airplane manufacturer to introduce a derivative model as a design update on a previously certificated Airplane and add the changed product onto an existing TC. The FAA approves such changes if it finds that the changes are not significant enough to warrant application for a new TC. This process enables a manufacturer to introduce derivative Airplane models without having to resubmit the entire Airplane design for certification review. The manufacturer can use the results of some of the analyses and testing from the original type certification to demonstrate compliance, in which case the regulations that were in effect on the date of the original TC apply.
Title 14 CFR 21.101, Subpart D, specifies the requirements for demonstrating airworthiness compliance for changed aeronautical products. The current revision of 14 CFR 21.101, amendment 21.92, which became effective on April 16, 2011, states that an application for a changed aeronautical product to be added to a TC "must show that the changed product complies with the airworthiness requirements applicable to the category of the product in effect on the date of the application." This regulation is more specific than previous revisions regarding what can be used from the original certification basis in an application for a derivative model involving a major change.

[22] A Type Certificate Data Sheet (TCDS) is a formal description of the Aircraft, engine or propeller. It lists limitations and information required for type certification including airspeed limits, weight limits, thrust limitations, etc.

On April 25, 2003, the FAA issued FAA Order 8110.48, How to Establish the Certification Basis for Changed Aeronautical Products, which provides the procedures that the FAA utilize for determining the certification basis for changes to type certificated products including changes made through an amended Type Certificate which is the method utilized for the G-IV. The handbook refers to FAA Advisory Circular 21.101-1, establishing the Certification Basis of Changed Aeronautical Products, which contains an acceptable means, but not the only means, to comply with 14 CFR 21.101. On July 21, 2107, this Order 8110.48 was cancelled and replaced by Order 8110.48A.

1.17.13.4 System Safety Assessment Process

The process for developing and certifying a safety-critical system must provide assurance that all significant single failure conditions have been identified and that all combinations of failures which lead to hazardous or catastrophic Airplane level effects have been considered and appropriately mitigated. Airplane manufacturers provide this assurance through their safety assessment processes.

The safety assessment process is divided into two parts; the Airplane level safety assessment and the individual system safety assessments. The Airplane safety assessment assures the robustness of the overall Airplane system design that implements the required Airplane functions.The individual system safety assessments assure the system designs meet their safety requirements and support the Airplane level safety assessment.

The Airplane assessment process begins by identifying the Airplane functions and determining which Airplane functions are required for continued safe flight and landing. A Functional Hazard Assessment (FHA) is performed on the functions required for safe flight and landing to identify potentially catastrophic and hazardous failure conditions. For each failure condition, the Airplane architecture (i.e. systems) which implements the function is identified and the high-level system failure conditions are determined. An engineering assessment is performed to verify system failure conditions are being addressed by the individual systems.

The basic structure of a system development process can be represented by a V-diagram, where time is represented horizontally (left to right) and system hierarchy is represented vertically (Reference, Figure 90). Initially (top left), the top-level design requirements (payload, range, passenger capacity, performance, etc) for the Airplane are selected. The Airplane requirements are then broken down into Airplane -level functions (e.g. control Airplane in the air); Airplane -level functions to system functions (e.g. control pitch, yaw and roll); system-level functions to systems (e.g. stabilizer system control); systems to subsystems (e.g. MCAS) in a top-down process. Following this system development process, requirements for each part item or piece of equipment are identified with each level providing validation of the level above. Validation is the process of ensuring that the requirements are sufficiently correct and complete. The right side of the V diagram involves a series of bottom-up evaluation activities to ensure the requirements are verified as met at each level in integration of the final product. Verification is the process of ensuring that the final product meets the design requirements. Verification activities may include analysis and testing the individual item of equipment (e.g. flight control computer software) and then progressively integrating the equipment into a complete system and even flight testing for verification of a fully integrated system on the Airplane.

Safety assessments are conducted by the applicant, and its suppliers, and are reviewed and approved by the FAA. The safety assessment process is outlined in AC 25.1309-1A and described in detail in SAE ARP4761. Although the safety assessment process outlined in the AC is not mandatory, the AC documents an established means, but not the only means, for an applicant to show compliance to the regulations. An applicant who chooses not to conduct safety assessments must demonstrate compliance in another way, which would have to be FAA-approved.

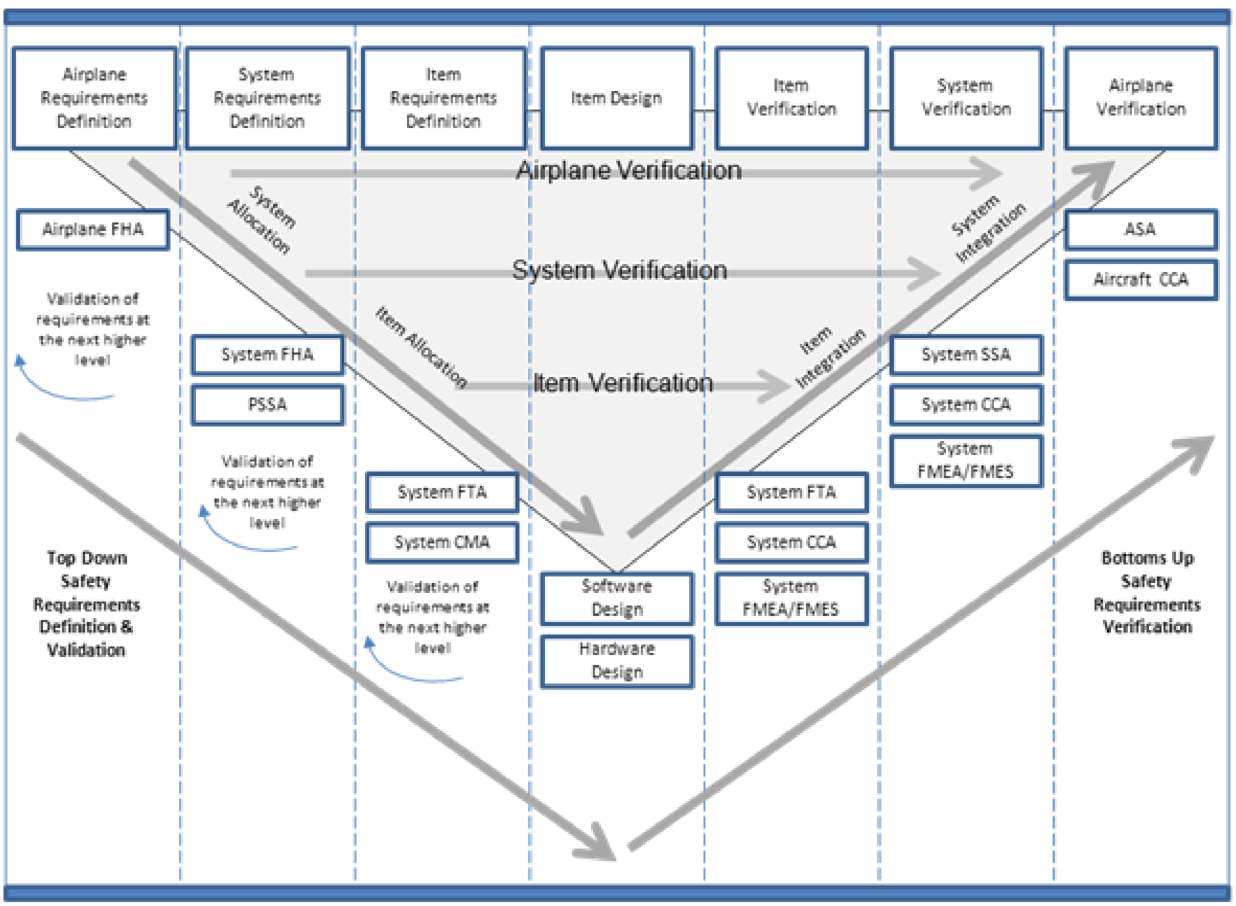

FIGURE91: V-DIAGRAM FOR A SYSTEM DEVELOPMENT PROCESS

1.17.13.5 Functional Hazard Assessment (FHA)

A functional hazard assessment (FHA) is a systematic examination of a system's functions and purpose, and it typically provides the initial, top-level assessment of a design and addresses the operational vulnerabilities of the system function. The FHA is therefore used to establish the safety requirements that guide system architecture design decisions. Performed independently of any specific design, an FHA evaluates what would occur if the function under question was lost or malfunctioned and classifies that effect to prioritize focus on the most serious outcomes. An FHA is conducted early in the design and development cycle to identify failure conditions and classify them by severity, beginning at the Airplane level and working down to individual systems.

FAA Advisory Circular AC 25.1309-1A, dated June 21, 1988 and SAE ARP4761 define the severity classes that are used to classify the effect of loss or malfunction as part of an FHA. AC 25.1309-1A defines the following three severity classes: catastrophic, major and minor, with the respective likelihoods, of extremely improbable (one-in-a billion/10-9 or less), improbable (one-in-ten million/10-7 or less), or no worse than probable (one-in-hundred thousand/10-5). The differences among the classes are associated with effects on the Airplane, occupants, and crew. According to SAE ARP4761, the determination of the classification is accomplished by analyzing accident/incident data, reviewing regulatory guidance material, using previous design experience, and consulting with flight crews, if applicable. The failure condition severities classifications are provided in a table contained within this document and are defined as follows:

- Catastrophic: prob of failure condition < 1E-09
- Major: 1E-09 < prob of failure condition < 1E-05
- Minor: no requirement on failure condition probability

• Catastrophic**:** All failure conditions which prevent continued safe flight and landing.

• Severe-Major/Hazardous**:** Large reductions in safety margins or functional capabilities higher workload or physical distress such that the crew could not be relied upon to perform tasks accurately or completely

• Major**:** Significant reduction in safety margins or functional capabilities significant increase in crew workload or in conditions impairing crew efficiency

• Minor**:**A slight reduction in safety margins, a slight increase in crew workload

1.17.13.6 SYSTEM SAFETY ASSESSMENTS

Safety assessments are a primary means of compliance for systems (as opposed to identifying structures or Airplane performance characteristics) that are critical to safe flight and operation. Safety assessments proceed in a stepwise, data-driven fashion, analogous to the system development process described above. Starting with Airplane functions, functional hazard assessments are performed to identify the failure conditions associated with each function. Systems functional hazard analyses are performed for system level functions. Preliminary safety assessments are performed as the system is developed adding more specific design and implementation detail to address specific hazards. The bottom-up Safety assessments are conducted by the applicant, and its suppliers, and are reviewed and accepted by the FAA. The safety assessment process is outlined in AC 25.1309-1A and described in detail in SAE ARP4761. Although the safety assessment process outlined in the AC is not mandatory, applicants who choose not to conduct safety assessments must demonstrate compliance in another, FAA-approved way (for example, by conducting ground or flight tests).

1.17.13.7 Organization Designation Authorization

In title 14, Code of Federal Regulations (CFR) United States of America Part 183, the Federal Aviation Administration (FAA) may delegate the specified functions to an organization on behalf of the Administrator related to engineering, manufacturing, operations, airworthiness, or maintenance.
In the Part 183 subpart D, the organization granted by the FAA for such delegation is referred as Organization Designation Authorization (ODA) which means the organization is authorized to perform certification functions on behalf of the FAA. FAA granted the Boeing Commercial Airplane (BCA) ODA in 2009. The delegated functions for a Type Certification ODA are:

- establishing and determining conformity of parts, assemblies, installations, test setups, and products (Airplane);
- finding compliance with airworthiness standards for new design, or major changes to design;
- issuing special flight permits for operation of Airplane;
- issuing issues airworthiness approvals for articles (Export), and Airplane (Standard or Export)

1.17.13.8 Oversight and Delegation

Inspector General Audit Report

According to a 2011 Office of Inspector General Audit report[23], "the FAA is responsible for overseeing numerous aviation activities designed to ensure the safety of the flying public. Recognizing that it is not possible for FAA employees to personally oversee every facet of aviation, public law allows FAA to delegate certain functions, such as approving new Airplane designs, to private individuals or organizations (approved by the FAA). Designees perform a substantial amount of critical work on FAA's behalf—for example, at one Airplane manufacturer, they made about 90 percent of the regulatory compliance determinations for a new Airplane design. FAA created the Organization Designation Authorization (ODA) program in 2005 to standardize its oversight of organizational designees."
According to FAA Order 8100.15A, 49 CFR 44702(d) allows the FAA to delegate to a qualified private person a matter related to issuing certificates, or related to the examination, testing, and inspection necessary to issue a certificate on behalf of the FAA Administrator as authorized by statute to issue under 49 CFR 44702 (a).

Boeing applied for and was granted ODA. Boeing's ODA is authorized to select and appoint individuals to perform some of the delegated functions as representatives of FAA. The delegated functions for a Type Certification (TC) ODA are:

- establishing and determining conformity of parts, assemblies, installations, test setups, and products (Airplane);
- finding compliance with airworthiness standards for new design, or major changes to design;
- issuing special flight permits for operation of Airplane;
- issuing issues airworthiness approvals for articles (Export), and Airplane (Standard or Export)

1.17.13.9 Guidance for Delegation of Compliance Findings

FAA Order 8110.4C, section 2.5, titled "Compliance Planning," discusses the FAA's involvement in a certification project, including providing guidance on oversight and delegation. According to the order, "For planningpurposes, the FAA's and the applicant's certification teams need to Know in which aspects of the project the FAA intends involvement and at what level. The heavy workloads for FAA personnel limit

[23] Reference Office of Inspector General Audit Report, AV-2011-136, issued on June 29, 2011

involvement in certificationactivities to a small fraction of the whole. FAA type certification team members must review the applicant's design descriptions and project plans, determine where their attention will derive the most benefit, and coordinate their intentions with the applicant."

Paragraph (a) (1) of section 2.5 provides guidance to the FAA and applicant on the identification of critical safety items requiring direct FAA involvement in the findings of compliance. According to the paragraph, "When a particular decision or event is critical to the safety of the product or to the determination of compliance, the FAA must be directly involved (as opposed to indirect FAA involvement by, for example, DER). Project team members must build on their experience to identify critical issues. Some key issues that will always require direct FAA involvement include rulemaking (such as for special conditions), development of issue papers, and compliance findings considered unusual or typically reserved for the FAA. While these items establish the minimum direct FAA involvement, additional critical safety findings must also be identified based on the safety impact or the complexity of the requirement or the method of compliance. Additional factors to consider in determining the areas of direct FAA involvement include the FAA's confidence in the applicant, the applicant's experience, the applicant's internal processes, and confidence in the designees."

1.17.13.10Delegation of Deliverables

CP13471 proposed delegation of all Flight Controls Primary & Secondary compliance findings. On April 14, 2015, the FAA approved the delegation of several deliverables; however, they indicated that the deliverable titled "737 Stabilizer System Description and Safety Analysis" (SSA) would be retained by the FAA and will not be proposed for delegation. In November 2016, Boeing submitted the 737 Stabilizer System Description and Safety Analysis (SSA), revision F, to the FAA for acceptance." In December 2016, the FAA's response to Boeing was to "accept" the submittal and with notation "delegated SSA approval to ODA."

Retention and delegation are accomplished with respect to compliance deliverables not to specific functions i.e., MCAS itself would not be delegated to the ODA.

- Consistent with the FAA authorization, the FAA have discretionary authority as to what is reviewed, whether submitted directly to the FAA for review and approval by an applicant or submitted by a designee or ODA recommending approval.
- When delegating at the end of a program, there has been some level of FAA involvement and the delegation confirms that the designee should make the final approval.
- In all cases, delegation is not accomplished by a single individual but follows a structured review process.

1.17.14 MANEUVERING CHARACTERISTICS AUGMENTATION SYSTEM (MCAS)

1.17.14.1 The Need for MCAS on B737 MAX

The 737 MAX 8 is a derivative of the 737-800 Model and is part of the 737 MAX families (737 MAX 7, 8, and 9[24]). The 737MAX incorporated the CFM LEAP-1B engine, which has a larger fan diameter and redesigned engine nacelle compared to engines installed on the 737 Next Generation (NG) families. Because the 737-8 is a derivative of the 737-800 model, its certification basis, which was established per 14 CFR 21.101 Changed Product Rule, required Boeing to demonstrate compliance with part 25 as amended by amendments 25-0-137, plus amendment 25-141 with exceptions permitted by 14CFR 21.101 for significant areas of change at the product level and those areas affected by the significant product level change.

During the preliminary design stage of the 737 MAX 8, Boeing tests and analysis revealed that the addition of the LEAP-1B engine and associated nacelle changes produced an Airplane nose-up pitching moment when the Airplane was operating at high angles of attack (AOA) and mid Mach numbers. This nose-up pitching moment was deemed likely to affect the stick force per g (FS/g) characteristics required by FAR 25.251, FAR 25.255, and the controllability and maneuverability requirements of FAR 25.143(f).

After the study of various options for addressing this issue, Boeing implemented aerodynamic changes as well as a stability augmentation function called the Maneuvering Characteristics Augmentation System (MCAS), as an extension of the existing Speed Trim System (STS), to improve Airplane handling characteristics and improve static longitudinal stability at elevated angles of attack.

As the development of the 737 MAX- 8 progressed, the MCAS function was expanded to low Mach numbers to comply with the stall characterstics requirements specified in FAR 25.201 and FAR 25.203. MCAS is designed to function only during manual flight (autopilot not engaged), with the Airplane's flaps up, at an elevated AOA.

Speed Trim & MCAS Description

To ensure that the 737-600/700/800/900 (737 NG) family of Airplanesmet the certification requirements for longitudinal static stability (speed stability), the Airplanes incorporated a Speed Trim System (STS) to

[24] Both the 737-8 and 737-9 were in service at the time of the accident. The 737-7 and 737-10 are planned future derivatives that have not yet entered service.

augment the basic Airplane's speed stability during certain low speed, high thrust flight conditions by moving the horizontal stabilizer during manual flight (autopilot is not engaged). For the 737 NG families of Airplane s, the Speed Trim System included the Speed Trim Function. The STS was carried over to the 737-7/-8/-9 (737 MAX) family of Airplanes. Additionally, on 737 MAXAirplanes, the MCAS function was added to the STS to address the pitch characteristics described above.

Speed Trim Function

The Speed Trim function, which is implemented as a control law within the flight control computer (FCC[25]), commands incremental stabilizer trim through the automatic trim control system circuitry. There are two different stabilizer trim rates depending on the position of the flaps[26]. A schedule determines the desired incremental stab deviation from the last trimmed position as a function of airspeed and flap position.

According to the Enhanced Digital Flight Control System (EDFCS) system safety analysis (SSA), the worst-case failure mode of the Speed Trimsystem was considered to be a runaway of the horizontal stabilizer trim actuator (HSTA) as a result of sensor or FCC failures, or FCC-to-stab trim motor (STM) wiring failures. The SSA indicated that during the runaway, the pilot is able to detect the fault by noticing the continuous running of the trim mechanical wheels in the flight deck or by the change in column force necessary to maintain pitch attitude, or through change in Airplane pitch attitude. The SSA indicated that the pilot compensates for the runaway through:

- column input in the direction opposing the uncommanded trim until activation of the column activated trim cutout switches, or
- activation of the main electric trim by either pilot in a direction opposing the uncommanded motion, which overrides the FCC commanded trim runaway, or
- moving the guarded stabilizer trim cutout switches[27] located on the aisle stand to the CUTOUT position, or restraining the stabilizer trim wheel,
- Speed/ Stab Trim runaways are limited by the inherent stab trim motor rate and column actuated trim cut-out switches. Sufficient means are available for the pilot to maintain control and recover from the runaway[28].

[25] The flight control computers (FCC) are part of the digital flight control system.
[26] When the flaps are down, the stabilizer rate is three times faster than when the flaps are up.
[27] Two stabilizer trim cutout switches on the control stand can be used to stop the main electric and autopilot trim inputs to the stabilizer trim actuator. The switches can be set to NORMAL or CUTOUT. If either switch is moved to CUTOUT both the electric and autopilot trim inputs are disconnected from the stabilizer trim motor. NORMAL is the default position to enable operation of the electric and autopilot trim.

1.17.14.2 Functional Hazard Assessment (FHA)

A functional hazard assessment (FHA) is a systematic examination of a system's functions and purpose, and it typically provides the initial, top-level assessment of a design and addresses the operational vulnerabilities of the system function.The FHA is therefore typically used to establish the safety requirements that guide system architecture design decisions. An FHA evaluates what would occur (the "hazard" in FHA) if the function under question was lost or malfunctioned and classifies the severity of that effect. An FHA is conducted early in the design and development cycle to identify hazards and classify them by severity, beginning at the Airplane level and working down to individual systems.

Federal Aviation Administration (FAA) Advisory Circular AC 25.1309-1A, dated June 21, 1988 and SAE ARP4761define the severity classes that are used to classify the effect of loss or malfunction as part of a FHA. AC 25.1309-1A defines the following three severity classes: catastrophic, major and minor, with corresponding acceptable probabilitiesof extremely improbable (1E-9) or less per flight hour), improbable (1E-5 or less), and no worse than probable (1E-3). European regulations (originally JAR and now EASA) include an additional category: hazardous, which falls between catastrophic and major and has an associated acceptable probability of 1E-7 or less. The differences among the classes are associated with effects on the Airplane, occupants, and crew.

To begin an FHA, engineering judgment is used to identify the failure conditions which require evaluation. According to the FHA sections[29] of Boeing's 737 NG/MAX Stabilizer Trim Control System Safety Analysis, (Reference section H.2.2 of this report), performance analyses and piloted simulations were accomplished as needed to help define the hazard categories for the identified conditions. **SourceError! Reference source ot found.** Shows the criticality categories used in developing the FHA and the corresponding minimum acceptable probabilities of occurrence. The failure conditions defined by the FHA provide the basis for the top-level events analyzed by the Fault Tree Analysis (FTA) to demonstrate compliance with FAR 25.671(c)(2) and 25.1309(b)(1). A fault tree analysis was performed on each failure condition determined to be either Catastrophic or Hazardous. Additionally, Major events are included in the FHA for reference, per FAA/JAA request.

[28] MCAS failures do allow the stabilizer to move at the flaps down trim rate, even if the flaps are up, but even the flaps down trim rate is a limit, albeit faster than the normal flaps up rate. Column cutout is always available in the forward direction but may not be available in the aft direction for certain MCAS failures.

[29]The safety analysis contained two sections that discussed hazard analysis; the first FHA was developed for the 737NG in the original release of the analysis (1997) and the second FHA was developed as part of the 737 MAX changes (2016).

TABLE 26: FAILURE EFFECT CATEGORIES

FAR/JAR Failure Effect Category Definitions

	FAR - AC 25.1309-1A definitions.	No significant degradation of aircraft capability. Crew actions well within their capabilities.		Reduction of the aircraft capability or of the crew ability to cope with adverse operating conditions.		Prevention of continued safe flight and landing of the aircraft.
Effects on aircraft and occupants of the identified failure condition.	AMJ No.1 of JAR 25.1309 definitions.	Slight reduction of safety margins, Slight increase in work load, (e.g. routine changes in flight plan), or Physical effects but no injury to occupants.		Significant reduction in safety margins, Reduction in the ability of the flight crew to cope with adverse operating conditions impairing their efficiency, or Injury to occupants.	Large reduction in safety margins, Physical distress or workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely, or Serious injury to or death of a relatively small portion of the occupants.	Loss of the aircraft and/or fatalities.
FAR effect category AC 25.1309-1A.		Minor		Major		Catastrophic
JAR effect category AMJ No. 1 of JAR 25.1309		Minor		Major	Hazardous	Catastrophic
Criticality category RTCA DO-178A		Non-essential (Level 3 software)		Essential (Level 2 software)		Critical (Level 1 software)
Criticality category RTCA DO-178B		Minor (Level D software)		Major (Level C software)	Hazardous (Level B software)	Catastrophic (Level A software)
FAR qualitative probability terms.		Probable		Improbable		Extremely Improbable
JAR qualitative probability terms.		Frequent	Reasonably Probable	Remote	Extremely Remote	Extremely Improbable
FAR and JAR quantitative probability ranges.		10^{-3} 10^{-5} 10^{-7} 10^{-9} Probability of Failure Condition (for one flight hour or flight if less than one hour).				

As part of the MCAS development phase, in late 2012, Boeing performed a preliminary functional hazard assessment[30] of MCAS using piloted simulations in their full motion Engineering Flight Simulator; the results were documented in an internal Boeing document[31] (an MCAS requirements document). Several hazards

[30]The hazard assessments were developed as part of Aircraft certification and based on AC 25.1309-1A.

[31]This requirements document, which defined the requirements for the MCAS function, formally conveyed the information regarding the safety impact of the design Change; it included documentation on the FHA and the results of that analysis. A March 30, 2016 revision to this document specifically reflects that the FHA was updated following the MCAS design change, and documents that the hazard classification categories for the expanded MCAS design satisfied all applicable regulatory and certification requirements. This document was circulated by 32Aerodynamics S&C to subject matter experts in the Primary Flight Controls, Autoflight and Flight Test (including the 737 Chief Pilots) and the Requirements groups.

were assessed at that time; however, this section of the report will focus only on the following two hazards: uncommanded MCAS operation up to its Maximum authority (0.6 degrees of Airplane nose down stabilizer) and uncommanded MCAS operation equivalent to a three (3) second stabilizer trim runaway[32]. To perform these simulator tests, Boeing induced a stabilizer trim input that would simulate the stabilizer moving at a rate and duration consistent with the MCAS function. Using this method to induce the hazard resulted in the following motion of the stabilizer trim wheel, increased column forces, and indication that the Airplane was moving nose down. Boeing indicated to the NTSB that this evaluation was focused on the pilot response to uncommanded MCAS operation, regardless of underlying cause. Thus, the specific failure modes that could lead to uncommanded MCAS activation, such as an erroneous high AOA input to the MCAS, were not simulated as part of these functional hazard assessment validation tests. As a result, additional flight deck effects (such as IAS DISAGREE and ALT DISAGREE alerts and stick shaker activation) resulting from the same underlying failure (for example, erroneous AOA) were not simulated and were not documented in the stabilizer trim and autoflight safety assessment reports reviewed by the NTSB.

TABLE27: ORIGINAL RESULTS OF PRELIMINARY HAZARD ASSESSMENT

Hazard	Hazard classification
Uncommanded MCAS operation up to its Maximum authority	Major
Uncommanded MCAS function operation equivalent to a 3second mistrim	Major

The FHA evaluations were conducted by Boeing in their Engineering Cab using FAA guidance regarding pilot response to flight control failures requiring trim input that is contained in FAA Advisory Circular AC25.7C[33]. In particular, Boeing uses the following assumptions in its flight controls FHAs:

Uncommanded system inputs are readily recognizable and can be counteracted by overriding the failure by movement of the flight controls in the normal sense by the flight crew and do not require specific procedures.

Action to counter the failure shall not require exceptional piloting skill or strength.

32The two events were assumed to start from a trimmed condition. Boeing also considered the hazard of uncommanded MCAS operation until pilot response. This condition had the same severity as the 3-second case.

[33]FAA advisory circular (AC) 25-7C, titled, "Flight Test Guide for Certification of Transport Category Aircrafts," dated October 16, 2012, provides guidance for the flight test evaluation of transport category Aircrafts.

The pilot will take immediate action to reduce or eliminate increased control forces by re-trimming or changing configuration or flight conditions.

Trained flight crew memory procedures shall be followed to address and eliminate or mitigate the failure.

Boeing advised that these assumptions are used across all Boeing models when performing functional hazard assessments of flight control systems and that these assumptions are consistent with the requirements contained in 14 CFR 25.671 & 25.672 and within the guidance contained in FAA Advisory Circular (AC) 25-7C for compliance evaluation of 14 CFR 25.143[34].

In March 2016, Boeing determined that MCAS should be revised to improve wings-level, flaps up, low Mach stall characteristics and identification. The MCAS was revised such that depending on AOA, it would be capable of commanding incremental stabilizer to a maximum of 2.5 degrees at low Mach decreasing to a Maximum of 0.65 degrees at high Mach.

Boeing's requirements document indicated that the preliminary functional hazard assessments of MCAS were re-evaluated by pilot assessments in the motion simulator and by engineering analysis and determined to have not changed in hazard classification as a result of the increase in MCAS authority to 2.5 degrees at low speed.

TABLE 28: RESULTS OF PRELIMINARY HAZARD ASSESSMENT FOR REVISED MCAS AUTHORITY

Hazard	Hazard classification
Uncommanded MCAS function operation up to its maximum authority	Major*
Uncommanded MCAS function operation equivalent to a 3 second mistrim **	Major

*Major Classification:

The uncommanded MCAS command to the Maximum nose down authority at low Mach numbers was evaluated in the 737 MAX cab and rated as Minor.The high Mach uncommanded MCAS command and subsequent recovery is the critical flight phase in establishing the hazard rating for erroneous MCAS commands.

[34] FAR 25.143(g) Controllability and Maneuverability – General, requires that changes of gradient that occur with changes of load factor must not cause undue difficulty in maintaining control of the Aircraft, and local gradients must not be so low as to result in a danger of over-controlling. Reference is made to CFR amendment 25-129 for the described FAR 25.143(g) requirement.

** Piloted Simulation not required:

According to Boeing, Engineering analysis determined no low Mach piloted simulation to be required as this failure is less critical than MCAS function operation to Maximum authority. Stabilizer motion for three seconds would not reach Maximum authority in low Mach conditions. The existing high Mach evaluations remain valid as the aerodynamic configuration has not changed significantly since the preflight evaluations, and the 3 second stabilizer motion is the same magnitude.

When assessing unintended MCAS activation in the simulator for the FHAs, the function was allowed to perform to its authority and beyond before pilot action was taken to recover. Failures were able to be countered by using elevator alone. Stabilizer trim was available to offload column forces, and stabilizer cutouts were available but not required to counter failures. This was true both for the preliminary FHAs performed in 2012 and for the reassessment of the FHAs in 2016.

In a 2019 presentation to the NTSB, Boeing indicated that the MCAS hazard classification of “major” for uncommanded MCAS function (including up to the new authority limits) in the Normal flight envelope were based on the following conclusions:

Unintended stabilizer trim inputs are readily recognized by movement of the stab trim wheel, flight path change or increased column forces.

Airplane can be returned to steady level flight using available column (elevator) alone or stabilizer trim.

Continuous unintended nose down stabilizer trim inputs would be recognized as a Stab Trim or Stab Runaway failure and procedure for Stab Runaway would be followed.

Boeing indicated that as part of the development process of MCAS, although not formally part of the FHA, engineering personnel and test pilots considered the scenario of multiple MCAS inputs due to pilot trim action following an erroneous AOA input. Their assessment was that each MCAS input could be controlled with column alone and subsequently re-trimmed to zero column force while maintaining the flight path. Five seconds after cessation of the pilot trim command, the subsequent MCAS command could be controlled in the same manner as the previous instance. Eventually, use of the stabilizer cutout switches would be an option to stop the uncommanded stabilizer motion per the runaway stabilizer procedure (which is a trained flight crew memory item).

1.17.15 ECAA TYPE CERTIFICATE ACCEPTANCE PROCESS

Referring to Ethiopian Civil Aviation Rules & Standards Part 5 – Airworthiness, section 5.2.1.5 Acceptance of Type Certificateevery Airplane, Airplaneengine, and Airplane propeller designed and produced overseas and imported into Ethiopia must obtain a type certificate acceptance. The Civil Aviation Rules & Standards (ECARAS Part 5–Airworthiness regulates the compliance procedure for the Ethiopian Civil Aviation Proclamation 1179/2020 and it is outlined in the Ethiopian Civil Aviation Authority's Airworthiness Inspector Handbook Part 2, Chapter 2-27 Type Certificate Acceptance process (Airplane , Engine and Propeller).

1.17.15.1 Airworthiness RegulationsAirworthiness Standard for Type Certificate

Airplane type certificate is issued by civil aviation authority to ensure the Airplane is manufactured in accordance with approved design and a product meets its type design and is in a condition for safe operation. The airworthiness standards for the issue of type acceptance certificates, and changes to those certificates, for transport category Airplanes in Ethiopia is described in the ECARAS PART 5 - Airworthiness: Transport Category and in the United States of America described in Federal Aviation Regulation (FAR) Part 25. Ethiopian Civil Aviation Rules and Standards Part 5 - Airworthiness section 5.2.1.2 states that Ethiopia accepts type certificates issued by Federal Aviation Administration (FAA) of the United States of America.

The relevant subparts in FAR related with Airplane certification requirements were as follows:
25.1 Applicability

a. This part prescribes airworthiness standards for the issue of type certificates, and changes to those certificates, for transport category Airplane s.

b. ECARAS PART 5, Section 5.2.1.5 states that the Authority may accept a type certificate or equivalent document issued by a State of Design in respect of an Airplane or Airplane component if:

The type certificate or equivalent document was issued based on an airworthiness code recognized by the Authority;

25.143 General.

a. The Airplane must be safely controllable and maneuverable during—

1. Takeoff;
2. Climb;
3. Level flight;
4. Descent; and

5. Landing.

b. It must be possible to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the Airplane limit-load factor under any probable operating conditions, including—

1. The sudden failure of the critical engine;
2. For Airplane with three or more engines, the sudden failure of the second critical engine when the Airplane is in the en route, approach, or landing configuration and is trimmed with the critical engine inoperative; and
3. Configuration changes, including deployment or retraction of deceleration devices.

c. The Airplane must be shown to be safely controllable and maneuverable with the critical ice accretion appropriate to the phase of flight defined in appendix C, and with the critical engine inoperative and its propeller (if applicable) in the minimum drag position:

1. At the minimum V2 for takeoff;
2. During an approach and go-around; and
3. During an approach and landing.

d. The following table prescribes, for conventional wheel type controls, the Maximum control forces permitted during the testing required by paragraphs (a) and (c) of this section:

e. Approved operating procedures or conventional operating practices must be followed when demonstrating compliance with the control force limitations for short term application that are prescribed in paragraph (d) of this section. The Airplane must be in trim, or as near to being in trim as practical, in the preceding steady flight condition. For the takeoff condition, the Airplane must be trimmed according to the approved operating procedures. 25.255 Out-of-trim characteristics.

a. From an initial condition with the Airplane trimmed at cruise speeds up to VMO/MMO, the air-plane must have satisfactory maneuvering stability and controllability with the degree of out-of-trim in both the Airplane nose-up and nose-down directions, which results from the greater of —

1. A three-second movement of the longitudinal trim system at its normal rate for the particular flight condition with no aerodynamic load (or an equivalent degree of trim for Airplanesthat do not have a power-operated trim system), except as limited by stops in the trim system, including those required by §25.655(b) for adjustable stabilizers; or
2. The Maximum mistrim that can be sustained by the autopilot while maintaining level flight in the high speed cruising condition.

b. In the out-of-trim condition specified in paragraph (a) of this section, when the normal acceleration is varied from +1 g to the positive and negative values specified in paragraph c. of this section —

1. The stick force vs. g curve must have a positive slope at any speed up to and including VFC/MFC; and
2. At speeds between VFC/MFC and VDF/MDF the direction of the primary longitudinal control force may not reverse.

c. Except as provided in paragraphs (d) and (e) of this section, compliance with the provisions of paragraph (a) of this section must be demonstrated in flight over the acceleration range —

1.-1 g to +2.5 g; or
2.0 g to 2.0 g, and extrapolating by an accept-able method to -1 g and +2.5 g

d. If the procedure set forth in paragraph (c) (2)of this section is used to demonstrate compliance and marginal conditions exist during flight test with regard to reversal of primary longitudinal control force, flight tests must be accomplished from the normal acceleration at which a marginal condition is found to exist to the applicable limit specified in paragraph (b)(1) of this section.

e. During flight tests required by paragraph (a) of this section, the limit maneuvering load factors prescribed in §§25.333(b) and 25.337, and the maneuvering load factors associated with probable inadvertent excursions beyond the boundaries of the buffet onset envelopes determined under§25.251(e), need not be exceeded. In addition, the entry speeds for flight test demonstrations at normal acceleration values less than 1 g must be limited to the extent necessary to accomplish a recovery without exceeding VDF/MDF.(f)In the out-of-trim condition specified in para-graph (a) of this section, it must be possible from an over speed condition at VDF/MDF to produce at least 1.5g for recovery by applying not more than125 pounds of longitudinal control force using either the primary longitudinal control alone or the primary longitudinal control and the longitudinal trim system. If the longitudinal trim is used to assist in producing the required load factor, it must be shown at VDF/MDF that the longitudinal trim can be actuated in the Airplane nose-up direction with the primary surface loaded to correspond to the least of the following Airplane nose-up control forces:

- The Maximum control forces expected in service as specified in §§25.301 and 25.397.
- The control force required to produce 1.5 g.
- The control force corresponding to buffeting or other phenomena of such intensity that it is a strong deterrent to further application of primary longitudinal control force.

25.1309 Equipment, Systems, and Installations

a. The equipment, systems, and installations whose functioning is required by this Decree, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.

b. The Airplane systems and associated components, considered separately and in relation to other systems, must be designed so that-

1. The occurrence of any failure condition which would prevent the continued safe flight and landing of the Airplane is extremely improbable, and

2. The occurrence of any other failure conditions which would reduce the capability of the Airplane or the ability of the crew to cope with adverse operating conditions is improbable.

c. Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.

d. Compliance with the requirements of paragraph (b) of this section must be shown by analysis, and where necessary, by appropriate ground, flight, or simulator tests. The analysis must consider

1. Possible modes of failure, including malfunctions and damage from external sources.
2. The probability of multiple failures and undetected failures.
3. The resulting effects on the Airplane and occupants, considering the stage of flight and operating conditions, and
4. The crew warning cues, corrective action required, and the capability of detecting faults.

e. In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered. For electrical generation, distribution, and utilization equipment required by or used in complying with this chapter, except equipment covered by Approved

Technical Specification or Technical Standard Orders containing environmental test procedures, the ability to provide continuous, safe service under foreseeable environmental conditions may be shown by environmental tests, design analysis, or reference to previous comparable service experience on other Airplanes

f. EWIS must be assessed in accordance with the requirements of sec.25.1709.

25.1329 Flight guidance system.

g. Under any condition of flight appropriate to its use, the flight guidance system may not produce hazardous loads on the Airplane, nor create hazardous deviations in the flight path. This applies to both fault-free operation and in the event of a malfunction, and assumes that the pilot begins corrective action within a reasonable period of time.

25.1585 Operating Procedures

a. Operating procedures must be furnished for—

1. Normal procedures peculiar to the particular type or model encountered in connection with routine operations;
2. Non-normal procedures for malfunction cases and failure conditions involving the use of special systems or the alternative use of regular systems; and

   Emergency procedures for foreseeable but unusual situations in which immediate and precise action by the crew may be expected to substantially reduce the risk of catastrophe.

b. Information or procedures not directly related to airworthiness or not under the control of the crew must not be included, nor must any procedure that is accepted as basic airmanship.
c. Information identifying each operating condition in which the fuel system independence prescribed in Sec. 25.953 is necessary for safety must be furnished, together with instructions for placing the fuel system in a configuration used to show compliance with that section.
d. The buffet onset envelopes, determined under Sec. 25.251 must be furnished. The buffet onset envelopes presented may reflect the center of gravity at which the Airplane is normally loaded during cruise if corrections for the effect of different center of gravity locations are furnished.

1.17.15.2 The Responsibility for Airworthiness

The Ethiopian Civil Aviation Rules and Standards (ECARAS) PART 9 — Air Operator Certification and Administration are applicable for the operation of Airplane within Ethiopian territory.
The Ethiopian Civil Aviation Rules and Standards (ECARAS) PART 9 subpart 9.2.3 describes:
(a) No person may operate an Airplane in commercial air transport unless that Airplane has an appropriate current airworthiness certificate, is in an airworthy condition, and meets the applicable airworthiness requirements for these operations, including those related to identification and equipment.

(b) The pilot in command of a civil Airplane is responsible for determining whether that Airplane is in condition for safe flight. The pilot in command shall discontinue the flight when un-airworthy mechanical, electrical, or structural conditions occur. (a) Each certificate holder is primarily responsible for
The Ethiopian Civil Aviation Rules and Standards (ECARAS) PART 9 — Air Operator Certification and Administrationrelated to regulation for Airplane maintenance responsibility is as follows:

Ethiopian Civil Aviation Rules and Standards (ECARAS) Part 9 Maintenance Responsibilities **(**Responsibilities for Airworthiness):

(1) (a) Each AOC holder shall ensure the airworthiness of the Airplane and the serviceability of both operational and emergency equipment by:-

(1) Assuring the accomplishment of preflight inspections;

(2) Assuring the correction of any defect and/or damage affecting safe operation of an Airplane to an approved standard, taking into account the MEL and CDL if available for the Airplane type;

(3) Assuring the accomplishment of all maintenance in accordance with the approved operator's Airplane maintenance program;

(4) The analysis of the effectiveness of the AOC holder's approved Airplane maintenance program;

(5) Assuring the accomplishment of any operational directive, airworthiness directive and any other continued airworthiness requirement made mandatory by the Authority; and

(6) Assuring the accomplishment of modifications in accordance with an approved standard and, for non-mandatory modifications, the establishment of an embodiment policy.

(b) Each AOC holder shall ensure that the Certificate of Airworthiness for each Airplane operated remains valid in respect to:-

(1) The requirements in paragraph (a);

(2) The expiration date of the Certificate; and

(3) Any other maintenance condition specified in the Certificate.

(c) Each AOC holder shall ensure that the requirements specified in paragraph (a) are performed in accordance with procedures approved by or acceptable to the Authority.

(d) Each AOC holder shall ensure that the maintenance, preventive maintenance, and modification of its Airplane /aeronautical products are performed in accordance with its maintenance control manual and/or current instructions for continued airworthiness, and applicable aviation rules and standards.

(e) Each AOC holder may make an arrangement with another person or entity for the performance of any maintenance, preventive maintenance, or modifications; but shall remain responsible of all work performed under such arrangement.

(f) An operator shall not operate an Airplane unless it is maintained and released to service by either an AMO certificated under Part 6 or by an equivalent system of maintenance, either of which shall be acceptable to the Authority If an equivalent system to an AMO is used, the AOC holder shall ensure that the person signing the maintenance release is licensed in accordance with Part 2.

(g) Each operator shall ensure that the maintenance of its Airplane is performed in accordance with the approved maintenance programmed.

(3) The operator of an Airplane over 5,700 kg Maximum certificated take-off mass and helicopter over 3175 kg Maximum certificated take-off mass shall monitor and assess maintenance and operational experience with respect to continuing airworthiness and provide the information as prescribed by the Ethiopian Civil Aviation Authority through the system specified in ECARAS Part 5.5.1.5.

(4) The operator an Airplane over 5700 kg Maximum certificated take-off mass and helicopter over 3175kg Maximum certificated take-off mass shall obtain and assess continuing airworthiness information and recommendations available from the organization responsible for the type design and shall implement resulting actions considered necessary in accordance with a procedure acceptable to the Ethiopian Civil Aviation Authority.

FAR related with Airplane CertificationRequirements:-

- This part prescribes airworthiness standards for the issue of type certificates, and changes to those certificates, for transport category Airplane s.
- ECARAS PART 5, Section 5.2.1.5 states that the Authority may accept a type certificate or equivalent document issued by a State of Design in respect of an Airplane or Airplane component if:

The type certificate or equivalent document was issued based on an airworthiness code recognized by the Authority;

25.143 General.

a. The Airplane must be safely controllable and maneuverable during: -Takeoff, Climb, Level flight, Descent, and Landing.

b. It must be possible to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the Airplane limit-load factor under any probable operating conditions, including—

-The sudden failure of the critical engine;

-For Airplaneswith three or more engines, the sudden failure of the second critical engine when the Airplane is in the en route, approach, or landing configuration and is trimmed with the critical engine inoperative; and

-Configuration changes, including deployment or retraction of deceleration devices.

c. The Airplane must be shown to be safely controllable and maneuverable with the critical ice accretion appropriate to the phase of flight defined in appendix C of the ECARAS and with the critical engine inoperative and its propeller (if applicable) in the minimum drag position:

4. At the minimum V_2 for takeoff;
5. During an approach and go-around; and
6. During an approach and landing.

d. For conventional wheel type controls, the Maximum control forces permitted during the testing required by paragraphs (a) and (c) of this section:

e. Approved operating procedures or conventional operating practices must be followed when demonstrating compliance with the control force limitations for short term application that are prescribed in paragraph (d) of this section. The Airplane must be in trim, or as near to being in trim as practical, in the preceding steady flight condition. For the takeoff condition, the Airplane must be trimmed according to the approved operating procedures. 25.255 Out-of-trim characteristics.

a. From an initial condition with the Airplane trimmed at cruise speeds up to VMO/MMO, the Airplane must have satisfactory maneuvering stability and controllability with the degree of out-of-trim in both the Airplane nose-up and nose-down directions, which results from the greater of —

3. A three-second movement of the longitudinal trim system at its normal rate for the particular flight condition with no aerodynamic load (or an equivalent degree of trim for Airplanes that do not have a power-operated trim system), except as limited by stops in the trim system, including those required by §25.655(b) for adjustable stabilizers; or
4. The Maximum mistrim that can be sustained by the autopilot while maintaining level flight in the high speed cruising condition.

b. In the out-of-trim condition specified in paragraph (a) of this section, when the normal acceleration is varied from +1 g to the positive and negative values specified in paragraph c. of this section —

1. The stick force vs. g curve must have a positive slope at any speed up to and including VFC/MFC; and
2. At speeds between VFC/MFC and VDF/MDF the direction of the primary longitudinal control force may not reverse.

c. Except as provided in paragraphs (d) and (e) of this section, compliance with the provisions of paragraph (a) of this section must be demonstrated in flight over the acceleration range —

1. -1 g to +2.5 g; or
2. 0 g to 2.0 g, and extrapolating by an accept-able method to -1 g and +2.5 g

d. If the procedure set forth in paragraph (c)(2)of this section is used to demonstrate compliance and marginal conditions exist during flight test with regard to reversal of primary longitudinal control force, flight tests must be accomplished from the normal acceleration at which a marginal condition is found to exist to the applicable limit specified in paragraph (b)(1) of this section.

e. During flight tests required by paragraph (a)of this section, the limit maneuvering load factors prescribed in §§25.333(b) and 25.337, and the maneuvering load factors associated with probable inadvertent excursions beyond the boundaries of the buffet onset envelopes determined under§25.251(e), need not be exceeded. In addition, the entry speeds for flight test demonstrations at normal acceleration values less than 1 g must be limited to the extent necessary to accomplish a recovery without exceeding VDF/MDF.(f)In the out-of-trim condition specified in paragraph (a) of this section, it must be possible from an over speed condition at VDF/MDF to produce at least 1.5 g for recovery by applying not more than125 pounds of longitudinal control force using either the primary longitudinal control alone or the primary longitudinal control and the longitudinal trim system. If the longitudinal trim is used to assist in producing the required load factor, it must be shown at VDF/MDF that the longitudinal trim can be actuated in the Airplane nose-up direction with the primary surface loaded to correspond to the least of the following Airplane nose-up control forces:

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b. The Airplane systems and associated components, considered separately and in relation to other systems, must be designed so that-

3. The occurrence of any failure condition which would prevent the continued safe flight and landing of the Airplane is extremely improbable, and
4. The occurrence of any other failure conditions which would reduce the capability of the Airplane or the ability of the crew to cope with adverse operating conditions is improbable.

c. Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.

d. Compliance with the requirements of paragraph (b) of this section must be shown by analysis, and where necessary, by appropriate ground, flight, or simulator tests. The analysis must consider-

5. Possible modes of failure, including malfunctions and damage from external sources.
6. The probability of multiple failures and undetected failures.
7. The resulting effects on the Airplane and occupants, considering the stage of flight and operating conditions, and
8. The crew warning cues, corrective action required, and the capability of detecting faults.

e. In showing compliance with paragraphs (a) and (b) of this section with regard to the electrical system and equipment design and installation, critical environmental conditions must be considered. For electrical generation, distribution, and utilization equipment required by or used in complying with this chapter, except equipment covered by Approved Technical Specification or Technical Standard Orders containing environmental test procedures, the ability to provide continuous, safe service under foreseeable environmental conditions may be shown by environmental tests, design analysis, or reference to previous comparable service experience on other Airplanes

f. EWIS must be assessed in accordance with the requirements of sec.25.1709.
25.1329 Flight guidance system.

g. Under any condition of flight appropriate to its use, the flight guidance system may not produce hazardous loads on the Airplane, nor create hazardous deviations in the flight path. This applies to both fault-free operation and in the event of a malfunction, and assumes that the pilot begins corrective action within a reasonable period of time.
25.1585 Operating Procedures
a. Operating procedures must be furnished for—
3. Normal procedures peculiar to the particular type or model encountered in connection with routine operations;
4. Non-normal procedures for malfunction cases and failure conditions involving the use of special systems or the alternative use of regular systems; and
   Emergency procedures for foreseeable but unusual situations in which immediate and precise action by the crew may be expected to substantially reduce the risk of catastrophe.

b. Information or procedures not directly related to airworthiness or not under the control of the crew must not be included, nor must any procedure that is accepted as basic airmanship.

The Responsibility for Aviation Regulation Directorate and Airworthiness Certification

The Aviation Regulation is organized as a component part of the Ethiopian Civil Aviation Authority organized in different directorates with various responsibilities and functions. Aviation Regulation, Deputy Director General is entrusted by Director General ECAA to carry out all required functions among others in the area of airworthiness. It is also responsible for: Perform airworthiness related tasks associated with the registration of Airplane, Airplanetype certification acceptance based on FAA and/or EASA and/or Transport Canada…..

1.17.16 Responsibilities of the Aviation Regulation in the Area of Airworthiness

Develop and Propose amendment as appropriate, national airworthiness rules and standards, policy, and guidance, based on a continual review of the viability and effectiveness of those rules and standards , policy and guidance; Establish working relationships with other CAAs and industry that facilitate the certification of foreign aviation products and parts to enable their import and export; Perform regular surveillance and audits of industry activities to ensure compliance with airworthiness requirements and associated specifications: Evaluating changes to a certificate/approval to ensure continued compliance with the applicable airworthiness requirements

1.18 SUMMARY ON INTERVIEWS

1. B737 CAPT.

Have you trained crew ET302?

- Accident PF was my student when he was in his initial training as FO on B737, after he became a Captain on recurrent training as well.

How was your evaluation of his flying and checking skill?

- As a captain he was very consistent and very serious in his performance, he had no problem at all. He knows his procedures, follows his SOP and on his personal character he is willing to work with all pilots. That is what I know about him: he was very good in CRM. When you say CRM there are 3 areas, Technical, procedural and interpersonal.

Can you briefly describe the training program of ETH as an Airline?

- After coming from pilot training you go through the ground school CBT and take examinations, when you pass you start your fixed base and you go through 11 sessions of full flight simulator, there after you go on observation flight and line training. There are some special classes like CRM, Indoctrination and other classes in between.

Can you describe MAX difference training?

- The MAX difference training was CBT training and it's around 6 hours training, maybe 8 hrs there was no simulation training for MAX at all except CBT training.

Can you give us what elements discussed containing the difference?

- The design of the A/C has some changes in the engine, on the A/C engine let's say it is bigger and has moved a little bit forward. Performance wise the T/OFF weight is higher than the 800 NG.

There is initial requirement training about STAB TRIM control

- Initial training we have established procedures. I do exactly by the procedure

  How much line simulator and ground school was given to each one?

- They should pass ground school before they come for Simulator training.
- The training department introduced Runaway stabilizer on requirement training because it was not there. But once we get this AD it was additionally & necessary in the proficiency training.

How were ET pilots notified of the AD and Boeing FCOM BULLETIN?

Training department provides AD and BULLETIN to the pilots to see how to identify this Runaway stabilizer, altitude disagrees and IAS disagrees. There was no other procedure given.

- We give digital updated data of charts and performance data of B737 A/C for pilots on the Logipad.

  How do you Know pilots have received data?

- Will be checked with Logipad synchronization. Pilots will synchronize their Logipad application after return from flight or by policy they have to synchronize every 7 days.

- The pilots will find new data on what's new section of the Logipad.
  How do you know if someone has synchronized his Logipad in 7 days?
- The Logipad system will produce reporting data.
  How do you know B737 released data has been disseminated?
- The report will be released. Before every flight, pilots synchronize data by policy, unless some pilots are 7 days away from home base.

What actions are taken if synchronization is not done in 7 days?

It will be reported to the chief pilot if synchronization was not done. - I have to look if there is a case that is not reported. Do you have awareness about B737 MAX AD if it was distributed? Yes we did and confirmed.

2. Capt.
Position – B737 NG/MAX pilot and Instructor

- Can you describe What MAX difference training is? The MAX difference training is CBT training and it is around 2 hours training, maybe if you sit continuously on your laptop for 6 hrs. There was no simulator training at all.

- What is the difference between MAX& NG –?
  The design of the A/C has some changes like MAX engine is bigger about 84” and moved a little bit forward, and Nose gear is extended up about 5.6” performance wise the T-OFF weight of MAX is higher than NG.

- Can you give us Normal procedures from start of T-OFF to CLB?

During T-OFF the Capt. will line up the A/C on the Runway, after completing the T-OFF checklist. Once the checklist is completed you get the clearance for T-off, Runway path is clear PF gives power to 40% N1 by pushing TOGA and start take-off roll, PM calls 80Kt Auto call V1 then Rotate, PM calls positive rate PF commands GEAR UP.
-What about Automation part?
Engage A/P at 400ft RA the A/T will go to climb thrust ,LNAV or HDG select will be engaged and clean the A/C and Climb .To practice manual flight Climb to 10,000 ft manually if needed. Normally we encourage the pilot to minimize its workload to engage the A/P as early as possible.
Can you tell us what IAS disagrees with?
It is caused by a difference between captain and FO Air speed indicatorcaused by unreliable AOA signal. Over speed warning has a clacker sound and RED/BLACK tape on the airspeed indicator. This is caused by exceeding the design airspeed limit.

3. Capt

Position – Training Manager, Qualification - ATPL Capt

How do you hire pilots?

After graduation we train CPL and MPL to FO on Q400

B737 then will be promoted to captain after acquiring 3500 hrs.

What is the training Package before being a pilot?

Indoctrination, Duties and Responsibilities for 2 weeks, CBT 2 weeks then they go through FBT (fixed base SIM training) and FFS (full flight simulator). The syllabus also includes special courses.

What is a Runaway stabilizer?

It is un-commanded stabilizer movement,

It is similar to Runaway Stabilizer. We let all pilots know about it, incorporated in the SIM syllabus but no MCAS; we gave them only RUNAWAY STABILIZER situations added on recurrent Training.

What Training syllabus was given about MAX from Boeing?

There was a CBT course of 4 hrs long supposed to cover the difference between MAX and NG. There was no information about MCAS in the system.

How do pilots confirm that they have received the AD?

Pilots are required to update their LOGIPAD at least every 7 days; one of the briefings we do give is to comply with and our technical dept will follow up and remind us if any. Any improvement on training about the AD, We did send a letter to Boeing to confirm if it is enough but Boeing never answered. We initiated to work on RUNAWAY STABILIZER.

Like any other person in this world I heard about MCAS .It is a pity to see signals coming from a single Angle of attack (AOA) could do this. They didn't even know about it.

Pilots who flew the Accident A/C

4. FO

I was a FO on B737NG/MAX for 1.5 years. I have a total of 1000hrs. I flew the Accident A/C i.e. ET- AVJ from JNB- ADD on the same day of the accident. I flew this particular A/C 3 times total, everything was good, nothing unusual observed on the A/C and nothing was reported on the Logbook. There is some difference in the engine of the MAX and NG .The Nose gear height and the display units in PFD/ND have differences.

We have taken training on Runaway Stabilizer; the stabilizer is controlled by Electrical Trim, A/P and manual trim.

Crew who flew the accident A/C

5. Capt. Position – Captain B737NG/MAX,

I have been 7 years in the Air Line for approximately 7000 hrs with Ethiopian, TTL time 19000 hrs. Command time TTL 12000 hrs. I have TRI/TRE on EASA became B737-200/400.

In this accident the flight departed from JNB before the day of the accident. We arrived at ADD in the morning of the accident at 06:00LT.With this A/C we had no problem either Flight control or any other. The Logbook was clear with no remark. I flew this A/C 2 times in 2 days and had no problem.
The difference training given about MAX is a Laptop training which is about 2 hrs. In this course we understood that there are differences between some systems like Size of the Engine which is 84” wide and moved a bit forward, the height of the nose gear about 5.6” high.
A week before the accident I took simulator Training on the old simulator which is NG. I received training on Runaway Stabilizer which is a new training after the Lion Air accident. I actually did this training which has nothing to do with MCAS.
The A/P engages by company policy at 500ft After T-OFF. When you press TOGA A/T is moving forward to give us the required thrust. If it is programmed in the FMC it will engage to climb thrust at 800ft AGL i.e. N1 on the PFD FMA. The A/T is functional from start of T-Off to Landing flare.
IAS disagree – Both on left and right PFD comes, which is Air speed unreliable either pitot or static ports or clogged the 2 air speed compare each other.

Documentation

Position- Senior Ground Instructor for 10 Years

How do you provide the CBT class?
There is a logipad feature uploaded by the engineers .There is a PayLess’s feature i.e. Server You can learn online reading & understanding.
What is your Dept. Role?
- To update the course, assign & check if the trainee has done it and give the examination.
  To make sure they have good preparation before the Simulator schedule.
  Was there any Exam?
- There were Questioners about the differences; unless you answer all will not let you go.
- We made a B737 track about the progress in the online PayLess’s.

From the Department data both accident pilots took briefing about the AD and Boeing's BULLETIN.
  Do you know the accident pilots?
- Yes I know them both. PF took the briefing by Flash. It was a 2 hours course. He did it on his Laptop and so did FO, same as the captain.

LINE PILOTS of the B737MAX

5. Capt.

Training on MAX has its own CBT but I haven't been trained on the simulator, there is a difference in training issued by and I read it. I never did SIM training on the MAX.

We have STAB control on the Yoke & on the control stand. When needed operate electrically, A/P and manual. If the system gives uncommanded operation in the A/P say Runaway condition we operate the cut out Switch and stop the runaway condition.
Over speed warning is a clacker and if the speed exceeds the Airplane design speed it clacks.
Stick shaker is also a warning system before the A/C stalls. The system is designed to Alert the
Pilot before actually stalls and stick shaker on both Yokes.
A/P and A/T, to start from the A/P it gives relief for the pilot, can engage the A/P at 400ft after T-OFF. If it is, CAVOK recommends flying manually.
A/T an important automation which will control the thrust levers depending on the requirement of the flight phase. A/T can engage on the ground during the flight and during landing. If you want to control manually, put the A/T off, it is after landing that you switch it off and the only time you do.

6. Capt.
Position _Cap B737 NG/MAX and TRI/TRE i.e. DCP
Experience TTL flying time –More than 10,000hrs of which 4000hrs is Captain. My duty as a line pilot is to take the flight from A-B safely considering weather, fuel & the progress of the flight. As an instructor teaching the Trainee's per the syllabus .I have trained the accident FO Touch and GO training on the actual A/C and he was an average pilot. I flew with him 2 weeks before the Accident ADD-JNB-ADD.
The accident flight captain we were intimate & never trained him. He was a very good Guy; only once or twice I have asked him to trade flights. Ethiopian Training syllabus is CBT based training depending on the experience of the pilot. The MAX training is 2 hrs CBT training and No Simulator training.
We use Automation on high density airports as much as we can at 400ft RA engage A/P. If there is good weather we let pilots to fly manually to 10,000ft and engage A/P during training I let them fly both manual and with A/P and A/T.

1.19 USEFUL OR EFFECTIVE INVESTIGATION TECHNIQUES

The investigation was conducted in accordance with the EAIB approved Proclamation No 957/2016, EAIB Rules and Standards, policy and Procedures, and with the standards and recommended practices of ICAO Annex 13.

2. ANALYSIS

In accordance with Annex-13 and the EAIB Rules and Standards; the investigation committee assessed all the required data, the relevant records of FDR, CVR, ATS communication, test and researches, Boeing documents, including crew training and proficiency and other information collected and analyses done accordingly.

The analysis will also discuss the additional safety issues that were identified prior to the accident flight, such as Airplane design, Airplane certification, and organizational issues.

2.1 Scenario of the Accident

On this flight the captain was pilot flying (PF) and the first officer was the pilot monitoring (PM).Flight data recorder shows the left angle of attack (AOA) value became erroneous 10 seconds after rotation. This resulted in the onset of the stick shaker followed by a master caution light. At the same time the following happened on the captain's primary flight display (left PFD):

- Indicated airspeed dropped from 170Kt to 156Kt
- Flight director bar rapidly moved downward to 10^0 below horizon (-10^0)
- Red and black minimum speed band suddenly increased to 170 Kt, which was 9 Kt higher than the Airplane current IAS
- According to the Manufacturer's system design and calculation theory, conditions were met for IAS DISAGREE and ALT DISAGREE alerts to appear, but they were not recorded on the FDR.

As the IAS DISAGREE and ALT DISAGREE alerts were not recorded on the FDRno recording of crew conversation about the alerts, if they occurred as calculated by the manufacturer can also be attributed to the appearance of the master caution light which may have taken the crews attention to the glare shield and perhaps to the overhead panel momentarily in trying to identify what caused the master caution alert, and perhaps the alerts could have appeared at this time and by the time they turned their eyes to their respective PFD's the messages may have been there already. It should be understood that an alert is easily recognizable when it corresponds to a change of state like appearance or disappearance, change of colour or is accompanied by aural alert.

With the onset of the stick shaker the captain initially responded by reducing the pitch which corresponds to one of the actions expected to be done by the pilot flying when a stick shaker triggers, as indicated in the approach to stall recovery manoeuvres stated in the quick reference hand book (QRH) [35]non-normal manoeuvres section of the B737. This reduction in pitch did not stop the stick shaker and proximity to the

[35]A note in the QRH -Non Normal Manoeuvres "Approach to Stall or Stall Recovery" requests not to use the flight director commands during the stall recovery

ground or airplane handling quality which indicates the stick shaker to be erroneously activated probably led the captain to stop applying further nose down column input at a pitch angle of 7-8^0 above horizon.

Approaching 400ft, the Captain called-out "*command"*attempted to engage the AP but it was not successful. At that time the FD pitch bars were out of view, this action, was not consistent with the procedure to be used with an ongoing stick shaker. As therewas no explicit discussion between the crew about using the autopilot, the investigation looked at two probable explanations for the above action.

1. He was trying to apply with the non-normal situations guideline found in the flight crew training manual (FCTM) which states "when a non- normal situation occurs, the Maximum use of auto flight system is recommended to reduce workload".

Approaching 400ft, the Captain called-out "*command"* and attempted to engage the AP but it was not successful. At that time the FD pitch bars were out of view. As there was no explicit discussion between the crew about using the autopilot, the investigation looked at two probable explanations for the above action.

Further look at how training was conducted at the airline level for approach to stall recovery was conducted. Most approaches to stall training were given in accordance with the Boeing flight crew training manual FCTM guidelines. Per the manual all approaches to stall training were given with the autopilot engaged and the auto throttle disconnected to simulate an approach to stall condition and the pilot initiates recovery by disengaging the autopilot and following the steps in the approach to stall recovery procedure of the QRH. Additionally the investigation also observed that the FCTM doesn't have a guideline on how to conduct an approach to stall training with the autopilot not engaged nor for a stall condition during departure.

Records at the airline show both pilots were trained in accordance with Boeing flight crew training guidelines. Thus, in all the training the pilot's received for an approach to stall condition, the crew would start recovery by disengaging the autopilot at the onset of stick shaker and the auto throttle was already disengaged prior to the training maneuver per the FCTM guideline.

2. The crew understanding of the airworthiness directive and FCOM Bulletin that was released after the lion air accident.

A thorough study was conducted regarding the airworthiness directive and the FCOM bulletin released after the Lion Air accident. The back ground information from the FCOM bulletin that calls for attention to "an AOA failure condition that occurs **during manual flight only**" was assessed during the investigation and was found that it creates confusing to the reader as it appears that the AOA failure condition would only occur during manual flight only. But it was found that the AOA failure condition can occur regardless of the autopilot engagement status and that only activation of MCAS would be dependent on it.

There might be a chance that the pilot perceived the bulletin in the above discussed manner and believed the problem would disappear given he engages the autopilot, and the reason for his repetitive attempt to engage the autopilot. A second attempt was made six seconds later, above 500 ft at this time the left hand FD pitch bar was at -10°. The Captain's reactions after the second engagement attemptper the CVR recording was "Yehe endet new" an Amharic expression meaning ("What's going on?") it was most likely an explanation asking oneself when unusual and unexpected multiple happenings occur. His verbal expression supports his expectation that the autopilot should have engaged. Shortly afterwards, the Captain requested the FO to contact the radar controller. At this time the Airplane was climbing through 800 ft radio altitude.

From take-off until the successful engagement of the autopilot on the third attempt, the airplane was kept in trim adequately by the Captain via the electrical trim command switches. The average force required on the control column was about 25% higher than previous take-offs recorded on the FDR activation of the Elevator Feel Shift system in response to the erroneous AOA values.

Passing 1000 ft/radio altitude, at the third attempt, the autopilot was successfully engaged. Just before the third AP engagement attempt, the pitch attitude was around 7°. The Captain's FD bars had been approximately centered for two or three seconds, which might have prompted him to try to engage the AP once more. On the FO's side, the FD pitch bar was 20°up.

The crew were faced with unprecedented change of events shortly after lift-off where the workload is high even on a normal take-off. This significantly increased the crew workload.

On several occasions, the captain asked the F/O to advise ATC of the inability to follow the planned departure due to flight control problem and to request runway heading and climb 14,000ft. It shows the captain has considered not resuming the normal flight and climb to the minimum safe altitude of 14,000ft around the airport to deal with the situation and decide on his next course of action. The heading mode was then selected on the mode control panel (MCP).

During the time when the autopilot remained engaged, the left stall management yaw damper computer (SMYD1) which was affected by inputs from a failed left AOA sensor calculated the left hand minimum operational airspeed erroneously above 340kt (VMO). At the start of the airspeed clacker (05:41:21) over speed warning triggered,and the captain called "SPEED" to which the F/O responded "SPEED"

Moreover, at that time, the auto throttle operation was affected by the erroneous left AOA sensor value so it remained in the Arm mode and failed to transition to N1 mode. Transition to the N1 mode would have reduced the take-off thrust to the climb thrust automatically. The auto throttle did not give a warning or a failure flag for the flight crew when its operation was affected by the failed AOA sensor value.

The first MCAS activation occurred within a second where the auto throttle was supposed to reduce from take-off thrust to climb trust. And in less than another second GPWS aural alert “DON’T SINK” sounded twice.

The activation of MCAS followed by GPWS aural alert with already ongoing stick shaker coupled with no failure flag or warning from the auto throttle as it failed to transition to climb thrust in an extremely high workload environment must have caused the auto throttle remaining in the ARM mode with take-off thrust set to remain unnoticed by the crew.The manufacturer revealed during the investigation that the flight management system responsible for calculating and sending thrust command was affected by the erroneous AOA inputs. There was no flight crew document (FCOM,AFM, QRH…) that states this could happen.

The erroneously calculated left hand minimum manoeuvring speed from the SMYD also gave the flight deck effects on the captain’s airspeed indication in terms of colour and manoeuvring band that the airplane was at a dangerously low airspeed. But the number in the airspeed indicator kept increasing as the airplane pitches down.

The pilot’s attention was already consumed with multiple alerts and managing the flight path at the same time. The effect of airspeed indication giving the pilot two different warnings, i.e. dangerously low airspeed indicated by stick shaker, minimum maneuvering band above current airspeed versus high airspeed indicated by the numbers in the speed tape was a point of concern. Although a pilot would normally look at both the maneuvering band and the number in the speed tape and compare the two for his actions, in this particular flight multiple events have occurred simultaneously which has an effect on the pilot’s cross checking. There is a high probability that the low speed feeling indicated by amber and red colour coupled with a stick shaker would weigh in the pilot’s judgment compared to the number indicated in the speed tape.

As a right turn was initiated after selected heading was changed to 197, the pitch decreased as a result of the combination of the nose-down command by the A/P and the right turn. This became visible on the vertical speed indicator which reached approximately -1 600 ft/mn. The red and black stripe band covered the speed tape entirely, which may have added confusion for the Captain. When the A/P disconnected, the

Captain stopped turning and tried to stop the nose down movement by pulling on the column. The Captain applied an increasing force between 50 Lbs and 75 Lbs[36]on the control column towards pitch up.

As the flaps reached the retracted position, MCAS activated for the first time and the stabilizer trim position decreased down from 4.6 to 2.1 units. Although the Captain was applying an increasing nose up force (between 100 and 125 Lbs), only a brief electric trim up input of 2 seconds was recorded, which was insufficient to trim out the MCAS inputs and to relieve the aerodynamic loads. The stabilizer remained at 2.1 units of trim. This short input may be explained by the fact that typical activation (pilot's muscle memory) of the electric trim is usually around 2 to 3 seconds.

It was noted that MCAS trim is very fast; however the pilot's inputs to re-trim to neutral were discontinued in the trim band range of 2.26 to 2.38 units ANU for some unknown reason and it was understood that the rapid onset and complexity of the emergency and its effect on the ET302 flight crew's actions.

"Ensure that if MCAS is erroneously activated, the MCAS system preserves the flight crew's ability, using basic piloting techniques, to control the airplane after the activation." However when an erroneous AOA value (nose high) exists, MCAS continually activate airplane nose-down stabilizer trim with incremental commands (moves the stabilizer a fixed amount regardless of current position of the stabilizer) five seconds after each time the pilot tries to return to trimmed condition.[37] Hence, MCAS denies trim authority and made it difficult to control the airplane from excessive nose dive and crashing.

The eCAB participants noted that attempting to duplicate the ET302 flight crew actions, the simulator crews felt it was instinctual to use as much electric trim as needed to reduce column forces in response to MCAS inputs, recognizing that a sustained input on the electric trim switch was longer than typical inputs that pilots are accustomed to making during routine operations. The force applied by the Captain on the control column during this phase only allowed keeping the airplane almost level (around 8,900 ft).

Five seconds after the pilot's trim input, MCAS activated a second time. Three seconds later, the GPWS aural "DON'T SINK" was triggered and the message "Pull Up" appeared in red on both PFDs. The Captain called "ARGEW CUT" a combination of Amharic and English languages which implies "cut it". Before the first officer responded to this, the captain prioritized and repeatedly said "Trim…trim with me". The captain applied a 9 second electric trim-up input. This trim input fully counteracted the second MCAS input and

[36]*Simulator crews considered column forces above 60 Lbs to be high and above 80 Lbs difficult to maintain level flight*

[37]*Summary of the FAA's Review of the Boeing 737 MAX « ensure if MCAS is erroneosly activated, the MCAS system preserves the flight's crew ability, using basic piloting techniques, to control the airplane after activation »*

stopped the GPWS warning even though it did not bring the aircraft to a neutral trim. It is because the activation of the MCAS made difficultto trim the airplane to the required level.

According to the runaway stabilizer procedure; once a pilot identifies a runaway condition that did not stop with autopilot disengagement or one that starts during manual flight, he should immediately put the stab-trim cut-out switches to cut-out position in order to avoid further mistrim. Further trimming and bringing the aircraft to neutral would then be accomplished by the use of a manual trim wheel. Simulator experience and procedural knowledge has probably built confidence in the pilots' perspective in the application of the procedure and in maniplating the manual trim wheel. The FCOM's bulletins which addresses the erroneous activation of MCAS with the runaway stabilizer non-normal checklist with a note regarding the option to bring the aircraft to neutral by using the electric trim before moving the stab trim cutout switches to cut-out does not concur with the procedural steps of the checklist nor the training that has been conducted. It would then be instinctual for the pilot to apply the procedure as was during the training for runaway stabilizer.In this connection, one of the questions raised by the Airline, addressed to Boeing after the Lion Air accident, could have given a better guidance to pilots but unfortunately, Boeing refrained from providing explanation or clarification.

In the meantime the FO recalled the captain's command and requested confirmation "*stab trim cut out*?" to which the captain agreed. The FO then moved the stab trim cut-out switches to cut-out.

At this time, the stabilizer was at 2.3 units of trim and the Captain was pulling on the control column with a force of 80 Lbs. The altitude was 9 100ft, IAS 332 kt, pitch 2°5, and vertical speed + 350 ft/min.

During abnormal situations, flight crews are assumed to be capable of maintaining control of the flight path and performing a rapid diagnosis that will allow them to identify the correct response and actions to apply. However, a significantly unusual abnormal situation can lead to a total loss of understanding. The stick shaker here represented a major disruption in managing the situation and the rapid onset of multiple inconsistent cues and abnormalities. As a consequence, the effectiveness the crew's CRM was seriously affected.

Five seconds after the end of the Captain's electric trim-up inputs, a third automatic nose-down trim was triggered. There was no corresponding motion of the stabilizer since the stab trim cut-out switches were in cut-out position. At that moment, IAS was 327Kt, and on the F/O's speed tape, the speed trend indicated that the Airplane was expected to reach VMO within the next 10s. Seven seconds after the stab trim cut-out switches were set to cut out, the captain asked the F/O to pull up with him. The force applied on his controls was around 100 Lbs. From that moment on, the pitch varied between + 7 ° and - 2 ° (corresponding to variations ranging from + 4,400 ft / min to - 2,500 ft / min). The values increased when both pilots pulled and decreased if only one pulled. The forces on the Captain's control column varied between 90 and 110 lbs. The flight crew was struggling against the high column forces.

Passing through 9500 ft (about 1900 ft above ground), the captain asked the FO to advise ATC that they wished to maintain "one four thousand feet" because they were having flight control problems and the F/O complied. 14,000ft was the minimum safe altitude around the departure airport. At that moment, the speed was reaching VMO and the airplane was climbing. The ATC communication congestion along with the stick shaker may have confused the F/O from detecting the excessive air speed at a key point. It seems the Captain wished to keep the navigation simple (runway heading) and to reach 14, 000ft (MSA) as a priority.The Captain's priority remained to control the airplane, which is in line with non-normal situations guideline in the B737 FCTM and the Ethiopian Airlines SOP regarding the prioritization of tasks in case of failure on board.

The speed exceeded VMO 340Kt (varying between 360 and 375Kt). The over speed warning triggered. The captain said « THE SPEED » at the start of the airspeed clacker (05:41:21.) to which the F/O responded 'SPEED' at 05:41:29. The uncontrollability of the airplane demanded extra ordinary physical and mental effort to be exerted by the crew. Repeatedly, the Captain asked the F/O to" *pitch up with him*". The force on the Captain's control was around 100lbs at that time sound of exhaustion and shortness of breath are heard on the CVR.

The captain requested the F/O to try the manual trim wheel. After 4 seconds of intense efforts identified on the CVR, the F/O told the Captain "*it's not working*". At this moment the stabilizer trim was at 2.3 units[38] the IAS at 340 Kt.

FCTM indicates "Excessive airloads on the stabilizer may require effort by both pilots to correct the mis-trim. In extreme cases it may be necessary to aerodynamically relieve the airloads to allow manual trimming. Accelerate or decelerate towards the in-trim speed while attempting to trim manually". Forces needed to turn the trim wheel with such a mistrim and high speed are much higher than those expected to be encountered during training or in operation and likely would have required either a two-handed effort by one pilot, or a two-pilot effort.[39]

[38]A stabilizer of 2.3 units represents a -2,7° mistrim

[39]Simulation and Trim Wheel Test Report §DCA19RA101 the predicted trim wheel static force at the 340 KCAS / -1.5° mistrim condition is 35 lb.

The possibility of both pilots applying force on the manual trim wheel inorder to overcome the huge force that was required to turn the manual trim wheel was over ruled as it was found to be inconvenient as well as impractical due to the fact that the captain was holding the control column with a huge amount of force that required a two handed input to prevent the aircraft from diving. At different times during the event flight the captain was heard requesting assistance from his FO to pull with him as well.

The effect of airspeed on the manual trim wheel operation was also observed in a level D simulator as well as flight control test rig (FCTR). It was noted in both assessments that at a high speed of 340Kt and lower speed of 220Ktwhile the same amount of mistrim is present and the captain pulling on the control column in an attempt to replicate the event flight, the manual trim operation was found to be extremely difficult even through one complete turn. It was also noted thatabout 40 turns were required to bring the aircraft to a neutral trim position.

The significant amount of force required to turn the manual trim wheel was found to be the excessive airload on the stabilizer attributed to the force held on the control column to stop the aircraft from pitching nose down and dive rather than the airspeed maintained at that moment.

This finding is also supported by a statement on the FCTM and simulator observations. The FCTM indicates the aircraft will accelerate and decelerate while accomplishing this technique indicating speed not to be a factor, and simulator observation has revealed the force required turning the manual trim wheel both at a high speed of 340Kt and lower speed of 220Kt was significantly high.

The FCTM guideline on such excessive airloads is to relieve **aerodynamically.** Thus; inorder to relieve aerodynamically the pilot had to decrease the amount of force that was held on the control column. Whether relieving aerodynamically using the procedure commonly referred to as the "roller coaster method" was applicable to the event flight was addressed during the investigation. Prior to reaching the point where the flight crew tried to use the manual trim, the crew were already faced with significant aircraft pitching down caused by MCAS activation that has resulted in a GPWS terrain warning, and at the time the crew used the manual trim wheel the captain was holding the control column with a force of about 100Lbs. The FDR shows that at that moment the pitch varied between 7^0 and $-2^0$with a corresponding variation on vertical speed between +4400ft/min to -2500 ft/min. The values increased when both pilot pull and decreased when one pilot pulled.

The Captain repeatedly requested the F/O to pitch up with him "*to go to 14 000*", the F/O complied.

The Captain asked the F/O to request from the ATC "*a vector to return"*, and the F/O complied. Hence, at that moment, it seems the captain decided to return back for landing. However, during the radio communications between the ATC and the F/O, the Captain advised the F/O, to stand-by and pitch up with him to 14, 000 ft.

During the radio communications with the ATC, the F/O's action on the control column was released which increased forces on the Captain's control column. The Captain then requested the F/O to check the Master Caution. Then, they both announced *"left alpha vane".* The FDR data at that time is consistent with the crew pressing the Master Caution recall button to review the existing faults. This might indicate the captain probably wanted to reassess the faults and get to the root cause of the problem which started when they first had a master caution light right after lift-off. At this time the airplane was almost reaching the minimum safe altitude. After about 10 seconds the Captain's then told the F/O that they should pitch up together and a straining sound of both pulling on the control column is recorded on the CVR. The captain then told the FO "PITCH IS NOT ENOUGH" & "PUT THEM UP". A sound similar to stab trim cut-out switches being returned to normal was recorded on the CVR, thus the stab trim cut out switches were most likely turned back on at that moment. After a failed attempt to trim using the manual trim wheel as per the runaway stabilizer non-normal checklist and significant and unbearable amount of force on the control column for the duration they held and the captain's last comment "pitch is not enough", It most likely appears that the flight crew were trying to find other means to relieve the force. The airplane was at 13, 800 ft level; IAS was 367kt, pitch just below 1°, stabilizer at 2.3 units of trim, bank angle 21° right

The crew was busy pulling on the controls with high muscular force trying to maintain airplane flight path control andreach 14, 000 ft, a target on which they remained focused. Trying to maintain flight path control was a very demanding task and represented here a high workload, physically and mentally, to the detriment of every other task. The over speed warning added another disruption and disturbance on board. The cockpit noise environment was unsettling and further impacted the flight crew's concentration.

Immediately after the Stab trim cut-out switches being put back in normal position, the crew attempted another unsuccessful A/P engagement as the plane was approaching 14, 000ft. At the same time, the Captain applied two brief electric trim up inputs of 1 second each while pulling on the control with an average force of 100 Lbs. The force on the controls remained between 75 and 100 Lbs. Five seconds after the trim-up inputs, the fourth MCAS triggered. The plane started to descend. During the 9-second MCAS activation, the stabilizer decreased from 2.3 units to 1 unit of trim. The Captain repeatedly shouted to pitch up with FO. The forces were physically unmanageable by both flight crews.

The airplane hit the ground eighteen seconds after the end of the 4th MCAS.

2.2 Recorded Reports in the Maintenance Log Book

The airplane's left Angle of Attack (AOA) Sensor failed immediately after takeoff sending faulty data to the flight control system. The erroneous data in turn triggered the Maneuvering Characteristics Augmentation System (MCAS) which repeatedly pitched the nose of the airplane down until the pilots lost control.

Intermittent flight control system abnormalities began well before the accident flight. Maintenance actions of relevance started occurring in December 2018 when the airplane was one month old and included several pilot write ups involving temporary fluctuations of vertical speed and altitude. There were also three reports of the airplane rolling during autopilot operation. Altitude and vertical speed indications on the PFD showed erratic and exaggerated indications. The airplane was only four months old at the time of its accident.

From the maintenance log book report the airplane also suffered intermittent electrical/electronic anomalies in addition to the flight control system malfunctions. For example, three days before the crash the Auxiliary Power Unit (APU) Fault Light illuminated, and the APU had a protective shutdown. The APU is a backup electrical and pneumatic power source. The new Honeywell manufactured APUs on the 737 MAX is praised for having a more reliable starting capability. The onboard maintenance function computer message also indicated the Start Converter Unit (SCU) showed the APU's start system was inoperative. The SCU is located in the electrical and electronics (E/E) compartment. The Captain's personal computer power outlet also had no power. The possibility of intermittent electrical/electronic system defects were an underlying issue.

From the above point of observation the AOA Sensor malfunction most likely occurred as the result of a power quality problem that resulted in the loss of power to the left AOA Sensor Heater. Evidence indicates the loss of power was likely due to a production related intermittent electrical/electronic failure involving the airplane's Electrical Wiring Interconnection System (EWIS) [40]and the AOA Sensor part. Boeing delivered the ET302 airplane to Ethiopian Airlines on Nov 15, 2018. Within a month of being placed into service, the airplane started experiencing a variety of intermittent electrical and electronic malfunctions.

According to the report, after the ET302 accident, Boeing informed the NTSB they had made an engineering design error in their initial AOA Sensor Hazard Analysis; Neither Boeing, the NTSB, nor the FAA informed Ethiopian authorities about this critical error that was communicated to the NTSB by Boeing four months earlier.

A miscalibrated sensor scenario for JT610 and a bird strike scenario for ET302 cannot explain the flight control system alerting, maintenance messages and electrical/electronic system faults that were occurring on these airplanes in the weeks and days before their accidents. These accidents were triggered by

[40]U.S. Title 14 Code of Federal Regulations (EWIS)

production quality defects that presented as intermittent system malfunctions. These types of defects are difficult to identify and troubleshoot. They frequently result in No Fault Found maintenance determinations.

MCAS and the lack of pilot training did not trigger these accidents; however it was the failure of the sensors due to the production quality defects. Simply put, if the intermittent defects did not cause the AOA Sensors to fail on these flights, MCAS would not have activated, and these two accidents would not have occurred. The MCAS would have remained as hidden threat until its true nature is exposed by some other valid or erroneous causes.

2.3Crew Resource Management

Crew Resource Management (CRM) refers to the effective use of all available resources: human resources, hardware, and information. These activities include communication, problem solving, and decision making, maintaining situational awareness, workload management, and dealing with automated systems.

The guidelines for handling a non-normal situation, according to the Non-Normal Operation chapter in the FCTM, are recognition of non-normal conditions, maintain Airplane control, analyze the situation, take the proper action, and evaluate the need.

During the event flight the crew was faced with multiple alerts and flight deck effects just 10 seconds after lift-off. The unprecedented events that unfolded were during a high workload time and very close to the ground. Maintaining airplane control was affected right from the first MCAS activation which happened at about 800ft above ground level. Per the non-normal situations guideline, airplane control was the first action to be accomplished by the pilot flying. For the majority of the event flight the captain was trying to control his aircraft as MCAS made it harder and harder for him to control. The flight crew's attention was consumed by the repetitive nose down commands from MCAS, terrain alert and the desire to climb to a safe altitude.The sudden and unexpected change in the situation right after takeoff, and the distraction due to high noise level (stick shaker, and associated aural warnings) in the cockpit coupled with the uncontrollability of to control the airplane affected the effectiveness of their CRM.

Pilot flying workload and task demand were high when attempting to maintain flight path as column force increased with MCAS activation. Simulator crews considered column forces above 60lbs to be high and above 80lbs very hard. It became difficult to find a neutral column and maintain level flight. For reference, after the autopilot disengagement, the ET302 captain experienced column forces on average above 90lbs. Column loads about 60-80 lbs were hard to differentiate – all are "high".The workload appeared to be high, and it was deemed a "demanding task" by the crew to maintain flight path control. It was noted that the stick shaker was a distraction when managing the emergency.

2.3.1 Crew Communications

Crew communication seemed normal and standard for majority of the flight but some expected call outs and conversations did not occur between the crew after the onset of the sticks shaker. This can be attributed to the nature of the events that followed after the stick shaker which caused the flight deck environment to be noisy, that was made worse by chattering from ATC and other airplanes. Different failures and flight deck warnings occurred in a row with only few seconds in between.

The CVR recording shows that after the crew performed the runaway stabilizer non-normal procedure and put the stab trim to cut-out; the captain asked the first officer what caused the master caution earlier and asked him to do a master caution recall. After which they both announced “left alpha vane”. It looked like the captain wanted to reassess his actions and get to the bottom of things but was quickly distracted by the huge amount of force he was holding and told the first officer “pitch is not enough” and requested the FO to assist him with pitch.

2.3.2 Flight Crew Situational Awareness

Flight crew situational awareness and ability to perceive each and every thing to the detail was greatly affected with the ever changing flight scenario and unsettling warnings and flight deck effects. Flight instrument display of high speed indication with low speed warning was one of the main events of the flight. The flight crew’s attention to speed and energy state of the airplane was greatly affected as their primary action of controlling the airplane per the non-normal situations handling guideline was not completely met as activation of MCAS repeatedly changed the flight path.

During abnormal situations, flight crews are assumed to be capable of maintaining control of the flight path and performing a rapid diagnosis that will allow them to identify the correct response and actions to apply. However, a significantly unusual abnormal situation can lead to a total loss of understanding and defeat this principle. The stick shaker here represented a major disruption in managing the situation and the rapid onset of multiple inconsistent cues and abnormalities since take-off impacted the crew’s ability to perceive the situation. The crew was in an unprecedented situation. Records at the airline level show that the crew had received training in accordance with Boeing guideline in the FCTM. In the event flight the pilot’s attention was consumed with multiple alerts and managing the flight path at the same time. The effect of airspeed indication giving the pilot two different warnings, i.e. dangerously low airspeed indicated by stick shaker, minimum manoeuvring band above current airspeed versus high airspeed indicated by the numbersin the speed tape could have confused the crew.

2.3.3 Decision Making

During the event flight the captain asked the first officer to request runway heading due to flight control problems. It is noted that the captain understood it would not be possible to fly the original clearance of standard instrument departure and make the navigation simple allowing more time for him to decide on the next course of action.

The captain also asked the first officer to request a stop climb at 14,000ft which is the minimum safe altitude around the departure airport. This was an indication that the captain understood it would not be possible to continue the normal climb profile and needed to level off at the lowest safe altitude in order to set things in order and decide on the next course of action.

After the second MCAS activation, the captain asked the first officer to trim with him and then put the stab trim cut-out switch to cut-out. The first officer confirmed with the captain and performed the procedure as per the AD and FCOM bulletin.

After a failed attempt to use the manual trim wheel and trim the airplane as per the runaway non-normal procedure and the training they have acquired, the captain decided to return back for landing and asked the first officer to get radar vectors for landing.

During the right turn for radar vectors, the captain who had been holding the aircraft with tremendous force for quite some time told the first officer “pitch is not enough”, “put them up”. The FDR and CVR data was concurrent with the stab trim cut-out switch being returned to normal position. Even if the decision to return the stab trims cut-out switches back to normal was not consistent with the AD nor the FCOM bulletin,it seems the captain understood that the force required on the control columns was beyond one he and his first officer could sustain for the remainder of the flight until a successful landing from the radar vectors.

Simulator observation and research during the investigation process has shown that an attempt to land with the miss trim level they have on the event flight where the stab trim switches were in cut-out position was unsuccessful.

2.4FCTR Evaluation

The Boeing constructed FCTR is designed to replicate the forces needed to move the trim wheel in a B737MAX at various mis-trim and airspeed combinations. A mis-trim of -1.5 units at airspeed of 340 KCAS (VMO) was the most difficult mis-trim/airspeed combination available in the FCTR. But during the accident flight, the mis-trim was -2.7 units at airspeed of 340 KCAS.

It was observed that the greater the mis-trim value, the greater the force required by the pilot on the control column to fly level flight and consequently the greater the force required rotating the manual trim wheel.

The trim wheel must complete 15 revolutions to move the stabilizer by 1 unit (degree) of trim. Consequently, to resolve a mis-trim of -1.5°, the wheel would have to be rotated through 22.5 revolutions; but to resolve a mis-trim of -2.7° it would have to be rotated through 40.5 revolutions, i.e., 80% more.
Initiating rotation and continuing for 40 revolutions on the accident flight would have been significantly more difficult than in the FCTR.
According to the cockpit voice recorder (CVR), the first officer indicated that he could not rotate the manual trim wheel. Moreover, Simulator and FCTR observations have revealed that the force required to operate the manual trim both at 340Kt and 220Kt was significantly high.

The force required to rotate the trim wheel depends on grip (overhand or underhand), seat (body) position in relation to the trim wheel, and the position of the handle on the wheel (which would change the direction of the force vector required to initiate or maintain rotation) could all affect how easy or difficult it was to move the manual trim wheel handle. Moreover, there was no mention of high forces that may be required to trim manually in either the QRH or the Boeing FCOM. Excessive air loads on the stabilizer may require effort by both pilots to correct the mis-trim. In extreme cases it may be necessary to aerodynamically relieve the air loads to allow manual trimming.

Therefore, the force required to correct the mis-trim of -2.7 was out of the acceptable capability of the crew.

2.5Flight Crew Training and Proficiency

The existence of MCAS and its function was not disclosed in any of the manuals provided by the manufacturer. Without MCAS description, function and its effect, it would be more difficult for the flight crew to understand the complexity. Instead of focusing on the runaway stabilizer in the AD, the crew would have been served better if training was provided about the effect of MCAS activation. With better understanding of the system the crew would have had better chances of mitigating the consequences of repetitive MCAS activations.

The investigation found that the Captain’s priority remained to control the airplane, which is in line with non-normal situations guideline in the B737 FCTM and the Ethiopian Airlines SOP regarding the prioritization of tasks in case of failure on board.The operator owns training manual which is approved by Ethiopian Civil Aviation Authority. According to this manual the accident pilot and first officer had taken the type rating, recurrent training, line check and proficiency check as it is clearly put in the Ethiopia civil aviation Rules and standards (ECARAS) Part 2, part 8 and part 9 and the operation training manual of the company.

Ethiopian Civil Aviation Authority based on ICAO Doc 8335, Manuals of procedures for operation inspection, Certification and continued surveillance conducts an oversight of the operator using inspector procedure hand book and audit policy manual for the compliance of ECARAS part 2, part 8 and part 9 Ref Operation Inspector Handbook chapter 1-06 Annual Inspection Program, chapter 4-08 training program Inspections, chapter 4-07 Training and Qualification Record inspection.

The PF and FO had taken proficiency checks on 30 November 2018 and 03 December, 2018 respectively and completed successfully. The accident crew has taken the MAX difference training in a 2 hour CBT training which was recommended by the manufacturer and approved by the regulators.

The CBT training recommended by the manufacturer and approved by regulators was made available to the pilots through the Airline's Logipad application on designated computer devices to each pilot. The Logipad application has the additional function of the training process and evaluation. (Learning Management System)

Logipad is also used to distribute manuals, Notices and Bulletins, other training and evaluation as well as aircraft performance calculations and reports. Boeing OMB and FAA AD were distributed to all pilots of the operator on the MAX fleet through the Logipad application. The Airline's policy requires that each flight crew member synchronizes his/her Logipad prior to each flight and as a minimum every seven days.

2.6FAA'sAirworthiness Directive and Boeing's Bulletin

After the Lion air accident on October 29th 2018, the manufacturer released bulletin ETH-12 on November 6, 2018 was incorporated on the Ethiopian airlines FCOM showing as in effect. The document clearly states that information in the bulletin is recommended by the manufacturer but may not be FAA approved at the time of writing. In the event of conflict with the FAA approved Airplane flight manual (AFM), the AFM shall supersede.

On November 7, FAA released emergency airworthiness directive AD #: 2018-23-51 for owners and operators of the Boeing company model 737-8 and -9 Airplanes. Both the FAA's AD and the manufacturer's bulletin were not updated or a revision was released after their initial release in November. The AD states that it is an interim action and if final action is later identified, FAA might consider further rule making then. The AD was presented in 10 parts labeled from (a) to (J). Part (e) unsafe condition: states that the AD was prompted by analysis performed by the manufacturer**.** Part (h) is AFM revision and it updates the operating procedures in the AFM.

(h) AFM Revision: Operating Procedures

Within 3 days after receipt of this AD, revise the Operating Procedures chapter of the applicable AFM to include the information in figure 2 to paragraph (h) of this AD.

Figure 2 to paragraph (h) of this AD – *Operating Procedures*

Required by AD 2018-23-51

Runaway Stabilizer

Disengage autopilot and control airplane pitch attitude with control column and main electric trim as required. If relaxing the column causes the trim to move, set stabilizer trim switches to CUTOUT. If runaway continues, hold the stabilizer trim wheel against rotation and trim the airplane manually.

Note: The 737-8/-9 uses a Flight Control Computer command of pitch trim to improve longitudinal handling characteristics. In the event of erroneous Angle of Attack (AOA) input, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds.

Looking at part (h) of the AD, the phrase *"if relaxing the column causes the trim to move, set stabilizer trim switch to CUTOUT."* assumes that there is a possibility for the runaway to be stopped by applying opposite control column force. This same phrase is not present on the manufacturer released bulletin which clearly shows that the manufacturer is aware of the fact that the control column mounted cutout is not effective for this specific scenario.

Assessment of Contents of the Bulletin:

BOEING

Flight Crew Operations Manual Bulletin for Ethiopian Airlines

The Boeing Company
Seattle, Washington 98124-2207

737

Number: ETH-12

IssueDate: November 6, 2018

Airplane Effectivity: 737-8 / -9

Subject: Uncommanded Nose Down Stabilizer Trim Due to Erroneous Angle of Attack (AOA) During Manual Flight Only

Reason: To Emphasize the Procedures Provided in the Runaway Stabilizer Non-Normal Checklist (NNC).

Information in this bulletin is recommended by The Boeing Company, but may not be FAA approved at the time of writing. In the event of conflict with the FAA approved Airplane Flight Manual (AFM), the AFM shall supersede. The Boeing Company regards the information or procedures described herein as having a direct or indirect bearing on the safe operation of this model airplane.

THE FOLLOWING PROCEDURE AND/OR INFORMATION IS EFFECTIVE UPON RECEIPT

Background Information

The Indonesian National Transportation Safety Committee has indicated that Lion Air flight 610 experienced erroneous AOA data. Boeing would like to call attention to an AOA failure condition that can occur **during manual flight only.** This bulletin directs flight crews to existing procedures to address this condition.

In the event of erroneous AOA data, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds. The nose down stabilizer trim movement can be stopped and reversed with the use of the electric stabilizer trim switches but may restart 5 seconds after the electric stabilizer trim switches are released. Repetitive cycles of uncommanded nose down stabilizer continue to occur unless the stabilizer trim system is deactivated through use of both STAB TRIM CUTOUT switches in accordance with the existing procedures in the Runaway Stabilizer NNC. It is possible for the stabilizer to reach the nose down limit unless the system inputs are counteracted completely by pilot trim inputs and both STAB TRIM CUTOUT switches are moved to CUTOUT.

In the back ground information of the bulletin, it states that:

"In the event of erroneous AOA data, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds.........
Repetitive cycles of commanded nose down stabilizer continue to occur unless the stabilizer trim system is deactivated through the use of both STAB TRIM CUTOUT switches in accordance with the existing procedure in the runaway stabilizer NNC."

As this feature of the pitch trim system is very new information to the FCOM, pilots or the operators, there should have been some description or statement that would explain why the pitch trim system would trim the nose of the airplane down repetitively and what this specific part of the pitch trim system considers as a precondition in order to activate.

After the Lion Air accident, the manufacturer revealed this feature of the pitch trim system as MCAS, and provided description of it to operators, including Ethiopian Airlines. At the time of the Ethiopian accident, the main body of the FCOM had not yet been updated by Boeing to include the information provided in the OMB. From the conditions that must be met to activate this feature of the pitch trim system (MCAS), one condition is repeatedly stated in the bulletin as "**During manual flight only**". In fact the bulletin gave so much attention to this very condition that it is written in **bold** wherever it appeared on the document but the other precondition that must be met like the position of the "**FLAPS"** was not mentioned.
It should be understood here that MCAS would never have activated the repeated nose down trim if the flaps were still left down, even in the presence of erroneous AOA. This crucial information was never revealed in the bulletin or in the airworthiness directive.

ASSESSMENT OF THE BULLETIN FROM THE CONTENT

The statement in the back ground of the bulletin gives unclear information:

Background Information

The Indonesian National Transportation Safety Committee has indicated that Lion Air flight 610 experienced erroneous AOA data. Boeing would like to call attention to an AOA failure condition that can occur **during manual flight only.** This bulletin directs flight crews to existing procedures to address this condition.

The above highlighted phrase in the back ground information "*calls attention to an AOA failure condition that can occur during manual flight only*". Actually, an AOA failure can occur in either manual or autopilot flight. It is the activation of MCAS which is dependent on the status of autopilot engagement, not only the failure of AOA.

Non- Normal Checklist

The indications stated in the bulletin of erroneous AOA are related to different checklists. But the bulletin instructs the pilot to do the runaway stabilizer NNC for this indication and does not mention any other checklist.
FDR data has revealed that the erroneous AOA signal has caused many failures to happen at the same time. When multiple failures occur all together, addressing only one failure scenario would not be enough to handle the situation, but the operational information section of the bulletin tried to direct in handling the situation with only Runaway stabilizer non-normal checklist.

As can be observed above, there was a possibility for the existence of confusion in understanding the failure scenario as well as in interpreting the operating procedures.

The investigation team did a survey on how this bulletin was perceived amongst pilots and the operator during interviews held with pilots, instructors and training department of the airline. It was discovered through this process that the airline had concerns about the interpretation of the bulletin and this concern was relayed to Boeing as early as November, 2018. An email correspondence between the operator and the manufacturer was also gathered through this process. From the email correspondence, the following were questions raised by the operator on 28 November 2018, quoted:

"Having attended the Boeing briefing on the 27th of November, held on a teleconferencing, and after mulling on the very precarious situation where the lion air crew was, we have come up with few questions mainly related to operations. The questions are summarized as follows:

First; According to the briefing there was no problem with the MCAS system at the time of the accident except being triggered at the wrong moment during the flight due to a single erroneous AOA data. Then why is the system designed in such a way that it operates depending on a single data source, especially when it is of a serious consequences, instead of interrogating data from other AOA sensors?

Second; any average skilled pilot experiencing multiple failures, as it were, would react to the abnormalities depending on their sequence of urgency starting with a stick shaker. All simulator trainings, so far provided, require at the first activation of a stick shaker to react in such a way to curb the impending actual stall. It is, though, obvious that all stall warnings are not true as was the case with the Lion Air 737 MAX involved in the accident, but once a pilot identified a stick shaker to be a nuisance, the next thing he would do is the AIRSPEED UNRELIABLE memory item not runaway stabilizer checklist. Because the AIRSPEED UNRELIABLE checklist puts a nuisance stick shaker to be an indication of unreliable airspeed, a pilot can't be expected to put the trim cut out switches to cut out before dealing with the above procedures unless there is a clear guidance or a QRH procedure addressing such scenario.

Third; the third question has to do with the very checklist recommended by the bulletin issued regarding the MCAS system and that is the RUNAWAY STABILIZER checklist. This checklist commands the pilot to put the stab trim cut out switches to cut out only if the runaway continues after the autopilot is disconnected and that is not the case with MCAS. MCAS does not continually trim down. It stops trimming, according to the bulletin, for 5 seconds if the control column trim switches are trimmed in the opposite direction. That will rule out the attempt to categorize the malfunction, if it is, as a runaway stabilizer and by implication the use of the checklist what is the delineation between an MCAS normal operation and runaway stabilizer?"

The manufacturer responded on 3 December 2018: declaring "I am happy to hear that you were able to take part in the Fleet Team meeting and will attempt to answer other questions from your pilots. However, because of our Annex 13 technical support to the [on-going Lion Air] accident investigation, we are unable to answer questions directly related to this event. I can only address the current system and the Operation's Manual Bulletin. The first two questions directly relate to the accident scenario; therefore, I will be unable to address them here. I have provided the answer to the third question below".

[Text of question 3 repeated in response]"The purpose of the Operations Manual Bulletin is to raise awareness of the relationship between an erroneous AOA indication and uncommanded stabilizer movement. Specifically, if the AOA is erroneous and also high, it may be high enough to trigger the MCAS flight control law. The pilot always has trim authority to override both the Speed Trim and MCAS flight control laws with the control wheel electric trim switches and ultimate authority to power off the entire stabilizer trim system using the Stabilizer Cutout Switches. As is stated in the OMB, if uncommanded stabilizer trim movement is experienced in conjunction with the erroneous AOA flight deck effects, the instructed course of action is to use the Stabilizer Cutout switches per the existing procedure. Additionally, in all phases of manual flight, it is expected that flight crews would use normal trim procedures to trim out undesired control forces or positions, regardless of axis – stabilizer, rudder, or aileron."

As seen above the concerns raised by Ethiopian airlines about task and checklist prioritization were not answered by Boeing stating they relate to an ongoing investigation. If this concern was addressed in time, the effect it would have on the Ethiopian airlines accident flight can not be overstated.

2.7Ethiopian Safety Management System (FCOM Bulletin & MOM Handling)

The Chief Executive Officer (CEO) is responsible for the overall safety of Ethiopian Airlines.

The Accountable Manager (the Chief Operating Officer–COO) is responsible for implementing safety standards and resolving operational safety issues. This responsibility includes the authority to establish support for the program in each operational unit. Responsibility for further implementing the Safety Program in all divisions rests with respective vice Presidents and their designate.

2.8 ORGANIZATIONAL ISSUE

2.8.1 ECAA Regulation and Certification

Referring to Ethiopian Civil Aviation Rules & Standards Part 5 – Airworthiness, section 5.2.1.5 Acceptance of Type Certificate every Airplane, Airplane engine, and Airplane propeller designed and produced overseas and imported into Ethiopia must obtain a type certificate acceptance. The Civil Aviation Rules & Standards (ECARAS Part 5 –Airworthiness regulates the compliance procedure for the Ethiopian Civil Aviation Proclamation 1179/2020 and it is outlined in the Ethiopian Civil Aviation Authority's Airworthiness Inspector Handbook Part 2, Chapter 2-27 Type Certificate Acceptance process (Airplane , Engine and Propeller).

After the Lion air accident on October 29th 2018 the FAA released an AD that required revising certificate limitations and operating procedures of the Airplane flight manual (AFM) to provide the flight crew with runaway horizontal stabilizer trim procedures to follow under certain conditions.

Accordingly the ECAA issued AD 2018-23-51 dated 08 Nov, 2018 which was released by FAA on November 07, 2018 applicable for 737 MAX-8, 9 Airplanes. The operator was advised to revise its AFM and operating procedures. The ECAA advised the operator implementing the AD and reported to the authority within the specific time provided and this was confirmed by the operator response that has been done accordingly. Even though the FAA's AD released after five months of the lion air accident the content of the AD was symptomatic of only a runaway stabilizer.

Then after, the ET 302 accident on 10 March, 2019 the Ethiopian Civil Aviation Authority as per ECARAS part 8, section 8.2.1.2 (a) notified that the Ethiopian Airlines Group that all Boeing 7373MAX-8 fleet of Airplane grounded and was not allowed to make commercial flights effective March 11, 2019.

2.9MCAS Design, Description and Certification,

The 737 MAX 8 is a derivative of the 737-800 Model and is part of the 737 MAX families (737 MAX 7, 8, and 9[41]). The 737MAX incorporated the CFM LEAP-1B engine, which has a larger fan diameter and redesigned engine nacelle compared to engines installed on the 737 Next Generation (NG) families. Because the 737-8 is a derivative of the 737-800 model, its certification basis, which was established per 14 CFR 21.101 Changed Product Rule, required Boeing to demonstrate compliance with part 25 as amended by Amendments 25-0 through 25-137, plus amendment 25-141 with exceptions permitted by 14 CFR 21.101for significant areas of change at the product level and those areas affected by the significant product level change.

During the preliminary design stage of the 737 MAX 8, Boeing tests and analysis revealed that the addition of the LEAP-1B engine and associated nacelle changes produced an Airplane nose-up pitching moment when the Airplane was operating at high angles of attack (AOA) and mid Mach numbers. This nose-up pitching moment was deemed likely to affect the stick force per g (FS/g) characteristics required by FAR 25.255 and the controllability and maneuverability requirements of FAR 25.143(f). After the study of various options for addressing this issue, Boeing implemented aerodynamic changes as well as a stability augmentation function called the Maneuvering Characteristics Augmentation System (MCAS), as an extension of the existing Speed Trim System (STS), to improve Airplane handling characteristics and improve static longitudinal stability at elevated angles of attack.

The AD issued following the Lion Air crash indicates that if one executes the Runaway stabilizer NNC the problem could be handled. However, the information about flap position as part of the MCAS logic was omitted from the AD,MCAS operates only when the flap was fully up. Following the issuance of this AD, certain MAX crew members asked clarification from Boeing via email whether they should do airspeed unreliable procedure first regarding certain aspects of the AD. The response they got was that Boeing could not make further comments as the case was under investigation, but later on Boeing answered some of the questions.

[41]Both the 737-8 and 737-9 were in service at the time of the accident. The 737-7 and 737-10 are planned future derivatives that have not yet entered service.

2.9.1 MCAS Description in FCOM

Boeing and the FAA engaged in extensive discussions about the appropriate content of MAX training and manuals for a period of several years prior to MAX certification in 2017. During discussions and communications with the FAA in 2016, Boeing proposed removing MCAS from the FCOM and the FAA agreed with that recommendation.

FAR 25.1585 provide direction for the content of Airplane operating procedures, such as the AFM.FAR 25.1585(b) states that "Information or procedures not directly related to airworthiness or not under the control of the crew must not be included, nor must any procedure that is accepted as basic airmanship." As relevant to this standard, Boeing's rationale for recommending MCAS's removal from the FCOM included that: (1) the MCAS function is automatic and operates in the background, without any control input from the flight crew and

(2) Crews were not expected to encounter MCAS in normal operation.

The investigation assessed documents that Boeing with its knowledge did not mention about MCAS; instead they were telling and emphasizing only the runaway stabilizer/un-commanded stabilizer to the operator and for the authorities.There was CBT training for a few hours long supposed to cover the difference between MAX and NG. There was no information about MCAS description in the system except the Airplane has wide and moved a bit forward body, Size of the Engine which is 84" and the height of the nose gear about 5.6" high.

2.9.2 Functional Hazard Assessment

During the process of developing and validating the Functional Hazard Analysis (FHA), Boeing considered four failure scenarios including uncommanded MCAS function to the Maximum authority limit of 2.5° of stabilizer movement. The uncommanded MCAS function to Maximum authority was flight simulated to high speed Maximum limit of 0.6°, and also the low speed Maximum limit of 2.5° of stabilizer movement and Boeing did not test repetitive erroneous MCAS activations in a flight simulation, but did consider the possibility of an erroneous AOA sensor potentially leading to repeated MCAS activations.

The specific failure modes that could lead to uncommanded MCAS activation, such as an erroneous high single AOA input to the MCAS, were not simulated as part of these functional hazard assessment validation tests. As a result, additional flight deck effects such as IAS DISAGREE and ALT DISAGREE were not assessed.

The unintended MCAS-commanded stabilizer movement due to erroneous single AOA input was considered a failure condition with Major effect in normal flight envelope. However, this classification did not consider the possibility of the increased workload associated with the additional flight deck effects.

MCAS was activated without pilot input and only operated in manual, flaps up flight. The system is designed to allow the flight crew to use column trim switch or stabilizer aisle stand cutout switches to override MCAS input. The function is commanded by the Flight Control computer using input data from sensors and other Airplane systems.

The major classification used by Boeing indicated a remote probability of this hazard occurring and that it could result in reduced control capability, reduced system redundancy, or increased crew workload. Other classification categories include “Minor,” “Hazardous,” and “Catastrophic.” Because uncommanded MCAS function was considered “Major,” Boeing did not perform a specific fault tree analysis for an uncommanded MCAS hazard.

Retention and delegation are accomplished with respect to compliance deliverables not to specific functions i.e., MCAS itself would not be delegated to the ODA.

Consistent with the FAA authorization, the FAA has discretionary authority as to what is reviewed, whether submitted directly to the FAA for review and approval by an applicant or submitted by a designee or ODA recommending approval.

When delegating at the end of a program, there has been some level of FAA involvement and the delegation confirms that the designee should make the final approval.

In all cases, delegation is not accomplished by a single individual but follows a structured review process.

2.9.3 FHA for MCAS Related Failures

The investigation reviewed sections of Boeing’s 737 NG/MAX Stabilizer Trim Control System Safety Analysis that pertained to MCAS. Boeing’s analysis included a summary of the functional hazard assessment findings for the 737 MAX stabilizer trim control system. For the normal flight envelope, Boeing identified and classified two hazards associated with “uncommanded MCAS” activation as “major”. The major classification used by Boeing indicated a remote probability of this hazard occurring and that it could result in reduced control capability, reduced system redundancy, or increased crew workload. Other classification categories include “Minor,” “Hazardous,” and “Catastrophic.” Because uncommanded MCAS function was considered “Major,” Boeing did not perform a specific fault tree analysis for an uncommanded MCAS hazard and failed to classify MCAS as a safety-critical system, which would have attracted greater FAA analysis during the certification process.

The specific failure modes that could lead to uncommanded MCAS activation, such as an erroneous high single AOA input to the MCAS, were not simulated as part of these functional hazard assessment validation tests. As a result, additional flight deck effects such as IAS DISAGREE and ALT DISAGREEdid not emerge.

The unintended MCAS-commanded stabilizer movement due to erroneous single AOA input was considered a failure condition with Major effect in normal flight envelope. However, this classification did not consider the possibility of the increased workload associated with the additional flight deck effects.

Much has been written about the engineering design errors associated with the 737 MAX especially the design errors associated with the development of the MCAS software. Similar design and testing errors were made with the MAX's AOA Sensor part (hardware). In a June 28, 2019, revision to the System Safety Analysis, Boeing informed the NTSB that Erroneous data from the Captain's AOA Sensor is revised to show three separate conditions combined with an OR gate, meaning any one by itself could result in erroneous AOA data: Erroneous AOA-L Sensor, Incorrect AOA output from ADIRU-L output, OR Loss of Power to AOA-L Heater.

According to the report, after the ET302 accident, Boeing informed the NTSB they had made an engineering design error in their initial AOA Sensor Hazard Analysis; Neither Boeing, the NTSB, nor the FAA informed Ethiopian authorities about this critical error that was communicated to the NTSB by Boeing seven months earlier.

FAA Oversight

According to a 2011 Office of Inspector General Audit report[42], "the FAA is responsible for overseeing numerous aviation activities designed to ensure the safety of the flying public. Recognizing that it is not possible for FAA employees to personally oversee every facet of aviation, public law allows FAA to delegate certain functions, such as approving new Airplane designs, to private individuals or organizations (approved by the FAA). Designees perform a substantial amount of critical work on FAA's behalf—for example, at one Airplane manufacturer, they made about 90 percent of the regulatory compliance determinations for a new Airplane design. FAA created the Organization Designation Authorization (ODA) program in 2005 to standardize its oversight of organizational designees."

According to FAA Order 8100.15A, 49 CFR 44702(d) allows the FAA to delegate to a qualified private person a matter related to issuing certificates, or related to the examination, testing, and inspection necessary to

[42] Reference Office of Inspector General Audit Report, AV-2011-136, issued on June 29, 2011

issue a certificate on behalf of the FAA Administrator as authorized by statute to issue under 49 CFR 44702(a).

Boeing applied for and was granted ODA. Boeing's ODA is authorized to select and appoint individuals to perform some of the delegated functions as representatives of FAA. The delegated functions for a Type Certification (TC) ODA are:

- establishing and determining conformity of parts, assemblies, installations, test setups, and products (Airplane);
- finding compliance with airworthiness standards for new design, or major changes to design;
- issuing special flight permits for operation of Airplane;
- issuing issues airworthiness approvals for articles (Export), and Airplane (Standard or Export)

Retention and delegation are accomplished with respect to compliance deliverables not to specific functions i.e., MCAS itself would not be delegated to the ODA.

Consistent with the FAA authorization, the FAA have discretionary authority as to what is reviewed, whether submitted directly to the FAA for review and approval by an applicant or submitted by a designee or ODA recommending approval.When delegating at the end of a program, there has been some level of FAA involvement and the delegation confirms that the designee should make the final approval. In all cases, delegation is not accomplished by a single individual but follows a structured review process.

In the accident flight crew response assumptions in the initial design process which, coupled with the repetitive MCAS activations, turned out to be incorrect and inconsistent with the FHA classification of Major.

FAA Regulation

The Federal Aviation Administration (FAA) is responsible for prescribing minimum standards required in the interest of safety for the design, material, construction, quality of work, and performance of Airplane, Airplane engines, and propellers (Ref. 49USC44701). Product certification is a regulatory process administered by the FAA to ensure that an Airplane manufacturer's product conforms with Federal Aviation Regulations (FAR). Successful completion of the certification process enables the FAA to issue a Type Certificate (TC) or an Amended Type Certificate.To obtain a TC or an Amended Type Certificate, the manufacturer must demonstrate to the FAA that the Airplane or product being submitted for approval complies with all applicable regulations. The FAA determines whether or not the applicant has met its responsibility to show compliance to the applicable regulations.

The Federal regulations that apply to type certification of transport-category Airplanesare 14 CFR Part 21, 25, 26, 33, 34, and 36. The Part 25 regulations are those concerned with the airworthiness standards for transport-category Airplanesand are organized into sub parts A through G. These regulations represent the minimum standards for airworthiness; an applicant's design may exceed these standards and the applicant's tests and analyses may be more extensive than required by regulation. The specific applicable regulatory requirements and how compliance will be demonstrated is documented in an FAA approved certification plan.

3. CONCLUSIONS

3.1Findings

Findings are statements of all significant conditions, events or circumstances in the accident sequence. The findings are significant steps in the accident sequence, but they are not always causal, or indicate deficiencies. Some findings point out the conditions that pre-existed the accident sequence, but they are usually essential to the understanding of the occurrence, usually in chronological order (ICAO Doc 9756 Part IV paragraph 3.1).

1. TheAirplane departed from Addis Ababa Bole International Airport bound to Nairobi, Kenya Jomo Kenyatta International Airport with 157 crew and passengers on board;

2. The flight crew members were licensed and qualified for flight in accordance with the existing ECARAS part 2; 2.3.6.
3. The captain was the pilot flying;

4. The Airplane has a valid certificate of airworthiness and maintained in accordance with applicable regulations and procedures;

5. The Airplane weight and balance was within the operating limits;

6. The Airplane took-off from runway 07R at field elevation of 7,656 ft with a flap setting of 5 degrees and a stabilizer trim setting of 5.6 units. Both flight directors (F/D) were ON with LNAV and VNAV modes armed. Auto throttle (A/T) was armed;

7. The takeoff roll and liftoff were normal, including normal values of left and right angle of attack (AOA). During takeoff roll, the engines stabilized at about 94% N1, from this point for most of the flight, the N1 reference remained at about 94%;

8. Shortly after liftoff, the left and right recorded AOA values deviated. The left AOA values were erroneous and reached 74.5° while the right AOA reached a Maximum value of 15.3°.The difference between the left and the right AOA values was 59° and near the end of the recording it was 49^0;

9. Immediately afterlift-off, the left stick shaker activated and remained active until the near end of the recording. It was followed by a Master Caution with the associated Anti-Ice messageon the MCP;

10. IAS, ALT DISAGREE alerts were not recorded in the FDR, but the time of appearance has been computed, as per computation, the IAS disagree alert should normally have triggered at 5 h 38 min 49 s, and stopped at 5 h 43 min 28 s; and no recording of the pilot's conversation about the alerts appearing on the PFD. This has led to uncertainty about the appearance of alerts and the crew who thus did not apply the Airspeed Unreliable Non-Normal Check-list;
11. As per computation, the ALT disagree alert should have triggered at 5 h 38 min 51s and stopped at 5 h 43 min 28s and it might have triggered again at 5 h 43 min 36s during 4s;
12. While the loss of valid FMC command did not trigger any alert or mode reversion, the underlying cause (erroneous AOA) should have triggered the IAS DISAGREE and ALT DISAGREE alerts, but from the manufacturer's computations, conditions were met for the IAS DISAGREE and ALT DISAGREE alerts to appear on both PFD's;
13. Erroneous AOA Sensor data ultimately triggered the Maneuvering Characteristics Augmentation System (MCAS) which repeatedly pitched the nose of the airplane down until the pilots lost control. Compounding factors included the pilots lack of awareness and training associated with MCAS, confusing alerts, and the startle factor.
14. During the event flight, A/T was engaged in the automatic takeoff sequence and due to the erroneous LH AOA values the FMC did not detect the thrust reduction altitude when it was sending valid engine commands;
15. Approaching 400ft, the Captain called-out "*command*" and tried to engage the AP. At that time the FD pitch bars were out of view;

16. A second attempt to engage the A/P was made six seconds later, above 500 ft. Passing 1000 ft/radio altitude, at the third attempt, the A/P was successfully engaged;

17. Although, the use of auto flight system in most non-normal scenarios would help reduce crew workload and give more time for the crew to analyse the situation, it was not consistent with the procedure to use

it with an ongoing stick shaker. It was identified from the CVR that the flight crew did not discuss any issue related to the stick shaker;

18. The crew was faced with unprecedented change of events shortly after lift-off which significantly increased crew workload;
19. MCAS design on a single AOA inputs made it vulnerable to undesired activation. Its repetitive activation of nose down stabilizer trim made the aircraft uncontrollable;
20. Post-accident analysis reveals new Airplane experienced unexplained electrical and electronic faults within weeks of entering service, and in the weeks and days prior to their accidents;
21. During the previous maintenance actions of relevance occurred in early December 2018 and involved several write-ups involving temporary fluctuations of vertical speed and altitude as well as a report of the Airplane rolling during autopilot operation. Prior to the accident flight, Altitude and vertical speed indication on the PFD showed an erratic and exaggerated fluctuation indication; maintenance actions were performed and none were reported to have recurred; however, the erratic and intermittent nature of the fluctuations made it difficult to insure a permanent solution of these parameters.
22. While the autopilot was engaged, systems were supplied by the erroneous LH AOA values. The A/P failed to fly to the target altitude resulting in accelerated speed. After reaching a maximum altitude of around 9,100 ft (right baro corrected altitude) the Airplane started to descend;
23. The A/P disconnected automatically after remaining engaged for 32 seconds;
24. The activation of MCAS followed by GPWS aural alert with ongoing stick shaker, coupled with no failure flag or warning to indicate that the auto throttle has failed to transition to climb thrust at the critical phase of flight indicate that multiple happenings taking place simultaneously because of the overlapping effects of the erroneous AOA inputs;
25. The Stall Management Yaw Damper Computer -1 (SMYDC 1) computed a LH minimum operational speed and a LH stick shaker speed greater than VMO (340Kt) without any alert or invalidity detection;
26. As the flaps reached the up position with the autopilot OFF and because of the erroneous left AOA value, the FCC activated the 1st automatic nose down trim (MCAS) for 9 seconds;
27. At the end of the first MCAS activation; the stabilizer position was 2.1 units with the PF pulling to pitch up the Airplane , with a force of around 90lbs;
28. At different times when the pilot applied electrical trim for short duration or longer duration the trim stopped at about 2.3 for unknown reason;

29. The 2nd MCAS activation, lasted 7 seconds as it was interrupted by the captain's electric trim up inputs which stopped the second automatic nose-down trim activation two seconds (automatic nose-down trim activated for around 7 s instead of 9 s);

30. The captain applied a 9 second electric trim-up input; this trim input fully counteracted the second MCAS input and stopped the GPWS warning but it did not bring the aircraft to a neutral trim for unknown reason;

31. When MCAS activated for the third time, an automatic nose-down trimwas commanded by the FCC.There was no corresponding motion of the stabilizer, which is consistent with the stabilizer trim cutout switches being in the ''cutout'' position;

32. The captain repeatedly requested the F/O to pull up with him. Both pilots applied high force on the control column. Pitch values oscillated between 7° nose up and -2° nose down. Pitch increased when both pilots applied forces, pitch decreased when a single pilot applied force (force oscillated between 80 lbs and 110 lbs). The vertical speed variations followed the variations of the pitch angle, with vertical speed was oscillating between -2,500 ft/min and 4,400 ft/min;

33. The right hand speed exceeded 340Kt and overspeed warning sounded.It remained active until the end of the recording. The RH speed values varied between 360Kt and 375Kt (RH values). The LH computed airspeed oscillated between 335Kt and 350Kt;

34. The captain requested the F/O to try the manual trim wheel, andafter seconds of intenseefforts (identified on the CVR), the F/O told the Captain that it was not working;

35. The amount of force required to turn the trim wheel by the pilots was calculated and verified in the simulator and flight control test rig (FCTR) that it was difficult to achieve the required trim effect ;

36. Simulator observation has revealed the force required to turn the manual trim during the event flight to be significantly high at different speed ranges from a high speed of 340Kt to a low speed of 220Kt;

37. The effect of airspeed indication giving the pilot two different warnings, i.e. dangerously low airspeed indicated by stick shaker, minimum manoeuvring band above current airspeed versus high airspeed indicated by the numbers in the speed tape was a point of concern for crew; have occurred simultaneously which has an effect on the pilot's cross checking;

38. The amount of force required to trim to neutral position both at high and low speed was found to be excessive during level D simulator and FCTR tests;

39. One unit of trim change requires 15 full turns and about 40 turns were required to bring the accident aircraft to neutral trim by using the manual trim wheel;
40. The captain asked the first officer to pitch up with him, and both flight crew members kept on pulling on the control columns with very intense efforts with intention to climb to the MSA (14,000 ft);
41. After unsuccessful attempt to use the manual trim wheel and while both crew members were pulling on the control column with an average force of about 110lbs, the captain told the first officer "pitch is not enough" Then the captain said "put them up". The FDR and CVR data synchronization was concurrent with the stab trim cut-out switches being returned to normal at this time;
42. The Captain applied two brief electric trim up inputs of 1 second each while pulling on the control column with an average force of 100 Lbs;
43. Five seconds after the trim-up inputs, the fourth MCAS triggered; the Airplane started to descend and the stabilizer decreased from 2.3 units to 1 unit of trim;
44. The Captain repeatedly commanded loudly to pitch up,the forces were physically unmanageable by both flight crew members; due to this there were sounds of exhaustion and shortness of breath were heard in the CVR;
45. The Airplane hit the ground eighteen seconds after the end of the 4th MCAS;
46. The Airplane was destroyed during the impact and all crew members and passengers onboard were fatally injured;
47. The FCC controlling the MCAS is dependent on a single AOA source and the MCAS contribution to cumulative AOA effects have not been assessed by the manufacturer during the functional hazard assessment;
48. Functional Hazard Assessment of MCAS considered the effect of undue activation of MCAS on flight controls. It did not consider the possible effect of underlying root causes on other systems, displays and warnings. Introduction of MCAS function did not lead to revisit the SSA for failures of AOA sensors;
49. There was CBT training for a few hours long which was supposed to cover the difference between MAX and NG but there was no information related to MCAS description in the CBT;
50. MCAS and the lack of pilot training did not trigger the accident; however it was the failure of the sensors due to the production quality defects. If the intermittent defects did not cause the AOA Sensors to fail on the accident flight, MCAS would not have activated, and the accident would not have occurred. The MCAS

would have remained as hidden threat until its true nature is exposed by some other valid or erroneous causes;

51. There was no information related to MCAS either in the FCOM provided by Boeing or in the AFM ;
52. The error of omission is that Boeing failed to disclose early and attentively the existence of MCAS to the operators;
53. During the whole flight, the multiple alerts (Stick shaker, clackers, warning lights, sounds) combined with the repetitive activation of the MCAS impacted the Crew Resource Management and increased the workload of the situation onboard;
54. The failure of originally installed and tested Boeing AOA Sensor parts associated with fatal plane crashes likely involving an open circuit, wire fatigue, evidence of multiple arcing events, unexplained electrical/electronic anomalies, and the loss of heater power;
55. Boeing has never acknowledged the electrical malfunctions that occurred on both MAX airplanes in the months, weeks, and days leading up to their accidents before MCAS was activated on their fatal flights;
56. Stress and startle effects were not considered by the manufacturer when trying to understand how crew might respond to the effects of an AOA sensor fault and the erroneous activation of MCAS;
57. The Captain's priority remained to control the Airplane, which is in line with flight crew training manual (FCTM) guideline and training at Ethiopian Airlines regarding the prioritization of tasks in case of failure on board;
58. Repetitive MCAS activation made airplane control difficult and did not give time for the flight crew to proceed with further steps of task prioritization;
59. During the preliminary design stage of the 737 MAX8, Boeing tests and analysis revealed that the addition of the LEAP-1B engine and associated nacelle changes produced an Airplane nose-up pitching moment when the Airplane was operating at high angles of attack (AOA) and mid-Mach numbers;
60. The B737MAX design included **aerodynamic**changes as well as a stability augmentation function called the Maneuvering Characteristics Augmentation System (MCAS)MCAS modifies aircraft handling characteristics as an additional function of the existing Speed Trim System (STS) ; to improve Airplane handling characteristics and decrease pitch-up tendency at elevated angles of attack;
61. MCAS was designed to function only during manual flight, with the Airplane's flaps up, at an elevated AOA; but it was later discovered that, the MCAS function was expanded to low Mach numbers;

62. MCAS is a function within the Speed Trim System and when activated, moves the stabilizer during flaps up, high angle of attack maneuvers to provide a desirable increase in stick force gradient and improve static longitudinal stability;

63. The manufacturer did not provide the operator with information and alerts related to MCAS to help them understand the system and know how to resolve potential issues;

64. Boeing has never discussed this AOA Sensor electrical design error publicly, did not inform the EAIB about this error either. A loss of power can be a symptom of a EWIS failure, power quality issue and/or a defect inside the AOA Sensor;

65. The AOA Sensor malfunction likely occurred as the result of power quality problem that resulted in the loss of power to the left AOA Sensor Heater. Evidence indicates that the loss of power was likely due to a production related intermittent electrical/electronic failure involving the airplane's Electrical Wiring Interconnection System (EWIS) and the AOA Sensor part;

66. In March 2016, Boeing determined that MCAS should be revised to improve wings-level, flaps up, low Mach stall characteristics and identification. The MCAS was revised such that depending on AOA, it would be capable of commanding incremental stabilizer to a Maximum of 2.5 degrees at low Mach decreasing to a maximum of 0.65 degrees at high Mach;

67. Uncommanded MCAS function was considered "Major"instead of being categorized as "Catastrophic" during the fault hazard assessment (FHA) by Boeing. Boeing reasoned that such a failure could be countered by using the elevator alone. In addition, stabilizer trim is available to offload column forces, and stabilizer cutout is also available but not required to counter failure. But the associated failures and flight deck effects were not considered in reaching this assessment;

68. During validation, Boeing considered MCAS activation could occur as a result of erroneous AOA but did not test repetitive erroneous MCAS activations in a flight simulation;

69. When Uncommanded MCAS function was considered "Major," Boeing did not perform a specific fault tree analysis for an uncommanded MCAS hazard and failed to classify MCAS as a safety-critical system, which would have attracted greater FAA analysis during the certification process;

70. The control column force to maintain level flight could eventually increase to a level where control forces alone may not be adequate to control the Airplane. The cumulative mistrim could not be countered by using the elevator alone which was contrary to the Boeing assumption during FHA. The events that led to the accident flight showed that in the event of repetitive MCAS activation without

sufficient trim commands to return to trimmed flight, the cumulative mistrim could not be countered by using elevator alone;

71. When MCAS authority was increased to 2.5 degrees at low speed, Boeing's requirements document indicated that the preliminary functional hazard assessments of MCAS were re-evaluated by pilot assessments in motion simulator and by engineering analysis and determined to have not changed in hazard classification of "Major";

72. Boeing's consideration regarding crew action to meet MCAS did not consider the cumulative effect of different flight deck alerts and warning as in the accident flights;

73. On ET 302 accident, the system failure led to a complicated series of events and flight crew response did not match the assumptions used in the initial design process upon which the FHA classification of Major was based;

74. The specific failure modes that could lead to uncommanded MCAS activation, such as an erroneous high single AOA input to the MCAS, were not simulated as part of the functional hazard assessment validation tests. As a result, additional flight deck effects (such as IAS DISAGREE and ALT DISAGREE alerts and stick shaker activation) resulting from the same underlying failure (for example, erroneous AOA) were not simulated and were not documented in the stabilizer trim and autoflight safety assessment;

75. A single AOA failure resulted in many failures and warnings to happen at the same time and MCAS which was dependent on single AOA kept pushing the airplane's nose down based on faulty data, which led to catastrophic consequences;

76. To obtain a type certification (TC) or an Amended Type Certificate, the manufacturer demonstrate to the FAA that the Airplane or product being submitted for approval complies with all applicable regulations, but there was no evidence that Boeing has complied with;

77. MCAS was added on the 737 MAX to address potentially unacceptable nose-up pitching moment at high angles of attack at high airspeeds; there was no mention that MCAS had been revised to improve flaps up, low Mach tall characteristics and identification.

78. MCAS would never have activated repeated nose down trim if the flaps were still left down, even in the presence of erroneous AOA. This critical information was not included in the FCOM bulletin or in the airworthiness directive;

79. The absence of MCAS description in the FCOM, in the flight crew training manual, and the absence of an AOA indicator made it difficultfor the flight crew to identify the problem on the accident Airplane and find the corrective measure to solve;

80. Boeing and FAA released FCOM bulletin ETH-12 on November 6, 2018 and FAA AD# 2018-23-51 on November 7, 2018 respectively. Both documents were incorporated in the Ethiopian airlines FCOM and AFM per the instruction therein;

81. The ECAA issued AD #2018-23-51 dated 08 Nov, 2018 to advise the operator to revise and implement its AFM and operating procedures and report to the authority within the specified time. The operator confirmed to the ECAA that it has complied with the instruction;

82. The FAA's AD and Boeing Bulletin released after Lion Air accident focused only on RUNAWAY STABILIZER;

83. The emergency AD pilot procedures were inadequate and unverified. AD 2018-23-51 does not mention the possibility of an auto throttle malfunction due to an erroneous AOA input;

84. The data from the flight data recorders, as summarized in reports of the Ethiopian Airlines Flight 302 accident and the Lion Air Flight 610 accident, indicated that if a single erroneously high AOA sensor input is received by the flight control system, the maneuvering characteristics augmentation system (MCAS) can command repeated Airplane nose-down trim of the horizontal stabilizer. This unsafe activation of the MCAS made the Airplane uncontrollable that led to excessive Airplane nose-down attitude, significant altitude loss, and impact with terrain;

85. After, the ET 302 accident the Ethiopian Civil Aviation Authority as per ECARAS part 8, section 8.2.1.2 (a) notified that the Ethiopian Airlines Group that all Boeing 7373MAX-8 fleet of Airplane grounded and was not allowed making commercial flights effective March 11, 2019;

86. The difference training from B737NG to B737MAX provided by the manufacturer was found to be inadequate;

87. Post Lion Air accident and prior to ET-302 accident, Ethiopian Airlines training department communicated to Boeing requesting clarification on the MCAS design and the operational procedures of the FCOM bulletin regarding checklist prioritization and whether run-away stabilizer checklist was enough to handle the situation and the need to include airspeed unreliable checklist.In its reply, Boeing did not answer all asked questions made by Ethiopian airlines training department, indicating that it was related to an ongoing Lion Air accident investigation;

88. The investigation found the questions raised by the airline to be safety critical and if Boeing had answered the questions raised by the training department either directly or indirectly through a revision of the FCOM bulletin or a suggested training, it would have significantly altered the outcome.

3.2Probable cause of the accident

Repetitive and uncommanded airplane-nose-down inputs from the MCAS due to erroneous AOA input, and its unrecoverable activation system which made the airplane dive with the rate of -33,000 ft/min close to the ground was the most probable cause of the accident.

3.3 Contributing Factors

1. The MCAS design relied on a single AOA sensor, making it vulnerable to erroneous input from the sensor;
2. During the design process, Boeing failed to consider the potential for uncommanded activation of MCAS, but assumed that pilots would recognize and address it through normaluse of the control column, manual electric trim, and the existing Runaway Stabilizer NNC. The OMB and Emergency AD issued after the Lion Air accident included additional guidance but did not have the intended effect of preventing another MCAS-related accident;
3. While Boeing considered the possibility of uncommanded MCAS activation as part of its FHA, it did not evaluate all the potential alerts and indications that could accompany a failure leading to an uncommanded MCAS;
4. The MCAS contribution to cumulative AOA effects was not assessed;
5. The combined effect of alerts and indications that impacted pilot's recognition and procedure prioritization were not evaluated by the Manufacturer;
6. Absence of AOA DISAGREE warning flag on the flight display panels (PFD);
7. The B737 MAX Crew difference CBT training prepared by Boeing and delivered to Pilots did not cover the MCAS system;
8. Failure by the manufacturer to design simulator training for pilots with regards to safety critical systems like MCAS with catastrophic consquences during undesired activation.
9. The manufacturer failed to provide procedures regarding MCAS operation to the crew during training or in the FCOM;

10. Failure by the manufacturer to address the safety critical questions raised by the airline which would have cleared out crew confusion and task prioritization;

4. SAFETY RECOMMENDATIONS

4.1 New Safety Recommendation

The EAIB identified safety issue that need to be considered, it is therefore recommended to address safety issues identified in this report and consider the safety actions were relevant to improve safety, and encourage the implementation of these safety actions. The EAIB also considered the action taken and put the responses under the recommended actions.

1. Multiple alerts, stick shaker, repetitive MCAS activations impacted the flight crew understanding of the situation on board and didn't enable them to handle the flight efficiently;This obscured the problem andthe flight crew could not arrive at a solution during the initial or subsequent automatic AND stabilizer trim input.

Therefore, the EAIB recommends that the Airplane manufacturer consider the effect of all possible flight deck alerts and indications on flight crew recognition and response; and incorporate design, flight crew procedures, and/or training requirements where needed to minimize the potential for flight crew actions that are inconsistent with manufacturer assumptions.

2. There was CBT training for a few hours long which were supposed to cover the difference between MAX and NG but there was no information related to MCAS description in the system. Instead, It was advised that the Airplane has wide and moved a bit forward body, Size of the Engine which is 84" and the height of the nose gear about 5.6" high.

The EAIB recommend that the manufacturer providesufficient time and adequate training associated witha new MCAS description in the system.

3. The specific failure modes that could lead to uncommanded MCAS activation, such as an erroneoushigh angle from a single AOA input to the MCAS, were not simulated as part of the functional hazard assessment validation tests. As a result, additional flight deck effects (such as IAS DISAGREE and ALT DISAGREE alerts and stick shaker activation) resulting from the same underlying failure (for example, erroneous AOA) were not simulated and documented in the stabilizer trim and autoflight safety assessment;

The EAIB recommends that the Boeing to reconsider the design of the system in such a way that AOA data input from both sensors (LH&RH)are received and analyzed by FCC before sending any command to MCAS.

4. Without descriptive MCAS awareness of the function and its effect, it would be more difficult for the flight crew to understand the complexity. Instead of focusing on the runaway stabilizer in the AD, the crewwould have been aware of MCAS which would have provided them with better understanding of the system and raise their chances of mitigating consequences of repetitive MCAS activations in the accident flight.

The EAIB recommendsthat Boeing instead of runaway stabilizer provide MCAS description and advise how to mitigate MCAS duringrepetitive AND command;

5. FHA of MCAS was considered the effect of undue activation of MCAS on flight controls, but it did not consider possible effect of underlying root causes on other systems, displays and warnings. Introduction of MCAS function did not lead to revise the SSA for failures of AOA sensors.

The EAIB recommends that the FAA to review all probable causes of failure which have been considered during functional hazard assessment.

6. The data from the flight data recorders, as summarized in reports of the ET 302 accident and the Lion Air Flight 610 accident, indicated that if a single erroneously high AOA sensor input is received by the flight control system, MCAS can command repeated Airplane nose-down trim of the horizontal stabilizer. This unsafe condition, if not addressed, could cause the flight crew to have difficulty controlling the Airplane , and lead to excessive Airplane nose-down attitude, significant altitude loss, and impact with terrain;

The EAIB recommends that the manufacturer put awareness for the effect of a single erroneously high AOA sensor input is received by the flight control system, the MCAS can command repeated Airplane nose-down trim of the horizontal stabilizer which leads to excessive Airplane nose-down attitude, significant altitude loss, and impact with terrain**;**

7. Ethiopian Civil Aviation Authority

The HAAB Airport emergency plan was applied as soon as the accident occurred but the required rescue team did not deploy soon after the accident, however the Abyssinian flight service and Ethiopian Air force helicopter seized action for rescuing the site.

The EAIB recommends that: The Civil Aviation Authority should dispatch a Search and Rescue team without delay and ensure appropriate action is taken at the accident site.

8. The Operator/ Ethiopian Airlines Group

The critical statement that was omitted from the AD was the flap position. MCAS operates only when the flap is fully up. Following the issuance of this AD, the ETH asked clarification from Boeing via email whether they should do airspeed unreliable procedures first. The response they got was that Boeing could not make further comments as the case was under investigation.

The EAIB recommends that: The ETH to initiate and develop procedure for continuous monitoring, follow up, and obtain clarification for asked questions in timely manner.

4.2. EAIB Interim Report Safety Recommendations

1. The design of MCAS should consider the use of data from both AOA and/or other independent systems for redundancy.

2. The regulator shall confirm all probable causes of failure have been considered during functional hazard assessment.

3. The manufacturer shall insure the minimum operational speed computed by the SMYD to be within logical value. There should also be logic to validate the computation.

4. The difference training should also include simulator sessions to familiarize with normal and non-normal MCAS operation. The Training simulators need to be capable of simulating AOA failure scenarios;
5. The manufacture should confirm the AOA DISAGREE alert is functional whether the optional angle of attack indicator is installed or not.

4.3. Boeing Responses to “EAIB Interim Report” Recommendations

1. The design of MCAS should consider the use of data from both AOA and/or other independent systems for redundancy.

Response to Recommendation 1:

In November 2020, Boeing published Service Bulletin 737-22A1342 which provides Flight Control Computer (FCC) Operational Program Software (OPS) version P12.1.2 for 737-8 and 737-9 airplane FCC OPS P12.1.2 incorporates several enhancements to the Speed Trim System, specifically to the Maneuvering Characteristics Augmentation System (MCAS) function. MCAS can only be activated while flaps up, autopilot disengaged and operating at elevated AOA. MCAS inputs incremental nose down stabilizer trim as a function of Mach and AOA to provide an increased column force gradient at elevated AOA.

The enhancements include AOA signal monitoring (from both AOA sensors), activation and stabilizer resynchronization logic, Maximum command limit and flight deck alerting. These enhancements provide additional functionality to prevent erroneous MCAS activation and ensure sufficient maneuver capability is provided in the event of multiple MCAS activations.

In November 2020, the FAA published Airworthiness Directive 2020-24-02 which requires operators to install FCC OPS P12.1.2 in accordance with Boeing SB 737- 22A1342.

2. The regulator shall confirm all probable causes of failure have been considered during functional hazard assessment.

3. The manufacturer shall insure the minimum operational speed computed by the SMYD to be within logical value. There should also be logic to validate the computation.

Boeing's response dated 13 January 2021

In November 2020, the FAA published Airworthiness Directive 2020-24-02 which set forth the requirements for the 737-8 to return to service. These requirements included software updates to both the Flight Control Computer (FCC) and the MAX Display System (MDS). Boeing is undertaking further safety enhancements to the 737-8 to reduce the workload which can arise as a result of erroneous angle-of-attack (AOA).

This work will involve additional AOA validity checks within the Air Data Inertial Reference Unit and the Stall Management Yaw Damper (SMYD). As part of this enhancement, the SMYD software will be updated to include specific checks on the minimum operational speed computed by the SMYD and used by the auto flight system. This work will be completed in conjunction with certification of the 737-10.

4. The difference training should also include simulator sessions to familiarize with normal and non-normal MCAS operation. The Training simulators need to be capable of simulating AOA failure scenarios.

Boeing's response dated 13 January 2021:

On 16 November 2020, The FAA published revision 17 to the B-737 Flight Standardization Board Report. This document, which was result of the FAA Airplane Evaluation Groups working with Boeing, provides flight crew member training, checking, and currency requirements.

The revision includes a new Appendix 7 which describes ground and flight training requirements associated with pilot qualification on the 737 MAX, including Level C or D Full Flight Simulator training. As noted in the appendix:

No pilot may operate the 737 MAX unless the ground and flight training documented in this appendix has been completed. References to "pilots" in this section include both PICs and SICs unless otherwise specified.

MCAS operation familiarization is required by paragraph 2.1:

2.1 Demonstration of MCAS activation accomplished by a pilot acting as PF.

Enclosure to 66-ZB-H200-ASI-19199

Response to Safety Recommendations #1 and #4 from Interim Report

Ethiopian Airlines 737-8 ET-AVJ Accident, Ejere, Ethiopia, 10 March 2019

2.1.1 MCAS activation during an impending stall (or full stall) and recovery demonstration during manual flight in a clean configuration.

2.1.2 Demonstrate MCAS activation stabilizer trim responses: Stabilizer trim in the nose down direction when above threshold AOA for MCAS activation during stall. Stabilizers trim in the nose up direction when below threshold AOA for MCAS activation during recovery

Paragraph 2.5 of Appendix 7 requires familiarization with erroneous high AOA during takeoff. This is the scenario which occurred during the ET302 accident, however, with the installation of FCC OPS P12.1.2, erroneous high AOA no longer leads to non-normal MCAS operation.

2.2. Erroneous high AOA during takeoff that leads to an unreliable airspeed condition accomplished by either pilot acting as PF.

2.2.1. Demonstrates flight deck effects (i.e., aural, visual, and tactile) associated with the failure.

2.2.2. Fault occurring during the takeoff procedure.

2.2.3 Must include a go-around or missed approach flown with erroneous highAOA condition

Special emphasis placed on FD behavior biasing out of view upon selecting takeoff/go-around (TO/GA).

5. The manufacture should confirm the AOA DISAGREE alert is functional whether the optional angle of attack indicator is installed or not.

In June 2020, Boeing published Service Bulletin 737-31-1860 which provides MAX Display System (MDS) Blockpoint (BP) 1.5.1 software for 737-8 and 737-9 airplane. In prior MDSBP versions, the Angle of Attack Disagree (AOA DISAGREE) alert message on the Primary Flight Display (PFD) was dependent on the activation of the AOA Round Dial display option. MDS BP 1.5.1 includes a revision to the display of the AOA DISAGREE alert message on the PFD to be independent of the AOA Round Dial option.

In November 2020, the FAA published Airworthiness Directive 2020-24-02 which requires operators to install MDS BP 1.5.1 in accordance with Boeing SB 737-31-1860.

4.4. Safety Actions Taken After the Lion Air Accident in Indonesia

On **6 November 2018**, Boeing issued a Flight Crew Operation Manual Bulletin (OMB) Number TBC-19 with subjected Un-commanded Nose down Stabilizer Trim Due to Erroneous Angle of Attack (AOA) During Manual Flight Only to emphasize the procedures provided in the runaway stabilizer non-normal checklist (NNC). The detail of the FCOM Bulletin (see *appendix A)*

Information in this bulletin is recommended by The Boeing Company, but may not be FAA approved at the time of writing. In the event of conflict with the FAA approved Airplane Flight Manual (AFM), the AFM shall supersede. The Boeing Company regards the information or procedures described herein as having a direct or indirect bearing on the safe operation of this model Airplane.

November 7, 2018 Emergency Airworthiness Directive (AD) 2018-23-51 was sent to owners and operators of the Boeing Company Model 737-8 and -9 Airplane s. (See *Appendix B)*

This emergency AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. This condition, if not addressed, could cause the flight crew to have difficulty controlling the Airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

This AD was issued in accordance with authority delegated by the Executive Director, Airplane Certification Service, as authorized by FAA Order 8000.51C. In accordance with that order, issuance of ADs is normally a function of the Compliance and Airworthiness Division, but during this transition period, the Executive Director has delegated the authority to issue ADs applicable to transport category Airplanesand associated appliances to the Director of the System Oversight Division.

- **Nov 08, 2018** The ECAA issued AD 2018-23-51 which was released by FAA on November 07, 2018 applicable for 737 MAX-8, 9 Airplane s. The operator was advised to revise its AFM and operating procedures. The ECAA advised the operator implementing the AD and report to the authority within the specific time provided and this was confirmed by the operator response that has been done accordingly, the details is available on (see *appendix C)*
- On **11 November 2018**, Boeing informed all 737NG/MAX Costumers, Regional Directors, Regional Managers and Boeing Field Service Bases via a Multi Operator Messages (MOM) detailing the MCAS Charasteristics.The details of the MOM (see *appendix D)*

4.5. Safety Actions Taken After the ET 302 Accident

March 11, 2019 after, the ET 302 accident the Ethiopian Civil Aviation Authority as per ECARAS part 8, section 8.2.1.2 (a) notified that the Ethiopian Airlines Group that all Boeing 7373MAX-8 fleet of Airplane grounded and was not allowed making commercial flights effective March 11, 2019. The detail of is available (see *appendix E)*

- **March 12, 2019** European Union Aviation Safety Agency declared Boeing 737-8 MAX and 737-9 MAX suspension of flight Operations.

Required Action(s) and Compliance Time(s):

From the effective date and time of this SD, do not perform commercial air transport operations with Boeing 737-8 'MAX' or Boeing 737-9 'MAX' into, within or out of the territory subject to the provisions of the Treaty on European Union. The detail of MAX suspension of flight Operations (see Appendix F)

- **March 13, 2019** with the potential relationship established between the two accidents, the FAA issued an Emergency Order of Prohibition (see Appendix **G** grounding 737 MAXAirplane.

In November 2020, Boeing published Service Bulletin 737-22A1342 which provides Flight Control Computer (FCC) Operational Program Software (OPS) version P12.1.2 for 737-8 and 737-9 Airplane. FCC OPS P12.1.2 incorporates several enhancements to the Speed. Trim System, specifically to the Maneuvering Characteristics Augmentation System (MCAS) function. MCAS can only be activated while flaps up, autopilot disengaged and operating at elevated AOA. MCAS inputs incremental nose down stabilizer trim as a function of Mach and AOA to provide an increased column force gradient at elevated AOA.

The enhancements include AOA signal monitoring (from both AOA sensors), activation and stabilizer resynchronization logic, Maximum command limit and flight deck alerting.

These enhancements provide additional functionality to prevent erroneous MCAS activation and ensure sufficient maneuver capability is provided in the event of multiple MCAS activations.

On November 2020, the FAA published Airworthiness Directive 2020-24-02 which requires operators to install FCC OPS P12.1.2 in accordance with Boeing SB 737-22A1342.

On 16 November 2020, The FAA published revision 17 to the B-737 Flight Standardization Board Report. This document, which was result of the FAA Airplane Evaluation Groups working with Boeing, provides flight crew member training, checking, and currency requirements.

The revision includes a new Appendix 7 which describes ground and flight training requirements associated with pilot qualification on the 737 MAX, including Level C or D Full Flight Simulator training. As noted in the appendix;

No pilot may operate the 737 MAX unless the ground and flight training documented in this appendix has been completed. References to “pilots” in this section include both PICs and SICs unless otherwisespecified.

MCAS operation familiarization is required by paragraph 2.1:

2.1 Demonstration of MCAS activation accomplished by each pilot acting as PF.

2.1.1 MCAS activation during an impending stall (or full stall) and recovery demonstration during manual flight in a clean configuration.

2.1.2 Demonstrate MCAS activation stabilizer trim responses:

- Stabilizer trim in the nose down direction when above threshold AOA for MCAS activation during stall.
- Stabilizer trim in the nose up direction when below threshold AOA for MCAS activation during recovery

Paragraph 2.5 of Appendix 7 requires familiarization with erroneous high AOA during takeoff. This is the scenario which occurred during the ET302 accident, however, with the installation of FCC OPS P12.1.2, erroneous high AOA no longer leads to non-normal MCAS operation.

2.5 Erroneous high AOA during takeoff that leads to an unreliable airspeed condition accomplished by either pilot acting as PF.

2.5.1 Demonstrates flight deck effects (i.e., aural, visual, and tactile) associated with the failure.
2.5.2 Fault occurring during the takeoff procedure.
2.5.3 Must include a go-around or missed approach flown with erroneous high AOA condition
2.5.3.1Special emphasis placed on FD behavior biasing out of view upon selecting takeoff/go-around (TO/GA).

4.6. NTSB Recommendations to FAA

On 19th September 2019, the U.S NTSB Board issued seven Safety Recommendations during the course of the investigations led by Indonesia and Ethiopia on the B 737 MAX accidents. These recommendations mainly focused on the US design certification process used to approve the original design of the Maneuvering Characteristics Augmentation System (MCAS) on the Boeing 737 MAX.

Require that Boeing (1) ensure that system safety assessments for the 737 MAX in which it assumed immediate and appropriate pilot corrective actions in response to uncommanded flight control inputs , from systems such as the Maneuvering Characteristics Augmentation System, consider the effect of all possible flight deck alerts and indications on pilot recognition and response; and (2) incorporate design enhancements (including flight deck alerts and indications), pilot procedures, and/or training requirements, where needed, to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions. **(A-19-10)**

Require that for all other US type -certificated transport-category Airplane s, manufacturers (1) ensure that system safety assessments for which they assumed immediate and appropriate pilot corrective actions in response to uncommanded flight control inputs consider the effect of all possible flight deck alerts and indications on pilot recognition and response; and (2) incorporate design enhancements (including flight deck alerts and indications), pilot procedures, and/or training requirements, where needed, to minimize the potential for and safety impact of pilot actions that are inconsistent with manufacturer assumptions**(A-19-11)**

Notify other international regulators that certify transport-category Airplane type designs (for example, the European Union Aviation Safety Agency, Transport Canada, the National Civil Aviation Agency-Brazil, the Civil Aviation Administration of China, and the Russian Federal Air Transport Agency) of Recommendation A-19-11 and encourage them to evaluate its relevance to their processes and address any changes, if applicable**(A-19-12)**

Develop robust tools and methods, with the input of industry and human factors experts, for use in validating assumptions about pilot recognition and response to safety -significant failure conditions as part of the design certification process **(A-19-13)**

Once the tools and methods have been developed as recommended in Recommendation A-19-13, revise existing Federal Aviation Administration (FAA) regulations and guidance to incorporate their use and documentation as part of the design certification process, including re-examining the validity of pilot recognition and response assumptions permitted in existing FAA guidance. **(A-19-14)**

Develop design standards, with the input of industry and human factors experts, for Airplane system diagnostic tools that improve the prioritization and clarity of failure indications (direct and indirect) presented to pilots to improve the timeliness and effectiveness of their response. **(A-19-15)**

Once the design standards have been developed as recommended in Recommendation A-19-15, require implementation of system diagnostic tools on transport-category Airplane to improve the timeliness and effectiveness of pilots' response when multiple flight deck alerts and indications are present.**(A-19-16)**

4.7. Design Certification Safety Recommendations Summary

On March 10, 2019, Ethiopian Airlines flight 302, a Boeing 737 MAX 8, Ethiopian registration ET-AVJ, crashed near Ejere, Ethiopia, shortly after takeoff from Addis Ababa Bole International Airport, Ethiopia. The flight was a scheduled international passenger flight from Addis Ababa to Jomo Kenyatta International Airport, Nairobi, Kenya. All 157 passengers and crew on board died, and the Airplane was destroyed. The investigation is being led by the Ethiopia Accident Investigation Bureau.[43]

The Airplane 's DFDR data indicated that shortly after liftoff, the left (captain's) AOA sensor data increased rapidly to 74.5° and was 59.2° higher than the right AOA sensor; the captain's stick shaker activated. Concurrently, the airspeed and altitude values on the left side disagreed with, and were lower than, the corresponding values on the right side; in addition, DFDR data indicated a Master Caution alert. Similar to the Lion Air accident flight, a 9-second automatic AND stabilizer trim input occurred after flaps were retracted and while in manual flight (no autopilot). About 3 seconds after the AND stabilizer motion ended, using the stabilizer trim switches, the captain, who was the pilot flying, partially countered the AND stabilizer input by applying ANU electric trim. About 5 seconds after the completion of pilot trim input, another automatic AND stabilizer trim input occurred. The captain applied ANU electric trim and fully countered the second automatic AND stabilizer input; however, the Airplane was not returned to a fully trimmed condition. Cockpit voice recorder data indicated that the flight crew then discussed the STAB TRIM CUTOUT switches, and shortly thereafter DFDR data were consistent with the STAB TRIM CUTOUT switches being moved to CUTOUT. However, because the Airplane remained in an out-of-trim condition, the crew was required to continue applying force to the control column to maintain level flight. About 32 seconds before impact, two momentary pilot-commanded electric ANU trim inputs and corresponding stabilizer movement were recorded, consistent with the STAB TRIM CUTOUT switches no longer being in CUTOUT. Five seconds after these short electric trim inputs, another automatic AND stabilizer trim input occurred, and the Airplane began pitching nose down.

[43]Information in this section is taken from the preliminary report on this accident,

Safety Issue Summary

On the previous Lion Air flight and the Lion Air and Ethiopian Airlines accident flights, the DFDR recorded higher AOA sensor data on the left side than on the right (about 20° higher in the previous Lion Air flight and the Lion Air accident flight and about 59° higher on the Ethiopian Airlines accident flight). As previously stated, the MCAS becomes active when the Airplane 's AOA exceeds a certain threshold. Thus, these erroneous AOA data inputs resulted in the MCAS activating on the accident flights and providing the automatic AND stabilizer trim inputs. The erroneous high AOA sensor input that caused the MCAS activation also caused several other alerts and indications for the flight crews. The stick shaker was activated on both accident flights and the previous Lion Air flight. In addition, IAS DISAGREE and ALT DISAGREE alerts occurred on all three flights. Also, the Ethiopian Airlines flight crew received a Master Caution alert. Further, after the flaps were fully retracted, the unintended AND stabilizer inputs required the pilots to apply additional force to the columns to maintain the Airplane's climb attitude.

Multiple alerts and indications can increase pilots' workload, and the combination of the alerts and indications did not trigger the accident pilots to immediately perform the runaway stabilizer procedure during the initial automatic AND stabilizer trim input.In all three flights, the pilot responses differed and did not match the assumptions of pilot responses to unintended MCAS operation on which Boeing based its hazard classifications within the safety assessment and that the FAA approved and used to ensure the design safely accommodates failures.

Certification Process Safety Issues

Incomplete consideration by Airplane manufacturers of the effect of multiple alerts and indications when making assumptions about and assessing pilot response to flight control system failure conditions.

Need for more robust, standardized methodology and/or tools for manufacturers' use in assessing and validating assumptions about pilot recognition and response to safety-significant failure condition(s).

Need for enhanced Airplane system diagnostic tools to improve pilot understanding of which actions take priority when responding to multiple failure indications and alerts.

APPENDIXES AND ATTACHMENTS

APPENDIX A: FLIGHT CREW OPERATION MANUAL

APPENDIX B: FAA EMERGENCY AIRWORTHINESS DIRECTIVE

APPENDIXC: ECAA EMERGENCY RECOMMENDATION LETTER

APPENDIX D: BOEING CORRESPONDENCE: MULTI OPERATOR MESSAGES

APPENDIX E: ECAA GROUNDING OF BOEING 737MAX-8 FLEET

APPENDIX F: EASA SAFETY DIRECTIVE

APPENDIX G:FAA RESCISSION OF EMEREGENCY ORDER OF PROHIBITION

APPENDIX H: ETHIOPIAN AIRLINES MESSAGE TO BOEING

APPENDIX I: NTSB737 MAX 8 SYSTEMS DESCRIPTIONS REPORT

APPENDIX J: FDR AND CVR EXAMINATION

APPENDIX K: BOEING RESPONSE

ATTACHMENT1: NTSB, BEA (APPENDED)

ATTACHMENT2: ET -AVJ GENERAL VIEW OF FDR DATA

ATTACHMENT3: GENERAL VIEW OF FLIGHT

ATTACHMENT4: CONTROL COLUMN FORCE RELATED PARAMETERS

ATTACHMENTS5: FD DISPLAYED DIFFERENCES

ATTACHMENT6: ET- AVJ FLIGHT PROFILE

ATTACMENT 7: ET –AVJ GROUND TRACK

APPENDIX A: FLIGHT CREW OPERATION MANUAL

BOEING

Flight Crew Operations Manual Bulletin
for
The Boeing Company

The Boeing Company
Seattle, Washington 98124-2207 737

Number: TBC-19
IssueDate: November 6, 2018

Airplane Effectivity: 737-8 / -9

Subject: Uncommanded Nose Down Stabilizer Trim Due to Erroneous Angle of Attack (AOA) During Manual Flight Only

Reason: To Emphasize the Procedures Provided in the Runaway Stabilizer Non-Normal Checklist (NNC).

Information in this bulletin is recommended by The Boeing Company, but may not be FAA approved at the time of writing. In the event of conflict with the FAA approved Airplane Flight Manual (AFM), the AFM shall supersede. The Boeing Company regards the information or procedures described herein as having a direct or indirect bearing on the safe operation of this model airplane.

THE FOLLOWING PROCEDURE AND/OR INFORMATION IS EFFECTIVE UPON RECEIPT

Background Information

The Indonesian National Transportation Safety Committee has indicated that Lion Air flight 610 experienced erroneous AOA data. Boeing would like to call attention to an AOA failure condition that can occur **during manual flight only.** This bulletin directs flight crews to existing procedures to address this condition.

In the event of erroneous AOA data, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds. The nose down stabilizer trim movement can be stopped and reversed with the use of the electric stabilizer trim switches but may restart 5 seconds after the electric stabilizer trim switches are released. Repetitive cycles of uncommanded nose down stabilizer continue to occur unless the stabilizer trim system is deactivated through use of both STAB TRIM CUTOUT switches in accordance with the existing procedures in the Runaway Stabilizer NNC. It is possible for the stabilizer to reach the nose down limit unless the system inputs are counteracted completely by pilot trim inputs and both STAB TRIM CUTOUT switches are moved to CUTOUT.

Flight Crew Operations Manual Bulletin No. TBC-19 , Dated November 6, 2018 (continued)

Additionally, pilots are reminded that an erroneous AOA can cause some or all of the following indications and effects:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- Inability to engage autopilot.
- Automatic disengagement of autopilot.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the AOA indicator option is installed)
- FEEL DIFF PRESS light.

Operating Instructions

In the event an uncommanded nose down stabilizer trim is experienced on the 737-8 /-9, in conjunction with one or more of the above indications or effects, do the Runaway Stabilizer NNC ensuring that the STAB TRIM CUTOUT switches are set to CUTOUT and stay in the CUTOUT position for the remainder of the flight.

Note: Initially, higher control forces may be needed to overcome any stabilizer nose down trim already applied. Electric stabilizer trim can be used to neutralize control column pitch forces before moving the STAB TRIM CUTOUT switches to CUTOUT. Manual stabilizer trim can be used after the STAB TRIM CUTOUT switches are moved to CUTOUT.

Administrative Information

Insert this bulletin behind the Bulletin Record page in Volume 1 of your Flight Crew Operations Manual (FCOM). Amend the FCOM Bulletin Record page to show bulletin TBC-19 "In Effect" (IE).

This Bulletin remains in effect until Boeing provides additional information on system updates that may allow this Bulletin to be canceled.

Please send all correspondence regarding Flight Crew Operations Manual Bulletin status, to the 737 Manager, Flight Technical Data, through the Service Requests Application (SR App) on the MyBoeingFleet home page.

APPENDIX B: FAA EMERGENCY AIRWORTHINESS DIRECTIVE

FAA
Aviation Safety

EMERGENCY AIRWORTHINESS DIRECTIVE

www.faa.gov/aircraft/safety/alerts/

DATE: November 7, 2018
AD #: 2018-23-51

Emergency Airworthiness Directive (AD) 2018-23-51 is sent to owners and operators of The Boeing Company Model 737-8 and -9 airplanes.

Background

This emergency AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. This condition, if not addressed, could cause the flight crew to have difficulty controlling the airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

FAA's Determination

We are issuing this AD because we evaluated all the relevant information and determined the unsafe condition described previously is likely to exist or develop in other products of the same type design. Due to the need to correct an urgent safety of flight situation, good cause exists to make this AD effective in less than 30 days.

AD Requirements

This AD requires revising certificate limitations and operating procedures of the airplane flight manual (AFM) to provide the flight crew with runaway horizontal stabilizer trim procedures to follow under certain conditions.

Interim Action

We consider this AD interim action. If final action is later identified, we might consider further rulemaking then.

Authority for this Rulemaking

Title 49 of the United States Code specifies the FAA's authority to issue rules on aviation safety. Subtitle I, Section 106, describes the authority of the FAA Administrator. Subtitle VII, Aviation Programs, describes in more detail the scope of the Agency's authority.

We are issuing this rulemaking under the authority described in Subtitle VII, Part A, Subpart III, Section 44701, "General requirements." Under that section, Congress charges the FAA with promoting safe flight of civil aircraft in air commerce by prescribing regulations for practices, methods, and procedures the Administrator finds necessary for safety in air commerce. This regulation is within the scope of that authority because it addresses an unsafe condition that is likely to exist or develop on products identified in this rulemaking action.

1

This AD is issued in accordance with authority delegated by the Executive Director, Aircraft Certification Service, as authorized by FAA Order 8000.51C. In accordance with that order, issuance of ADs is normally a function of the Compliance and Airworthiness Division, but during this transition period, the Executive Director has delegated the authority to issue ADs applicable to transport category airplanes and associated appliances to the Director of the System Oversight Division.

Presentation of the Actual AD

We are issuing this AD under 49 U.S.C. Section 44701 according to the authority delegated to me by the Administrator.

2018-23-51 The Boeing Company: Product Identifier 2018-NM-151-AD.

(a) Effective Date

This Emergency AD is effective upon receipt.

(b) Affected ADs

None.

(c) Applicability

This AD applies to all The Boeing Company Model 737-8 and -9 airplanes, certificated in any category.

(d) Subject

Air Transport Association (ATA) of America Code 27, Flight controls.

(e) Unsafe Condition

This AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer. We are issuing this AD to address this potential resulting nose-down trim, which could cause the flight crew to have difficulty controlling the airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain.

(f) Compliance

Comply with this AD within the compliance times specified, unless already done.

(g) Revision of Airplane Flight Manual (AFM): Certificate Limitations

Within 3 days after receipt of this AD, revise the Certificate Limitations chapter of the applicable AFM to include the information in figure 1 to paragraph (g) of this AD.

Figure 1 to paragraph (g) of this AD – *Certificate Limitations*

Required by AD 2018-23-51

Runaway Stabilizer

In the event of an uncommanded horizontal stabilizer trim movement, combined with any of the following potential effects or indications resulting from an erroneous Angle of Attack (AOA) input, the flight crew must comply with the Runaway Stabilizer procedure in the Operating Procedures chapter of this manual:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the option is installed).
- FEEL DIFF PRESS light.
- Autopilot may disengage.
- Inability to engage autopilot.

(h) AFM Revision: Operating Procedures

Within 3 days after receipt of this AD, revise the Operating Procedures chapter of the applicable AFM to include the information in figure 2 to paragraph (h) of this AD.

Figure 2 to paragraph (h) of this AD – *Operating Procedures*

Required by AD 2018-23-51

Runaway Stabilizer

Disengage autopilot and control airplane pitch attitude with control column and main electric trim as required. If relaxing the column causes the trim to move, set stabilizer trim switches to CUTOUT. If runaway continues, hold the stabilizer trim wheel against rotation and trim the airplane manually.

Note: The 737-8/-9 uses a Flight Control Computer command of pitch trim to improve longitudinal handling characteristics. In the event of erroneous Angle of Attack (AOA) input, the pitch trim system can trim the stabilizer nose down in increments lasting up to 10 seconds.

In the event an uncommanded nose down stabilizer trim is experienced on the 737-8/-9, in conjunction with one or more of the indications or effects listed below, do the existing AFM Runaway Stabilizer procedure above, ensuring that the STAB TRIM CUTOUT switches are set to CUTOUT and stay in the CUTOUT position for the remainder of the flight.

An erroneous AOA input can cause some or all of the following indications and effects:

- Continuous or intermittent stick shaker on the affected side only.
- Minimum speed bar (red and black) on the affected side only.
- Increasing nose down control forces.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert (if the option is installed).
- FEEL DIFF PRESS light.
- Autopilot may disengage.
- Inability to engage autopilot.

Initially, higher control forces may be needed to overcome any stabilizer nose down trim already applied. Electric stabilizer trim can be used to neutralize control column pitch forces before moving the STAB TRIM CUTOUT switches to CUTOUT. Manual stabilizer trim can be used before and after the STAB TRIM CUTOUT switches are moved to CUTOUT.

(i) Alternative Methods of Compliance (AMOCs)

(1) The Manager, Seattle ACO Branch, FAA, has the authority to approve AMOCs for this AD, if requested using the procedures found in 14 CFR 39.19. In accordance with 14 CFR 39.19, send your request to your principal inspector or local Flight Standards District Office, as appropriate. If sending information directly to the manager of the certification office, send it to the attention of the person identified in paragraph (j) of this AD. Information may be emailed to: 9-ANM-Seattle-ACO-AMOC-Requests@faa.gov.

(2) Before using any approved AMOC, notify your appropriate principal inspector, or lacking a principal inspector, the manager of the local flight standards district office/certificate holding district office.

(j) Related Information

For further information about this AD, contact Douglas Tsuji, Senior Aerospace Engineer, Systems and Equipment Section, FAA, Seattle ACO Branch, 2200 South 216th St., Des Moines, WA 98198; phone and fax: 206-231-3548; email: Douglas.Tsuji@faa.gov.

Issued in Des Moines, Washington, on November 7, 2018.

Original signed by
Chris Spangenberg,
Acting Director,
System Oversight Division,
Aircraft Certification Service.

APPENDIXC: ECAA EMERGENCY RECOMMENDATION LETTER

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ቀን 08 NOV. 2018
Date

ቁጥር AR/03-016-001/1,58/18
Ref.

Manager, Engineering Quality Assurance
Ethiopian Airlines
Addis Ababa

Subject: **Emergency AD 2018-23-51**

Federal Aviation Administration FAA has released an emergency Airworthiness Directive AD 2018-23-51 which is applicable to B737-8 and -9 airplanes. Accordingly owners and operators are required to revise their AFM manual and operating procedure within three (03) days effective 07 November 2018.

Hence I would like to inform you that you shall take required actions as appropriate and report to the Authority within the specific time period in the emergency AD 2018-23-51.

With regards,

Haish Beyene

For/ Director, Aircraft Registration and Airworthiness Certification

CC:- **Air Operators Certification and Surveillance Directorate ECAA, Addis Ababa**

Received on
09-11-18

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e-mail: address caa.airnav@ethionet.et
CAA 46-100-053
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APPENDIX D: BOEING CORRESPONDENCE: MULTI OPERATOR MESSAGES

FROM: THE BOEING COMPANY

TO: Boeing Correspondence (MOM)

[MESSAGE NUMBER:MOM-MOM-18-0664-01B] Multi Operator Message

MESSAGE DATE: 10 Nov 2018 1810 US PACIFIC TIME / 11 Nov 2018 0210 GMT

This message is sent to all 737NG/MAX Customers, Regional Directors, RegionalManagers and Boeing Field Service Bases.

CATEGORY: Maintenance, Engineering, Flight Operations, Management, Safety

SERVICE REQUEST ID: 4-4298138108

ACCOUNT: Boeing Correspondence (MOM)

DUE DATE: No Action Required

PRODUCT TYPE: Airplane

PRODUCT LINE: 737

PRODUCT: SEVERAL

ATA: 0000-57

SUBJECT: Information - Multi-Model Stall Warning and Pitch Augmentation

Operation

REFERENCES:

/A/ MOM-MOM-18-0655-01B

- -

SUMMARY:

Boeing has received many requests for the same information from 737 fleetoperators in response to the reference /A/ message.This message providestechnical information and operational details.

- -

DESCRIPTION:

A pitch augmentation system function called "Maneuvering Characteristics

Augmentation System" (MCAS) is implemented on the 737-8, -9 (MAX) to enhancepitch characteristics with flaps UP and at elevated angles of attack.

TheMCAS function commands nose down stabilizer to enhance pitch characteristicsduring steep turns with elevated load factors and during flaps up flight atairspeeds approaching stall. MCAS is activated without pilot input and onlyoperates in manual, flaps up flight. The system is designed to allow theflight crew to use column trim switch or stabilizer aisle stand cutoutswitches to override MCAS input. The function is commanded by the FlightControl computer using input data from sensors and other Airplane systems.

The MCAS function becomes active when the Airplane Angle of Attack exceeds athreshold based on airspeed and altitude. Stabilizer incremental commands arelimited to 2.5 degrees and are provided at a rate of 0.27 degrees per second.

The magnitude of the stabilizer input is lower at high Mach number andgreater at low Mach numbers. The function is resets once angle of attack fallsbelow the Angle of Attack threshold or if manual stabilizer commands areprovided by the flight crew. If the original elevated AOA condition persists, the MCAS function commands another incremental stabilizer nose down commandaccording to current Airplane Mach number at actuation.

The MCAS function is not incorporated on 737NG Airplanes.

If you have further questions, you may contact the appropriate Airline

Support Manager.

Auto flight Technical Lead Engineer

Sr. Manager - Systems

Customer Support

The Boeing Company

APPENDIX E: ECAA GROUNDING OF BOEING 737MAX-8 FLEET

12/3/2019
F-3/11/11

ETHIOPIAN AIRLINES MAIL ROOM
13 MAR 2019
RECEIVED

Group Chief Executive Officer
Ethiopian Airlines Group
Addis Ababa, Ethiopia

Subject: **Grounding of Boeing 737MAX-8 Fleet**

We are deeply saddened about the loss of lives following crash of Ethiopian Airlines Boeing 737MAX-8, Flight number ET-302 on its scheduled flight to Nairobi departing from Addis Ababa Bole International Airport on March 10, 2019.

Even though it is not possible to rule out anything, it is also impossible to attribute the cause of the accident to something at this point of time, the accident has some degree of similarity with that of the Lion Air accident in which both accidents involved newly delivered Boeing 737-8 airplanes and happened during take-off phase.

Hence, this is to officially notify Ethiopian Airlines that its all Boeing 737MAX-8 fleet of aircraft is grounded and are not allowed to make commercial flights effective March 11, 2019 until further notice in consultation with the aircraft manufacturer and State of Design of the aircraft.

Sincerely,

Wosenyeleh Hunegnaw (Col.)
Director General

11/03/2019

11/03/2019

APPENDIX F: EASA SAFETY DIRECTIVE

EASA SD No.: 2019-01

EASA
European Union Aviation Safety Agency

Safety Directive

SD No.: **2019-01**

Issued: **12 March 2019**

Note: This corrective action to an urgent safety problem is issued by the Agency in accordance with Art. 76 (6) of Regulation (EU) 2018/1139. It is mandatory for organisations for which EASA is the Competent Authority, including Third Country organisations holding an EASA certificate.

Subject: Boeing 737-8 MAX and 737-9 MAX - Suspension of Flight Operations

Effective Date: 12 March 2019, 19:00 UTC

Supersedure: Not applicable

Applicability:
Third Country Operators (TCOs) authorised by EASA pursuant to Commission Regulation (EU) No 452/2014 to perform commercial air transport operations with Boeing 737-8 'MAX' or Boeing 737-9 'MAX' into, within or out of the territory subject to the provisions of the Treaty on European Union.

Definitions:
For the purpose of this Safety Directive (SD), the following definitions apply:

None.

Reason:
Prompted by a fatal accident with a Boeing 737-8 'MAX' aeroplane, the exact causes of which are still being investigated, the Federal Aviation Administration (FAA), representing the State of Design for the affected aeroplanes, issued Emergency AD 2018-23-51 (later replaced by a Final Rule AD) to require certain changes to the Airplane Flight Manual (AFM) regarding Runaway Horizontal Stabilizer Trim Limitations and Procedures.

Since that action, another fatal accident occurred. At this early stage of the related investigation, it cannot be excluded that similar causes may have contributed to both events. Just after the second event, the FAA issued CANIC 2019-03, providing information concerning progress on the development of mitigating actions.
Based on all available information, EASA considers that further actions may be necessary to ensure the continued airworthiness of the two affected models (Boeing 737-8 'MAX' and Boeing 737-9 'MAX').

For the reasons described above, pending the availability of more information, EASA has decided to issue the Emergency Airworthiness Directive referenced below and to require the suspension of commercial air transport operations of the two affected Models into, within or out of the territory subject to the provisions of the Treaty on European Union.

This SD is considered an interim action, and further action is expected to follow.

Required Action(s) and Compliance Time(s):
From the effective date and time of this SD, do not perform commercial air transport operations with Boeing 737-8 'MAX' or Boeing 737-9 'MAX' into, within or out of the territory subject to the provisions of the Treaty on European Union.

Note: non-commercial operations (e.g. ferry flights) are not within the scope of this SD.

Ref. Publications:
EASA AD 2019-0051-E.

Remarks:
1. The results of the safety assessment have indicated the need for immediate publication and notification, without the full consultation process.
2. Enquiries regarding this SD should be referred to the EASA Safety Information Section, Certification Directorate. E-mail: ADs@easa.europa.eu.

EASA
European Union Aviation Safety Agency

Airworthiness Directive

AD No.: **2019-0051R1**

Issued: **25 March 2019**

Note: This Airworthiness Directive (AD) is issued by EASA, acting in accordance with Regulation (EU) 2018/1139 on behalf of the European Union, its Member States and of the European third countries that participate in the activities of EASA under Article 129 of that Regulation.

This AD is issued in accordance with Regulation (EU) 748/2012, Part 21.A.3B. In accordance with Regulation (EU) 1321/2014 Annex I, Part M.A.301, the continuing airworthiness of an aircraft shall be ensured by accomplishing any applicable ADs. Consequently, no person may operate an aircraft to which an AD applies, except in accordance with the requirements of that AD, unless otherwise specified by the Agency [Regulation (EU) 1321/2014 Annex I, Part M.A.303] or agreed with the Authority of the State of Registry [Regulation (EU) 2018/1139, Article 71 exemption].

Design Approval Holder's Name:	Type/Model designation(s):
THE BOEING COMPANY	737-8 and 737-9 aeroplanes

Effective Date:	Revision 1: 26 March 2019 Original issue: 12 March 2019, 19:00 UTC
TCDS Number(s):	EASA.IM.A.120
Foreign AD:	None
Revision:	This AD revises EASA Emergency AD 2019-0051-E dated 12 March 2019.

ATA – SUSPENSION OF FLIGHT OPERATIONS

Manufacturer(s):
The Boeing Company, Commercial Airplanes Group

Applicability:
Model 737-8 and 737-9 (commercially known as 'MAX') aeroplanes, all serial numbers.

Definitions:
For the purpose of this AD, the following definition apply:

- **Ferry flight**: Any non-passenger flight conducted after the effective date of this revised AD, operating with a permit-to-fly issued under Regulation (EU) 748/2012, Part 21, and under flight conditions approved by EASA.

Reason:
Prompted by a fatal accident with a Boeing 737-8 'MAX' aeroplane, the exact causes of which are still being investigated, the Federal Aviation Administration (FAA), representing the State of Design for the affected aeroplanes, issued Emergency AD 2018-23-51 (later replaced by a Final Rule AD) to require certain changes to the Airplane Flight Manual (AFM) regarding Runaway Horizontal Stabilizer Trim Limitations and Procedures.

Since that action, another fatal accident occurred. At this early stage of the related investigation, it cannot be excluded that similar causes may have contributed to both events. Just after the second event, the FAA issued CANIC 2019-03, providing information concerning progress on the development of mitigating actions. Based on all available information, EASA considered that further actions may be necessary to ensure the continued airworthiness of the two affected models.

For the reasons described above, pending the availability of more information, EASA issued Emergency AD 2019-0051-E to suspend all flight operations of the two affected models. That AD allowed a single non-commercial ferry flight (up to three flight cycles) to return the aeroplane to a location where the expected corrective action(s) can be accomplished.

Since that AD was issued, EASA has reconsidered the ferry flight aspects. Consequently, this AD is revised to define the conditions under which ferry flights can be performed.

This AD still is considered an interim action and further AD action is expected to follow.

Required Action(s) and Compliance Time(s):
Required as indicated, unless accomplished previously:

From the effective date of this revised AD, do not operate the aeroplane, except for ferry flights as defined in this AD.

Ref. Publications:
None.

Remarks:

1. If requested and appropriately substantiated, EASA can approve Alternative Methods of Compliance for this AD.

2. Based on the required actions and the compliance time, EASA have decided to issue a Final AD with Request for Comments, postponing the public consultation process until after publication.

3. Enquiries regarding this AD should be referred to the EASA Safety Information Section, Certification Directorate. E-mail: ADs@easa.europa.eu.

4. Information about any failures, malfunctions, defects or other occurrences, which may be similar to the unsafe condition addressed by this AD, and which may occur, or have occurred on a product, part or appliance not affected by this AD, can be reported to the EU aviation safety reporting system.

5. For a copy of related service information, if any, contact Boeing Commercial Airplanes, Attention: Contractual & Data Services (C&DS), 2600 Westminster Blvd., MC 110-SK57, Seal Beach, California 90740-5600, United States of America; Telephone: +1 562-797-1717; Internet: https://www.myboeingfleet.com.

EASA AD No.: 2019-0051-E

EASA
European Union Aviation Safety Agency

Emergency Airworthiness Directive

AD No.: **2019-0051-E**

Issued: **12 March 2019**

Note: This Emergency Airworthiness Directive (AD) is issued by EASA, acting in accordance with Regulation (EU) 2018/1139 on behalf of the European Union, its Member States and of the European third countries that participate in the activities of EASA under Article 129 of that Regulation.

This AD is issued in accordance with Regulation (EU) 748/2012, Part 21.A.3B. In accordance with Regulation (EU) 1321/2014 Annex I, Part M.A.301, the continuing airworthiness of an aircraft shall be ensured by accomplishing any applicable ADs. Consequently, no person may operate an aircraft to which an AD applies, except in accordance with the requirements of that AD, unless otherwise specified by the Agency [Regulation (EU) 1321/2014 Annex I, Part M.A.303] or agreed with the Authority of the State of Registry [Regulation (EU) 2018/1139, Article 71 exemption].

Design Approval Holder's Name:
THE BOEING COMPANY

Type/Model designation(s):
737-8 and 737-9 aeroplanes

Effective Date:	12 March 2019, 19:00 UTC
TCDS Number(s):	EASA.IM.A.120
Foreign AD:	None
Supersedure:	Not applicable

ATA – SUSPENSION OF FLIGHT OPERATIONS

Manufacturer(s):
The Boeing Company, Commercial Airplanes Group

Applicability:
Model 737-8 and 737-9 aeroplanes, all serial numbers.

Definitions:
For the purpose of this AD, the following definitions apply: None

Reason:
Prompted by a fatal accident with a Boeing 737-8 'MAX' aeroplane, the exact causes of which are still being investigated, the Federal Aviation Administration (FAA), representing the State of Design for the affected aeroplanes, issued Emergency AD 2018-23-51 (later replaced by a Final Rule AD) to require certain changes to the Airplane Flight Manual (AFM) regarding Runaway Horizontal Stabilizer Trim Limitations and Procedures.

Since that action, another fatal accident occurred. At this early stage of the related investigation, it cannot be excluded that similar causes may have contributed to both events. Just after the second event, the FAA issued CANIC 2019-03, providing information concerning progress on the development of mitigating actions.

Page 1 of 2

Based on all available information, EASA considers that further actions may be necessary to ensure the continued airworthiness of the two affected models.

For the reasons described above, pending the availability of more information, EASA has decided to suspend all flight operations of the two affected models.

This AD is considered an interim action and further AD action is expected to follow.

Required Action(s) and Compliance Time(s):
Required as indicated, unless accomplished previously:

From the effective date and time of this AD, do not operate the aeroplane, except that a single non-commercial ferry flight (up to three flight cycles) may be accomplished to return the aeroplane to a location where the expected corrective action(s) can be accomplished.

Ref. Publications:
None.

Remarks:

1. The results of the safety assessment have indicated the need for immediate publication and notification, without the full consultation process.

2. Enquiries regarding this AD should be referred to the EASA Safety Information Section, Certification Directorate. E-mail: ADs@easa.europa.eu.

3. Information about any failures, malfunctions, defects or other occurrences, which may be similar to the unsafe condition addressed by this AD, and which may occur, or have occurred on a product, part or appliance not affected by this AD, can be reported to the EU aviation safety reporting system.

4. For a copy of related service information, if any, contact Boeing Commercial Airplanes, Attention: Contractual & Data Services (C&DS), 2600 Westminster Blvd., MC 110-SK57, Seal Beach, California 90740-5600, United States of America; Telephone: +1 562-797-1717; Internet: https://www.myboeingfleet.com.

APPENDIX G:FAA RESCISSION OF EMEREGENCY ORDER OF PROHIBITION

UNITED STATES DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Operators of Boeing Company Model 737-8 and Boeing Company Model 737-9 Airplanes	))))))

RESCISSION OF EMERGENCY ORDER OF PROHIBITION

The Federal Aviation Administration (FAA) Emergency Order of Prohibition issued March 13, 2019, applicable to Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes, is rescinded with effect as described below. This rescission enables operation of Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes only upon satisfaction of applicable requirements for return to service.

BACKGROUND

When the Administrator determines that an emergency exists related to safety in air commerce and requires immediate action, the Administrator may issue immediately effective orders to meet the emergency. *See* 49 U.S.C. § 46105(c). On March 13, 2019, upon receiving information indicating the possibility of a shared cause for accidents involving Boeing Model 737-8 airplanes operated by Lion Air (Flight 610) on October 29, 2018 and Ethiopian Airlines (Flight 302) on March 10, 2019, the FAA determined that an emergency existed and issued an Emergency Order of Prohibition that restricted the operation of Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes. *See* 84 Fed. Reg. 9705. Following issuance of such an order, the FAA is to begin a proceeding immediately about the emergency and give preference, when practicable, to the proceeding. *See* 49 U.S.C. § 46105(c).

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BASIS FOR RESCISSION

The FAA determined that the Lion Air and Ethiopian Airlines accidents involved a common cause, identified an unsafe condition that existed in the product and was likely to exist or develop in other products of the same type design, and began proceedings to address the unsafe condition. On August 6, 2020, the FAA issued a notice of proposed rulemaking (NPRM) proposing an Airworthiness Directive that would apply to U.S.-registered Boeing Company Model 737-8 and Boeing Company Model 737-9 airplanes and would require owners and operators to complete certain corrective action necessary to address the unsafe condition. *See* 85 Fed. Reg. 47698. On November 18, 2020, after considering public comments on the NPRM, the FAA issued Airworthiness Directive 2020-24-02 as a final rule that requires certain corrective action to address the unsafe condition before further flight and conforms the aircraft to the amended Model 737-8 and 737-9 type designs that FAA approved on November 17, 2020. The Airworthiness Directive will become effective upon its publication in the Federal Register.

Together, the Airworthiness Directive and the design approval address the unsafe condition as to the existing U.S.-registered fleet of Boeing Company Model 737-8 and 737-9 airplanes and as to any Model 737-8 and 737-9 airplanes for which The Boeing Company hereafter seeks airworthiness certificates and export certificates of airworthiness. It is now practicable for the FAA to give preference to the proceedings that the FAA began in response to the emergency.

First, the Emergency Order of Prohibition is no longer necessary as to any Boeing Company Model 737-8 and 737-9 airplanes that hereafter receive original FAA airworthiness certificates and export certificates of airworthiness based on the amended type designs.

Second, for any Boeing Company Model 737-8 and 737-9 airplanes not falling into that first category, the Emergency Order of Prohibition is unnecessary as to foreign-registered airplanes operating in U.S. airspace. With respect to foreign-registered Boeing Company Model 737-8 and 737-9 airplanes, the FAA will apply Article 33 and Annex 8 of the Convention on International Civil Aviation (the Chicago Convention) to take appropriate action to restrict access to U.S. airspace and address any non-compliance with U.S. laws where the foreign civil aviation authority of the state of registry does not require conformance with the newly amended type design or an alternative that achieves at least an equivalent level of safety.

Finally, upon the publication of Airworthiness Directive 2020-24-02 in the Federal Register, the legal force of that Airworthiness Directive will supersede any need to apply the Emergency Order of Prohibition as to the existing U.S.-registered fleet of Boeing Company Model 737-8 and 737-9 airplanes that the FAA previously certificated. With respect to those airplanes, Airworthiness Directive 2020-24-02 requires corrective action before further flight.

Importantly, in the scenarios identified above, before returning Boeing Company Model 737-8 and 737-9 airplanes to service, operators must also meet all other applicable requirements, such as completing new training for pilots and conducting maintenance activity.

RESCISSION

For the foregoing reasons, the March 13, 2020 Emergency Order of Prohibition is rescinded as follows:

(1) effective immediately as to any Boeing Company Model 737-8 and 737-9 airplanes that hereafter receive FAA airworthiness certificates and export certificates of airworthiness;

(2) effective immediately as to any foreign-registered Boeing Company Model 737-8 and 737-9 airplanes operating in U.S. airspace; and

(3) effective upon publication in the Federal Register of Airworthiness Directive 2020-24-02 as to all U.S.-registered Boeing Company Model 737-8 and 737-9 airplanes.

RESCISSION CONTACT OFFICIAL

Direct any questions concerning this rescission, to Ian Won, Federal Aviation Administration, Aircraft Certification Service, Seattle ACO Branch, 2200 South 216th Street, Des Moines, WA 98198 (Email: 9-FAA-SACO-AD-Inquiry@faa.gov; Tel: 206-231-3500).

Dated: NOV 1 8 2020

Steve Dickson
Administrator
Federal Aviation Administration

4

APPENDIX H: ETHIOPIAN AIRLINES MESSAGE TO BOEING

Capt. Yohannes Hailemariam Seifu

Subject: FW: Questions to Boeing

From: Webb (US), James D [mailto:james.d.webb4@boeing.com]
Sent: Monday, December 03, 2018 7:22 AM
To: Capt. Yohannes Hailemariam Seifu <YohannesHM@ethiopianairlines.com>
Cc: Bradley (US), Joseph W <joseph.w.bradley@boeing.com>
Subject: RE: Questions to Boeing

Good evening Capt. Yohannes,

I am happy to hear that you were able to take part in the Fleet Team meeting and will attempt to answer other questions from your pilots. However, because of our Annex 13 technical support to the accident investigation, we are unable to answer questions directly related to this event. I can only address the current system and the Operations Manual Bulletin. The first two questions directly relate to the accident scenario; therefore, I will be unable to address them here. I have provided the answer to the third question below:

Third; our third question has to do with the very checklist recommended by the bulletin issued regarding the MCAS system. And that is the RUNAWAY STABILIZER checklist. This checklist commands the pilot to put the stab trim cut out switches to cut out only if the runaway continues after the autopilot is disconnected . But that is not the case with MCAS. MCAS does not continually trim down. It stops trimming, according to the bulletin, for 5 seconds if the control column trim switches are trimmed in the opposite direction. That will rule out the attempt to categorize the malfunction, if it is, as a runaway stabilizer. And by implication the use of the checklist. So in short what is the delineation between an MCAS normal operation and runaway stabilizer? The purpose of the Operations Manual Bulletin is to raise awareness of the relationship between an erroneous AOA indication and uncommanded stabilizer movement. Specifically, if the AOA is erroneous and also high, it may be high enough to trigger the MCAS flight control law. The pilot always has trim authority to override both the Speed Trim and MCAS flight control laws with the control wheel electric trim switches and ultimate authority to power off the entire stabilizer trim system using the Stabilizer Cutout Switches. As is stated in the OMB, IF uncommanded stabilizer trim movement is experienced in conjunction with the erroneous AOA flight deck effects, the instructed course of action is to use the Stabilizer Cutout switches per the existing procedure. Additionally, in all phases of manual flight, it is expected that flight crews would use normal trim procedures to trim out undesired control forces or positions, regardless of axis – stabilizer, rudder, or aileron.

1

If there are other questions with respect to the system or the bulletin, please feel free to submit them either to me or through Joe through a BCS message. We will continue to assemble the questions coming from other customers and the answers provided back to them in an effort to share with everyone the common responses we are providing.

Captain Jim Webb

Chief Pilot - 737

Boeing Test & Evaluation, Seattle, WA

(206) 225-4371 (Mobile)

From: Capt. Yohannes Hailemariam Seifu [mailto:YohannesHM@ethiopianairlines.com]
Sent: Saturday, December 01, 2018 9:15 AM
To: Webb (US), James D <james.d.webb4@boeing.com>
Cc: Bradley (US), Joseph W <joseph.w.bradley@boeing.com>
Subject: FW: Questions to Boeing

Dear Capt Webb,

Following the Webex last Tuesday, the pilots still have some questions to be clarified by Boeing. Please find below their questions for your review and answers. We would also like to share any relevant question(s) from other operators.

Best regards,

From: nathan elias <nthnelias@yahoo.ca>
Date: November 28, 2018 at 14:35:04 GMT+3
To: "yohannesh_mariam@yahoo.com" <yohannesh_mariam@yahoo.com>
Subject: Questions to Boeing
Reply-To: "nthnelias@yahoo.ca" <nthnelias@yahoo.ca>

Dear capt yohannes greetings! !

I have sent the same email via company mail but since i had a problem with my outlook, i couldn't check if you got the mail. So i have sent you this one again.

2

Having attended the Boeing briefing on the 27th of November, held on a tele conferencing, and after mulling on the very precarious situation where the lion air crew were, we have come up with few questions mainly related to operations. The questions are summarized as follows

First; According to the briefing there was no problem with the MCAS system at the time of the accident except being triggered at the wrong moment during the flight due to a single erroneous AOA sensor. Then why is the system designed in such a way that it operates depending on a single data source, especially when it is of a serious consequences, instead of interrogating data from other AOA sensors?

Second; Any average skilled pilot experiencing multiple failures, as it were, would react to the abnormalities depending on their sequence of urgency. Starting with a stick shaker. Because all simulator trainings , so far provided, require at the first activation of a stick shaker to react in such a way to curb the impending actual stall. It is, though, obvious that all stall warnings are not true as was the case with the Lion Air 737 Max involved in the accident. But once a pilot identified a stick shaker to be a nuisance, the next thing he would do is the AIRSPEED UNRELIABLE memory item. Not runaway stabilizer checklist. Because the AIRSPEED UNRELIABLE checklist puts a nuisance stick shaker to be an indication of unreliable airspeed. With all these in mind, how can a pilot be expected to put the trim cut out switches to cut out before dealing with the above procedures unless there is a clear guidance or a QRH procedure addressing such scenario?

Third; our third question has to do with the very checklist recommended by the bulletin issued regarding the MCAS system. And that is the RUNAWAY STABILIZER checklist. This checklist commands the pilot to put the stab trim cut out switches to cut out only if the runaway continues after the autopilot is disconnected . But that is not the case with MCAS. MCAS does not continually trim down. It stops trimming, according to the bulletin, for 5 seconds if the control column trim switches are trimmed in the opposite direction. That will rule out the attempt to categorize the malfunction, if it is, as a runaway stabilizer. And by implication the use of the checklist. So in short what is the delineation between an MCAS normal operation and runaway stabilizer?

With best regards!!

3

APPENDIX I: NTSB737 MAX 8 SYSTEMS DESCRIPTIONS REPORT

NATIONAL TRANSPORTATION SAFETY BOARD OFFICE OF AVIATION SAFETY

WASHINGTON, D.C. 2059 4

November 27, 2019

737 MAX 8 SYSTEMS DESCRIPTIONS REPORT

NTSB ID: DCA19RA101

A. Accident:

Operator: Ethiopian Airlines Group

Location: 28 NM South East of Addis Ababa, Ethiopia

Date: March 10, 2019

Airplane: 737 MAX 8, Registration ET-AVJ

B. Summary:

On March 10, 2019, Ethiopian Airlines flight 302, a Boeing 737 MAX 8, Ethiopian registration ET-AVJ, crashed 28 NM South East of Addis Ababa, Ethiopia, shortly after takeoff from Addis Ababa Bole International Airport, Ethiopia. The flight was a scheduled international passenger flight from Addis Ababa to Jomo Kenyatta International Airport, Nairobi, Kenya. All 157 passengers and crew on board died, and the Airplane was destroyed. The investigation is being led by the Ethiopia Accident Investigation Bureau.[45]

This document provides a description of the Airplane systems on the 737 MAX 8 which was active during the accident flight.

[45]Informationinthissectionistakenfromthepreliminaryreportonthisaccident

C. 737 MAX and the Need for MCAS:

During the preliminary design stage of the 737 MAX 8, Boeing tests and analysis revealed that the addition of the LEAP-1B engine and associated nacelle changes produced an Airplane nose-up pitching moment when the Airplane was operating at high angles of attack (AOA) and mid Mach numbers. This nose-up pitching moment was deemed likely to affect the stick force per g (FS/g) characteristics required by FAR 25.255 and the controllability and maneuverability requirements of FAR 25.143(f). After a study of various options for addressing this issue, Boeing implemented aerodynamic changes on the wing as well as a stability augmentation function called the Maneuvering Characteristics Augmentation System (MCAS), as an extension of the existing Speed Trim System (STS), to improve Airplane handling characteristics and decrease pitch-up tendency at elevated angles of attack.

As the development of the 737 MAX 8 progressed, the MCAS function was expanded to low Mach numbers. MCAS is designed to function only during manual flight (autopilot not engaged), with the Airplane's flaps up, at an elevated AOA.

D. Pitch Control System Description:

Pitch control for the Boeing 737 MAX 8 is provided by two elevators and a horizontal stabilizer, which are both moveable control surfaces located on the empennage.

D.1 Elevator System:

The Boeing 737 MAX 8 elevator control system provides primary pitch control of the Airplane using two elevators that are hydraulically powered with manual reversion available in the event of a loss of hydraulics. This control system is activated by fore and aft motion of the captain's and first officer's control columns, which are connected via a torque tube with a forward cable control quadrant mounted at each end. Elevator control cables are routed from the quadrants aft and attach to a pair of aft elevator control quadrants, which are mounted on the lower elevator input torque tube. This tube is mechanically connected, via linkages, to each of the two power control units (PCUs) input control arm assembly. When rotated, the lower torque tube input arm assembly provides a simultaneous command to each PCU to extend or retract. The two PCUs operate in unison and are powered by separate hydraulic systems, the left unit from hydraulic system "A" pressure and the right unit from hydraulic system B pressure. The output rod of each PCU is connected to the upper torque tube, which is directly linked by pushrods to each elevator.

Aft elevator controls a relocated in he empennage aft of the stabilizer rear spar.

D.1.1 Elevator Feel System:

An elevator feel computer provides simulated aerodynamic forces on the control column based on total pressure (from two dedicated pitot probes mounted on the vertical stabilizer) and stabilizer position. Feel force is transmitted to the control columns by the elevator feel and centering unit. To operate the feel system the elevator feel computer uses either hydraulic system A or B pressure, whichever is higher.

Stall warning and control is enhanced by the Elevator Feel Shift (EFS) module and the speed trim system. The speed trim system is a function within the Flight Control Computers (autopilot) which enhances speed stability characteristics. MCAS is a sub function of the speed trim system. These systems work together to help the pilot prevent further movement into a stall condition. Higher aft control column forces and the stick shaker system provide warning that the Airplane is about to be in or is in a stall condition.

During high AOA operations, the Stall Management/Yaw Damper (SMYD) reduces yaw damper commanded rudder movement. The EFS module increases hydraulic system pressure to the elevator feel and centering unit during a stall. This approximately doubles control column forces for a typical stall entry. The EFS module is armed whenever an inhibit condition is not present. Inhibit conditions are Airplane on the ground, radio altitude less than 100 feet, or autopilot engaged. However, if EFS is active when descending through 100 feetRA, it remains active until AOA is reduced below approximately stickshaker threshold. There are no flight deck indications that the system is properly armed or activated. As airspeed decreases towards stall speed, the speed trim system trims the stabilizer nose down and enables MCAS above stickshaker AOA. With this trim schedule the pilot must pull more aft column to stall the Airplane. With the column aft, the amount of column force increase with the onset of the EFS module is more pronounced.

D.2 Horizontal Stabilizer System:

As shown in Figure 1, the horizontal stabilizer controls the pitch trim of the Airplane; its leading edge can be moved to a Maximum position of 4.2 degrees up and 12.9 degrees down by the rotation of a jackscrew, which is connected to the front spar fitting of the stabilizer via a ball nut. The horizontal stabilizer is positioned by a single electric trim motor controlled through either of the stabilizer trim switches located on the pilots' control wheels or autopilot trim. The Speed Trim System, including the Speed Trim function and the MCAS function, can also command the trim motor when the autopilot is off. The main electric and autopilot stabilizer trim functions have two speed modes; high speed with flaps extended and low speed with flaps retracted. If the autopilot is engaged, actuating either pair of stabilizer trim switches automatically disengages the autopilot. The stabilizer trim wheels rotate whenever electric stabilizer trim is actuated.

The stabilizer may also be positioned by manually rotating the stabilizer trim wheels.

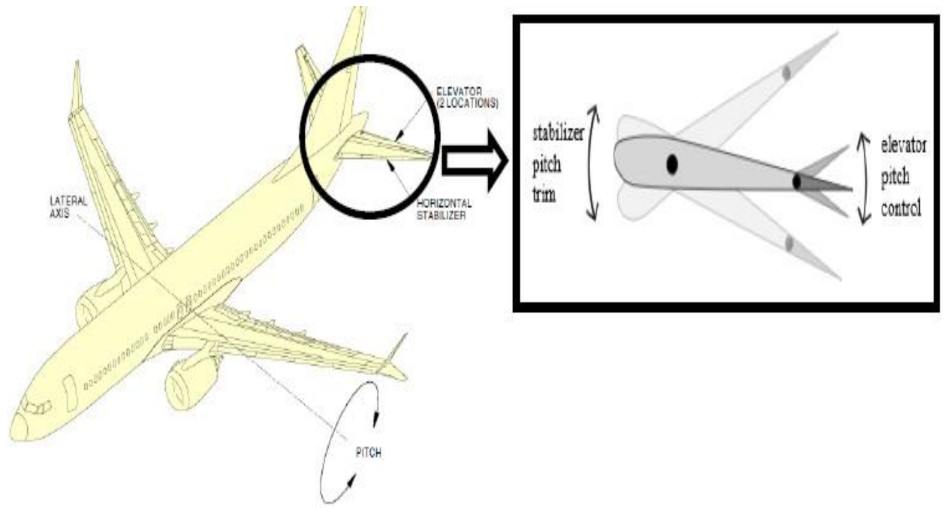

Figure1: HorizontalStabilizerMovement

The total range of the Horizontal Stabilizer movement is 17.1 degrees (or units) which is depicted on the scale on the stabilizer trim indicator located on the center pedestal in the cockpit. As shown in Figure 2, when the stabilizer trim indicator is at the 0 position, the Horizontal Stabilizer is at its full leading-edge up position (Airplane is trimmed full Airplane nose-down).

Figure2: Stabilizer Trim Indicator

D.2.1 Stabilizer System – Operation with Autopilot Off:

D.2.1.1Electric Trim Switch Control:

Stabilizer trim can be commanded by the flight crew by using electric trim switches located on the outboard side of the captain's and first officers control wheels. Each control wheel contains two switches (arm and control) mounted side by side; when activated, the arm switch closes a relay to provide electrical power (115V AC) to the stabilizer trim motor; while the control switch provides the directional control to the stabilizer trim motor. Both switches (arm and control) must be activated in an Airplane nose up or nose down direction in order for the stabilizer trim motor to rotate the stabilizer jackscrew to reposition the horizontal stabilizer.

D.2.1.2Manual Trim Wheel Control:

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 when there is no electric command present to move the stabilizer. Manual rotation of the trim wheels can be used to override the brake systems, autopilot, or main electric trim. The effort required to manually rotate the stabilizer trim wheels may be higher under certain flight conditions. If the stabilizer trim system is actively trimming, grasping the stabilizer trim wheel will stop stabilizer motion. Approximately 15 rotations of the stabilizer trim wheel are required for each degree (unit) of stabilizer movement.

D.2.1.3Speed Trim Function:

The 737 -300, -400 and -500 (737 Classic) as well as the -600/700/800/900 (737 NG) family of Airplanesincorporated a Speed Trim System to augment the basic Airplane 's speed stability during certain low speed, high thrust flight conditions by moving the horizontal stabilizer during manual flight (autopilot is not engaged). The STS was carried over to the 737-7/-8/-9 (737 MAX) family of Airplane s. Additionally, on 737 MAXAirplane s, the MCAS function was added to the STS to address the pitch characteristics described above

The Speed Trim function, which is part of the Speed Trim System, is implemented as a control law within the flight control computer (FCC[3]), and commands incremental stabilizer trim through the automatic trim control system circuitry.There are two different stabilizer trim rates depending on whether position of the flaps[4]. A schedule determines the desired incremental stab deviation from the last trimmed position as a function of airspeed and flap position.

3 The flight control computers (FCC) are part of the Enhanced Digital Flight Control System.

D.2.1.4 MCAS Detailed Description:

The MCAS is a function within the Speed Trim System and, when activated, moves the stabilizer during non- normal flaps up, manual flight, high angle of attack maneuvers to provide a desirable increase in stick for gradient and a reduced pitch up tendency. Similar to the Speed Trim function, the MCAS function is also a flight control law[5] contained within each of the two FCCs. MCAS is only active in the master FCC for that flight. At Airplane power-up, the master FCC defaults to the left side FCC; and will then alternate between the left and right FCC by flight. The master FCC is not affected by the position of the Flight Director switches. The FCCs receive inputs from several systems including the Air Data Inertial Reference System (ADIRS). Figure 3 Specific to the MCAS, the control law commands the stabilizer trim as a function of the following: air/ground signal, flap position, angle of attack, pitch rate, true airspeed and Mach.

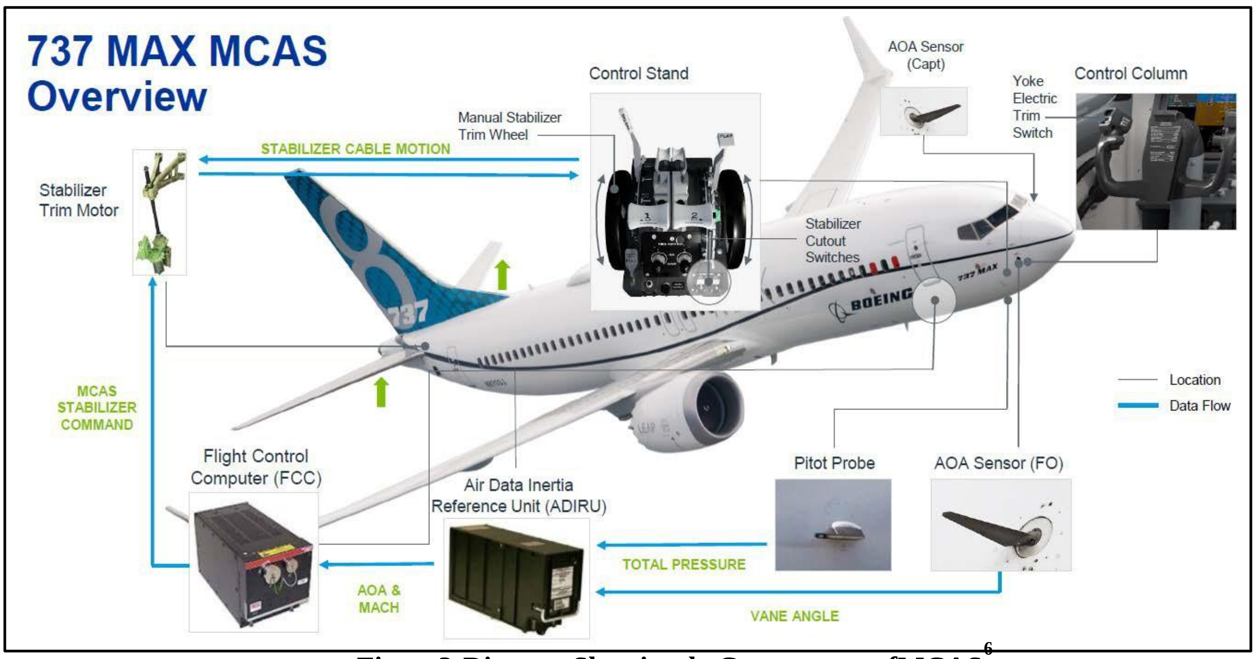

Figure3:DiagramShowingtheComponentsofMCAS[6]

[5] MCASisanopenloopflightcontrollaw.

[6] ReferenceBoeing737MAXMCASbriefing,dated March25,2019.

[7] TheSWSoperatesthecontrolcolumnstickshakerstoalertthecrewwhentheAirplane isnearinganaerodynamic

The AOA and Mach inputs are provided to each FCC by the associated air data inertial reference unit (ADIRU). Each ADIRU receives AOA information from one of the two resolvers contained within the associated AOA sensor (i.e. the Left ADIRU uses left AOA vane and the Right ADIRU uses the right AOA vane). Information from the other resolver contained within the AOA sensor is provided to the Stall Management Yaw Damper Computer (SMYD), which is used, along with data from other sources, for the purpose of calculating and sending commands to the Stall Warning System (SWS) [7]

As originally delivered, the MCAS became active during manual, flaps-up flight (autopilot not engaged) when the AOA value received by the master FCC exceeded a threshold based on Mach number. When activated, the MCAS provided a high rate automatic trim command to move the stabilizer AND. The magnitude of the AND command was based on the AOA and the Mach. After the non-normal maneuver that resulted in the high AOA, and once the AOA fell below a reset threshold, MCAS would move the stabilizer ANU to approximately the original position and reset the system. At any time, the stabilizer inputs could be stopped or reversed by the pilots using their yoke-mounted electric stabilizer trim switches, and then the MCAS system will reset after a 5 second delay.

The latter behavior is based on the assumption that flight crews use the trim switches to completely return the Airplane to neutral trim. In the FCC software version current at the time of the accident, if the original elevated AOA condition persists for more than five seconds following an MCAS flight control law reset, the MCAS flight control law will command another stabilizer nose down trim input (with the magnitude based on the AOA and Mach sensed at that time).

On all 737 models, column cutout switches interrupt stabilizer commands, either from the auto flight system (e.g. FCC) or the electric trim switches in a direction opposite to elevator command. On the 737NG and MAX, two column cutout switching modules, one for each control column, are actuated when the control columns are pushed or pulled away from zero (hands off) column position. When actuated, the column cutout switching modules interrupt the electrical signals to the stabilizer trim motor that are in opposition to the elevator command.

The MCAS function requires the stabilizer to move nose down in opposition to the column commands when approaching high angles of attack. To accommodate MCAS, the column cutout function in the first officer’s switching module was modified to inhibit the aft column cutout switch while MCAS is active, allowing Airplane nose-down (AND) stabilizer motion with Airplane nose-up (ANU) column input. Once MCAS is no longer active, the normal column cutout function in the stabilizer nose down direction is re-instated.

D.2.2 Stabilizer System – Operation with Autopilot On:

When an autopilot is engaged, the trim commands are intended to move the stabilizer in the direction to reduce the amount of trim held by the elevators. With flaps up, the stabilizer trims at .09°/s and with flaps down, the rate is 0.27°/sec.

D.3 Stabilizer Trim Cutout Switches:

There are two stabilizer trim cutout switches located next to each other on the aisle stand just aft of the flap lever. They are identified as the STAB TRIM PRI (stabilizer trim primary) cutout switch and the STAB TRIM B/U (stabilizer trim back up) cutout switch. If either switch is positioned to CUTOUT, power is removed from the stabilizer trim motor and neither main electric trim nor automatic trim can move the stabilizer.

E. Air Data Inertial Reference System:

The Boeing 737 MAX 8 is equipped with an Air Data Inertial Reference System (ADIRS) that provides flight data to the flight deck display panels, flight management computers, flight controls, engine controls and all other systems requiring inertial and air data information. The ADIRS combines the Air Data System (ADS) function and the Inertial Reference System (IRS) function into a single device identified as an Air Data Inertial Reference Unit (ADIRU). The ADIRUs provide inertial position and track data to the flight management system and provide attitude, altitude and airspeed data to the flight deck displays. The ADIRUs process information measured by internal gyros and accelerometers and information from the air data sensors.

E.1 Pitot and Static System:

The pitot static system is comprised of three separate pitot probes and six flush static ports; two of these pitot probes and four of the static ports interface with the Air Data Modules (ADM), which convert pneumatic pressure to electrical signals and send these data to the ADIRUs. The remaining auxiliary pitot probe and alternate static ports provide pitot and static pressure to the standby instruments. The auxiliary pitot probe is located on the first officer's side of the Airplane.

The ADM connected to the Captain's pitot probe sends information to the left ADIRU, while the ADM connected to the First Officer's pitot probe sends information to the right ADIRU. The remaining ADMs are located at the balance centers of the Captain's and First Officer's static ports.The ADM connected to the Captain's static ports sends information to the left ADIRU for display of the captain's instruments, while the ADM connected to the First Officer's static ports sends information to the right ADIRU for display on the first officer's instruments.

The data from the ADIRU is processed by the Display Processing Computer (DPC) in the MAX Display System. The Boeing 737 MAX 8 has two DPCs. The DPC receives ARINC 429 digital data and analog discrete from various Airplane systems. The DPCs processes these data to be displayed on the Display Units (DU) located within the flight deck. Both DPCs receive data from both the left and right ADIRU and either DPC is capable of driving the captain's and first officer's displays.

E.1.1 Air Data Reference (ADR):

The Air Data Reference (ADR) function of the ADIRU is to sense the Airplane 's pitot and static pressures external to the Airplane and convert them into digital electrical signals. These pressures, in conjunction with the Total Air Temperature (TAT) and the Airplane's AOA are used by the ADIRU to calculate basic air data information (parameters) for transmission to various systems on the Airplane. Some of the parameters that the ADIRU transmits include: altitude, computed airspeed, and true airspeed. Another function of the ADIRU is to provide AOA information (corrected angle of attack) directly to the Flight Control Computers as an input to the MCAS function.

Both the altitude and airspeed use static pressure which includes calculations for a correction factor of the Static Source Error Correction (SSEC).This is a compensation for pressure errors caused by the airframe's aerodynamic effects on the static port. The static ports have been located to minimize errors. Compensation for the remaining errors is provided by a correction algorithm comprised of three factors: basic correction, thrust effect compensation and ground effects compensation.

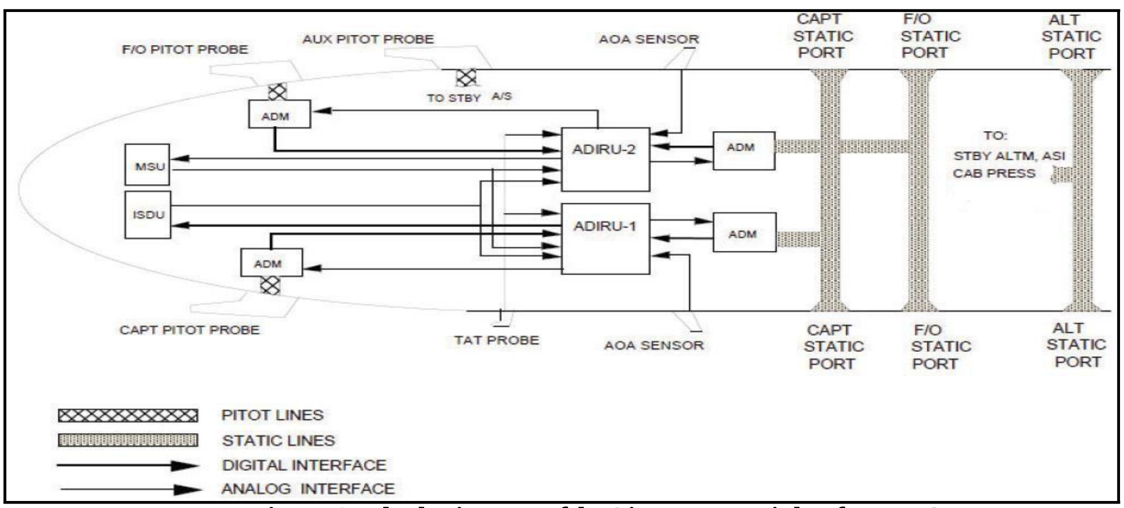

Figure4: BlockDiagramoftheAirDataInertialReferenceSystem

E.2 Altitude and Airspeed PFD Indications:

In the event of certain system failures, the ADIRU output data provided to other systems, including the Display Processing Computer (DPC), may become invalid, e.g. No Computed Data (NCD) or Failure Warning (FW). In response, the Primary Flight Display (PFD) may show a flag on the particular parameter (ALT, SPD, ATT, etc.) with amber color and/or the particular parameter will not be shown in the PFD.

The ALT and/or SPD flags will appear on the PFD if the altitude and/or computed airspeed data from the ADIRU is invalid. The respective altitude and/or computed airspeed data will not be shown on the PFD. These parameter flags are shown in Figure 5 below

Figure5: InstrumentSPDandALTFlagsAppearonPFD

In the DFDR, there is no discrete parameter indicating that the SPD flag is being displayed. However, if either the DFDR parameter of computed airspeed (CAS) left or right shows the characteristic "saw tooth" pattern, that indicates an invalid data status from which it can be concluded that the SPD flag is being displayed on Captain or First Officer primary flight display (PFD).

ALT Flag (amber) means the altitude display has failed. In the DFDR, there is no discrete parameter indicating that the ALT flag is being displayed. However, the DFDR records four parameters of barometric altitude on each altimeter. If these altitudes are marked by the ADIRU as invalid, the DFDR records a "saw tooth" error pattern from which it can be concluded that the ALT flag is being displayed on captain's or FO's PFD.

If the airspeed or altitude values from the left and right ADIRU diverge sufficiently for a certain period of time, the corresponding disagree message will be displayed on both PFDs.

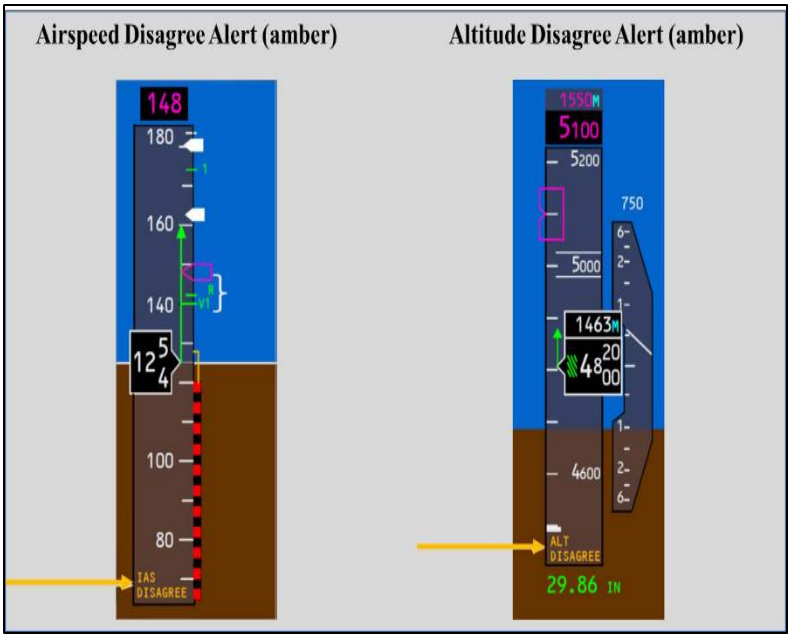

Figure 6: IAS and ALT Disagree Messages on the PFD

The AIRSPEED LOW annunciation alerts the flight crew of low air speed. The alert is an Airplane operational alert that is calculated by the Enhanced Ground Proximity Warning System (EGPWS) and the MAX Display System which occurs when the computed airspeed (from the ADIRU) falls below threshold airspeed between the minimum maneuver speed and stick shaker speed.

The aural alert coincides with the low airspeed alert on the airspeed indication. The minimum maneuver speed is indicated by the top of the amber bar on the PFD when the Airplane is in flight. This airspeed provides:

- The 1.3 g maneuvere capability to stick shaker below approximately 20,000 feet.
- The 1.3 g maneuver capability to low speed buffet (or an alternative approved maneuver capability set in the FMC maintenance pages) above approximately 20,000 ft.

The minimum speed is indicated by the red and black barber pole. The top of barber pole indicates the speed at which stick shaker occurs.

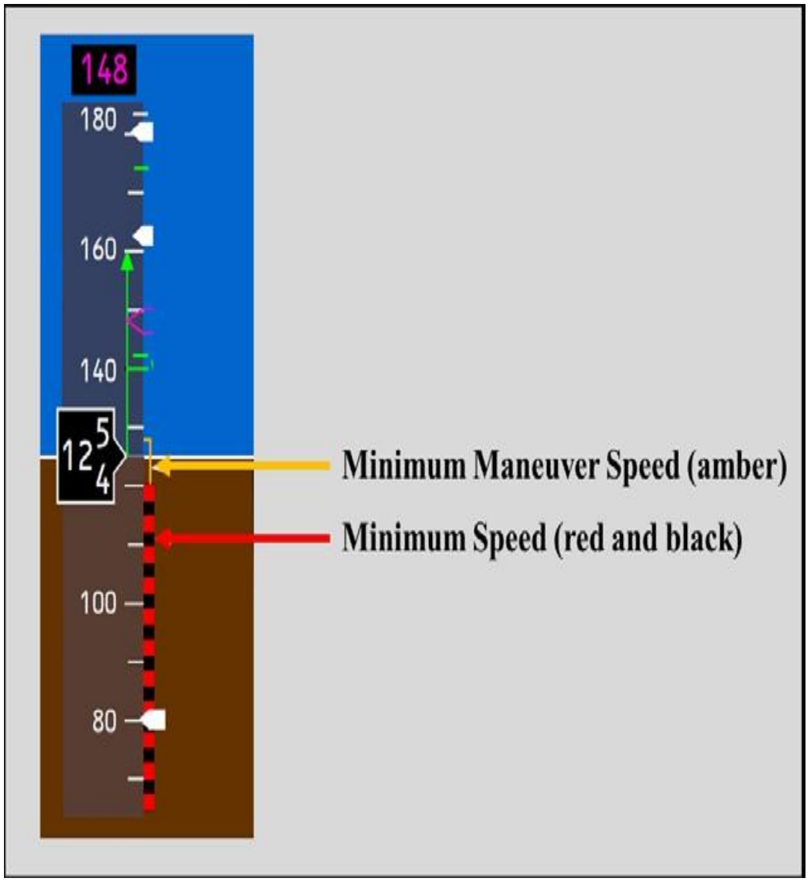

Figure7: MinimumManeuverSpeedandMinimumSpeedIndicationsonthePFD

The Maximum operating speed (Maximum Mach operating speed (Mmo) or Maximum operating speed (Vmo)) is displayed by the red and black barber pole warning band and the Maximum maneuver speed is displayed by the amber bar on top of the speed tape indication on the PFD. The Maximum operating speed is shown in Figure 8 below. The bottom of the barber pole indicates the Maximum speed as limited by the lowest of the following:

- Vmo/Mmo
- Landing gear placard speed
- Flap placard speed

When an over-speed condition occurs, a clacker aural warning will active. The warning clackers can be silenced only by reducing airspeed below Vmo/Mmo.

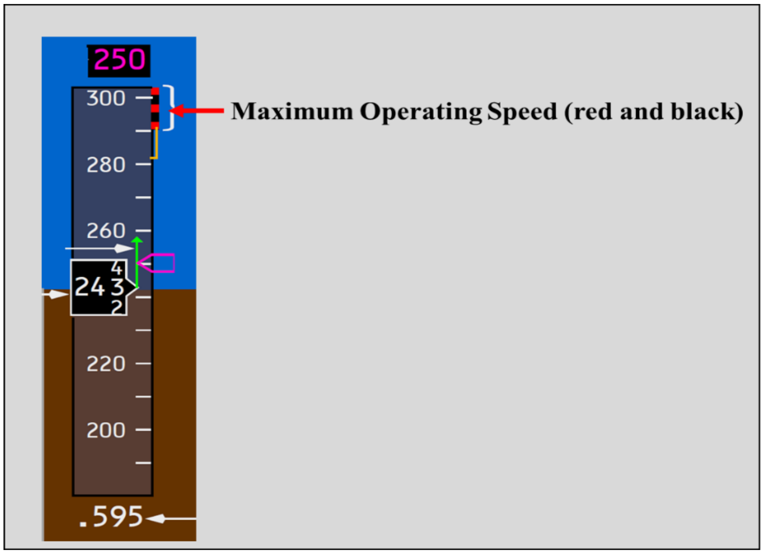

Figure8: Maximum OperatingSpeed

E.3 Angle of Attack (AOA) Sensors

The Boeing 737 MAX 8 has two independent angle-of-attack (AOA) sensors, one on each side of the forward fuselage. The AOA sensors consist of an external vane which rotates to align with the local airflow connected to two internal resolvers which independently measure the rotation angle.

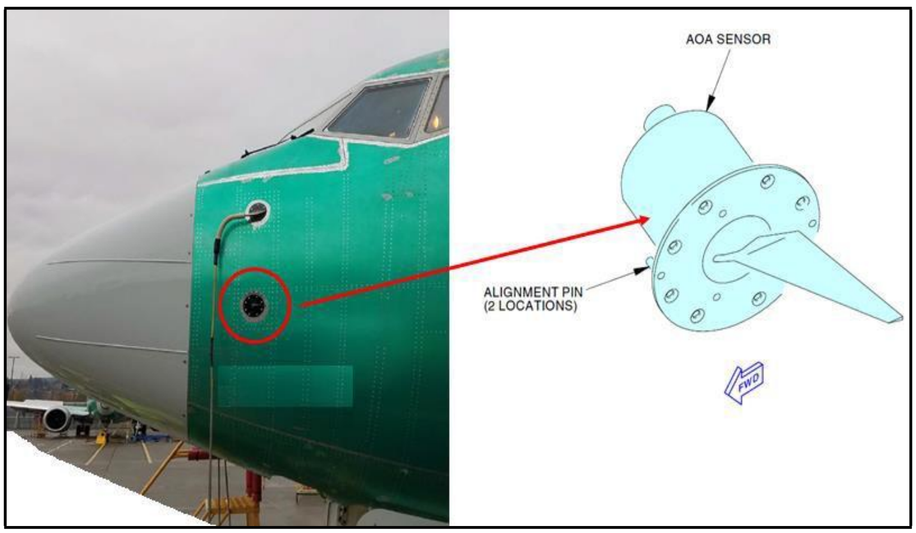

Figure9: AngleofAttack (AOA) Sensor

For each AOA sensor (left and right), one resolver is connected to the respective Stall Management Yaw Damper (SMYD) computer and the second resolver is connected to the respective ADIRU. Both the SMYD and ADIRU monitor the resolvers within the AOA sensor for short or open circuits. If a fault is detected, the AOA resolver information is not used and the fault will result in the ALT and SPD flags being displayed on the PFD.

There is no scheduled maintenance for AOA sensors. Any required maintenance is a consequence of annunciated faults or observed malfunctions. This practice is Known as “on-condition” maintenance.

E.3.1 AOA Display Option

Boeing provides the option for the operator to install the AOA indicator on the PFD for Boeing 737 MAX 8. The respective PFD will show the AOA information as shown in Figure 10 below

Figure10:AOA Indicator on PFD

As shown in Figure 11 the AOA DISAGREE message appears on the captain’s and first officer’s PFDs when the values of the left and right AOA transmitted by the ADIRUs sufficiently diverge. The annunciation is only displayed in the air because AOA values are unreliable when the Airplane is stationary on the ground.

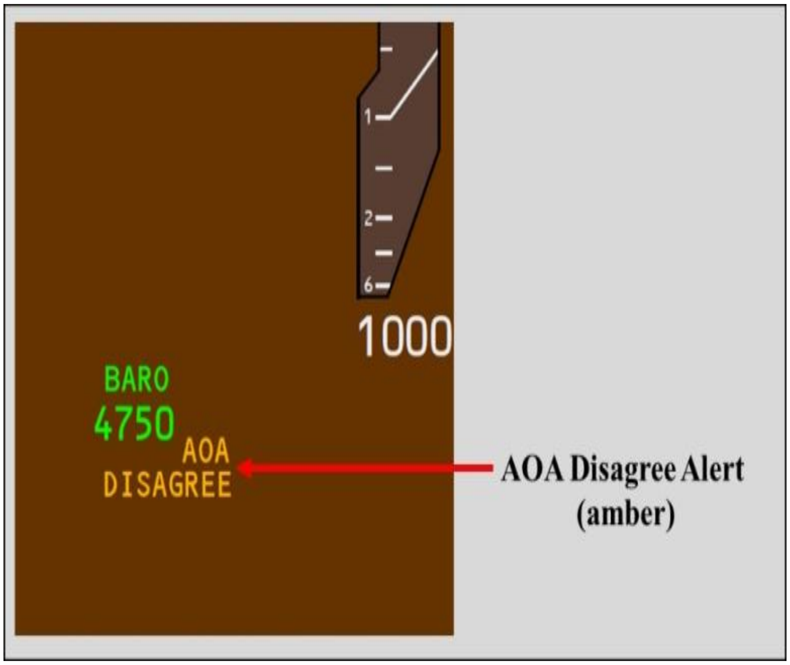

Figure11:AOA Disagree Message on the PFD

The AOA DISAGREE message was first implemented on the Boeing 737 NG fleet in 2006 in response to customer requests. Since 2006, the AOA DISAGREE alert has been installed on all newly manufactured Boeing 737 NG Airplane and is available as a retrofit for older Airplane. The requirements for the AOA DISAGREE alert were carried over from the Boeing 737 NG to the Boeing 737 MAX 8. In 2017, however, within several months after beginning Boeing 737 MAX 8 deliveries, Boeing identified that the 737 MAX 8 display system software did not correctly implement the AOA DISAGREE alert requirements. As with the Boeing 737 NG, the Boeing display system requirements for the 737 MAX 8 called for the activation of the AOA DISAGREE alert as a standard feature on all Airplanes. The software delivered to Boeing, however, linked the AOA DISAGREE alert to the AOA position indicator, which is an optional feature on the Boeing 737 MAX series. Accordingly, the software activated the AOA DISAGREE alert only if an airline opted for the AOA indicator. At the time of the accident, Boeing advised that the AOA indicator has been selected by approximately 20% of airlines.

Boeing advised that new software implementing the AOA DISAGREE alert will be available before the 737MAX 8 Airplane returns to service.

F. Autopilot, Flight Director, and Autothrottle:

The Boeing 737 MAX 8 is equipped with an Enhanced Digital Flight Control System (EDFCS). The EDFCS system on the 737 MAX 8 is the same as the 737 NG with the following added functionality in the flight control computer (FCC) software: 1) Maneuvering Characteristics Augmentation System (MCAS), 2) Emergency Descent in Autopilot and Flight Level Change Mode, 3) Spoiler Control Electronics Interface, and 4) Autopilot Roll Command Alerting System. The EDFCS provides integrated operation of the following major flight control functions:

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- Altitude Alert
- Autopilot (including Autoland)
- Flight Director
- Speed Trim
- Mach Trim
- Maneuvering Characteristics Augmentation System (MCAS)

- FMC Interface & Mode Control
- Autothrottle Interface, N1 Limits, & Mode Control (for those Airplanesequipped with a separate external auto throttle computer)

The EDFCS has a mode control panel (MCP), two FCC's, and actuator inputs to the flight control system. The MCP is the primary interface between the flight crew and the FCCs. The FCCs get inputs from several systems such as the Air Data Inertial Reference System (ADIRS) and the Flight Management Computer (FMC) and sends commands to the aileron and elevator actuators. These actuators control the movement of the ailerons and elevators, which control the flight path of the Airplane. There are two autopilots, autopilot A from FCC A and autopilot B from FCC B. When you engage an autopilot from the MCP, the autopilot can control the Airplane attitude through these phases of flight: Climb, Cruise, Descent, Approach, Go-around and Flare.

F.1 Autopilot

The autopilot is engaged by selecting one of two autopilot push button engage switches located near the right edge of the MCP, between the Vertical Speed display window and the right hand Flight Director toggle switch. The control column force must be less than 5 lbs. and the control wheel force must be less than 3 lbs. for the autopilot to engage. If the forces exceed these values, then attempting to engage the autopilot results in an autopilot disconnect warning.

The normal autopilot disengagement mechanism is via the quick disconnect pushbutton switches on the captain's and first-officer's control wheels. An alternate disengage mechanism is provided by the disengage bar located on the bottom edge of the MCP just below the engage buttons. An amber strip is exposed when the bar is down to positively indicate activation of the disengage bar. Pressing a lighted engage pushbutton also disconnects the autopilot (except when dual engaged for fail operational autoland—in this case only the corresponding channel disconnects).

Certain failures of the EDFCS or interfacing systems will cause the autopilot to automatically disconnect when the failure occurs. The autopilot may also automatically disconnect upon use of certain source select switches but can (sometimes) be reengaged.

Upon autopilot disconnect, the autopilot disengage light on the Autoflight Status Annunciator will indicate disconnect by flashing red. The annunciator is located just above both the Captain's and First Officer's Secondary EFIS displays. This will be accompanied by an aural warning. The pilot may reset the warnings by pressing the autopilot disengage switch on the wheel or the light on the Warn Annunciator. The warning will continue for 2 seconds regardless of how quickly the pilot might reset the warning. The disengage light will illuminate steady red for the following conditions, indicating that the pilot should disengage the autopilot or that it is unusable:

- Altitude Acquire inhibited from autopilot go-around due to elevator position being beyond single channel authority.
- A detected failure of the FCC/MCP Interface during autopilot go-around
- The system is in BITE mode.
- Stabilizer is out of trim during dual channel approach below 800' R/A.
- Incompatible FCC part numbers.

F.2 Flight Director

Selecting a Flight Director toggle switch to the ON position activates the Flight Director. The left switch enables the Flight Director Command bars on the captain's primary EFIS display. The right switch enables them on the first officer's display. When a Flight Director is initially selected ON, the bars will be out of view and there will be no active mode. Subsequent use of the TOGA switch or an MCP mode selection will bring the bars into view.

The Flight Director Master light located next to the switch indicates which baro correction is currently in-use by the autopilot/Flight Director for calculations such as Altitude Alert or Altitude Acquire. Under normal operations, the left FCC provides the Flight Director commands for the left display and the right FCC provides similar commands for the right display. The Flight Director Command bars are biased out of view in the event of a mode failure. Flight Director Selection is annunciated by a green “FD” on the primary EFIS display when the autopilot is not engaged. Flight Director Modes may be engaged and used alone or may be displayed in conjunction with autopilot operation.

F.3 Autothrottle

The auto throttle (A/T) system provides automatic thrust control from the start of takeoff through climb, cruise, descent, approach and go–around or landing. The A/T system controls engine thrust in response to the mode selected by the flight crew through the EDFCS, Mode Control Panel (MCP), Flight Management Computer (FMC) and ADIRU. The speed information taken from the ADIRU is used to calculate throttle lever rate commands to set engine thrust during changing flight conditions. All the information is processed by FCC A, which provides commands to the thrust lever servo motors controlling thrust lever movement.

The auto throttle Arm switch is a magnetically held two-position switch, located on the left side of the MCP, between the IAS/MACH display window and the left Flight Director toggle switch. Arming the A/T is preparing the system to engage in the N1, MCP SPD, or FMC SPD mode. A green light near the auto throttle Arm switch is illuminated when the auto throttle Arm switch is in the ARM position. In the ARM state the auto throttle will accept mode requests from the autopilot or TOGA switch and engage the appropriate auto throttle mode. While on the ground, the FMC must be in the takeoff mode for the auto throttle Arm switch to hold in the ARM position and arm the system. Moving the auto throttle Arm switch to OFF or activating an auto throttle quick disengage switch (which causes the auto throttle Arm switch to move to the OFF position) disconnects the auto throttle. There is an auto throttle quick disengage switch installed on the outside edge of each thrust lever. Four auto throttle modes are available: N1, Speed, Go-Around and Retard. For each flight phase the flight crew can select the A/T N1 or speed modes from the MCP or directed by the FMC. During takeoff, pushing TO/GA switch engages the A/T in N1 mode and causes the engine thrust to increase to the takeoff (TO) N1.

Mode	Function
Speed	Maintain a user-selected speed. Throttle will be controlled from idle up to the N1 thrust limit shown on the EICAS display as needed. Throttle movements occur at a slow throttle rate.
N1	Maintains thrust at the full N1 limit.
Go-Around	Advances thrust sufficient for a reasonable climb. Further advances thrust to G/A limit if TOGA switch pressed a second time.
Retard	Retard throttles to idle during level change descents and flare.
Throttle Hold	Holds thrust lever position (autothrottle servomotors depowered) during takeoff when speed exceeds 80kts to protect against autothrottle erroneous retard failures.

Figure12:AutothrottleModes

G. Stall Warning:

Natural stall warning (buffet) usually occurs at a speed prior to stall. In some configurations the margin between stall and natural stall warning is less than desired. Therefore, an artificial stall warning device, a stick shaker, is used to provide the required warning.

Each control column has an eccentric weight motor which can vibrate the column to alert the pilots before a stall develops. The system is armed in flight at all times. The system is deactivated on the ground, except during the ground test. Two independent, identical SMYD computers determine when stall warning is required based upon:

Alpha vane angle of attack outputs
ADIRU outputs
Anti–ice controls
Wing configurations
Air/ground sensing

Thrust
FMC outputs

The AOA sensor is connected to the SMYD and provides the measured angle of the direction of airflow relative to the fuselage. If the AOA sensor detects an excessive angle of attack compared to the design characteristic of the 737 MAX 8, the SMYD will activate the stick shaker to provide aural and tactile alert to the flight crew.

Two SMYD computers provides output for stall warning to include stick shaker, Pitch Limit Indicator, and maneuver and operating airspeed limits. The No.1 SMYD activates the Captain's stick shaker, and the No. 2 SMYD activates the F/O stick shaker. Vibrations from either stick shaker can be felt in both columns through the mechanical column interconnect.

H. Enhanced Ground Proximity Warning System (EGPWS):

The Enhanced Ground Proximity Warning System (EGPWS) provides the aural alert "Bank Angle" when excessive roll of the Airplane occurs. The alert is based on radio altitude and bank angle under the following conditions:

- From 5 feet to 30 feet AGL, the alert sounds when the bank angle exceeds 10 degrees
- From 30 feet to 130 feet AGL, when the alert sound varies linearly from a bank angle of 10 degrees at 30 feet AGL, to a bank angle of 35 degrees at 130 feet AGL
- Above 130 feet AGL, the alert sounds when the bank angle exceeds 35 degrees.

A "Don't Sink" aural is generated by EGPWS Mode 3. Mode 3 provides alerts for excessive altitude loss after takeoff. Mode 3 is based primarily on radio altitude, altitude[8], and altitude rate[9]. The Mode 3 alerting envelope is a function of radio altitude and altitude loss. The amount of altitude loss required for an alert varies as a function of flight profile and time.

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[8]AltitudeusedforMode3isIRUinertialaltitude, internallycomputedinertialaltitude,or ADC barometric altitude

[9]AltituderateusedforMode3isIRUinertialverticalspeed, internally computed inertial altituderate, or ADC barometric altitude rate

APPENDIX J: FDR AND CVR EXAMINATION

The FDR was first visually examined. The chassis was damaged and folded on itself. The acquisition boards were visible as well as some internal connectors. The protected module Crash Survival Module Unit (CSMU) was still attached to the chassis and presented scratches. There was no ULB attached to the CSMU. A recorder identification plate was found close to the CSMU on the chassis, but not fixed to the chassis, on which the following numbers were written: P/N 2100-4945-22, S/N 001217995

FIGURE 1: FDR FOUND IN THE SUITCASE BROUGHT BY ETHIOPIAN EAIB

As the chassis and the CSMU were damaged, it was decided to open the CSMU to extract the memory puck. The CSMU was unscrewed from the chassis. The interface board located under the CSMU was damaged. The flex connector between the interface board and the memory puck was found broken and the flex between the interface board and the chassis was also found broken.

The identification located under the CSMU was P/N 253-E5675-05 and S/N 001230922. According to *Model FA2100 FDR CMM*, published by L3, version Fev 2018, the part number 253E5675-05 corresponds to a FDR CSMU of 2GB NAND memory. The identification sticker under the CSMU confirmed that this recorder was a FDR. In addition, the identification plate found on top of the recorder confirmed that this was the FDR of ET-AVJ Airplane.

The cover of the CSMU was unscrewed. The insulation material inside the CSMU was no longer compact and it was scooped out to access the memory puck.

FIGURE 2: AT OPENING THE FDR CSMU, SHOWING THE MEMORY PUCK AND FLEX

It was first attempted to extract the memory puck by gently pulling on the flex. It was found that the connector was not properly attached to the memory puck.

The memory puck was opened and the electronic board containing the memory component support was extracted. The memory board identification was P/N 205-E5458-04, S/N 001157901 and the flex identification was 024-E5675-20 REV, 1809-1.

FIGURE3: FDR MEMORY BOARD, FLEX AND CONNECTOR

The memory board was visually inspected with a Keyence microscope. Apart from the connector pads, the memory board was in good condition. There was no trace of impact. The two memory chips as well as the micro-processor were found in good condition.

FIGURE 4: FDR MEMORY BOARD

At the connector location on the memory board the first 8 pads (on Figure 4)) were found missing. The holes were filled with insulation dust. The last 12 pads were in good condition.

When examining the flex and connector, it was found that the missing pads from the memory board had migrated to the connector pins. There were also pieces of PCB material on the connector pins.

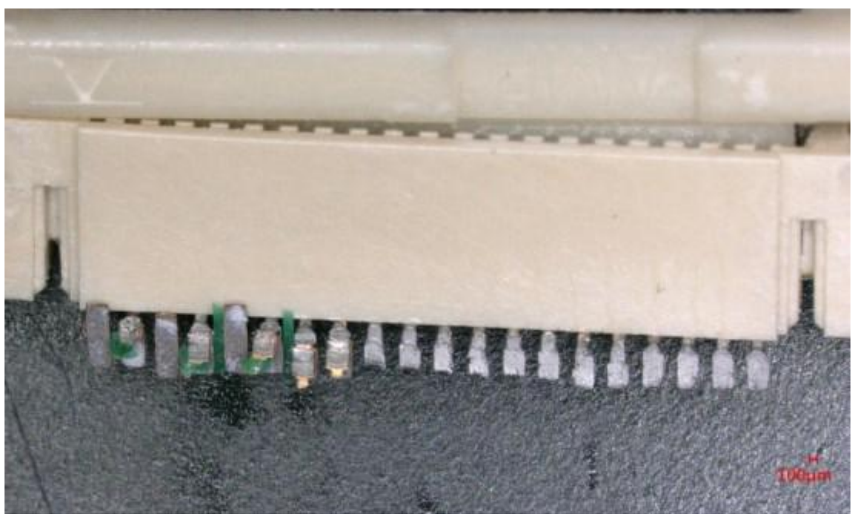


Figure5: Pads and pieces of PCB material on the connector pins

The FDR memory board was also inspected with the X-ray machine. This confirmed that the first 8 pads of the connector were missing on the memory board (*Figure 4*) and that the 12 others were in good condition. There was continuity between those 12 pads and their vias (left side on *Figure 4*).

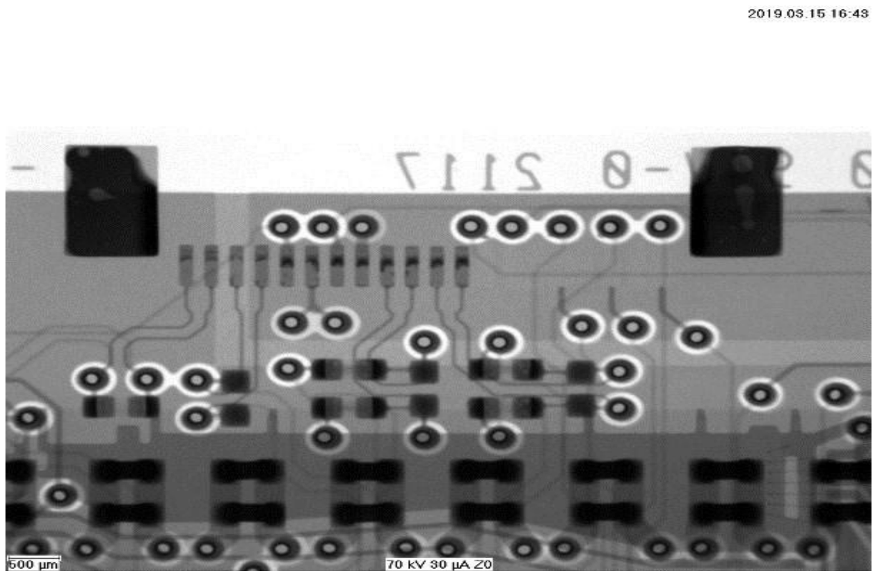


FIGURE 6: X-RAY EXAMINATION OF THE FDR MEMORY BOARD SHOWING THE 8 MISSING PADS

This confirmed that data extraction operations could not be performed without re-soldering a new connector on the memory board.

Discussion with the recorder manufacturer

On March 15th, following the opening operations of the FDR, it was decided to consult the recorder manufacturer L3. The objective was to present a repair proposal with a connector from a similar new unit, to obtain an agreement from L3 to proceed and have mapping information on the connector.
During the conference call, L3 confirmed that the repair proposal was adequate to repair the board.
L3 also confirmed that the two versions of the flex cable, cable 024-E5675-02 REV and cable 024-E5675-20 REV are interchangeable. The new version -20 was developed to enhance the resistance of the flex.

L3 confirmed late evening on March 15th that the 8 missing pads (1 to 8) were not necessary for the download of the data. Pins 1 to 6 are used for programming the memory and pins 7 and 8 are reserved for future use.
On March 16th, all parties agreed that it was only necessary to resolder the last 12 pins of a new connector (pins 9 to 20, on the left side of *Figure 10*) to the FDR memory board to download the data.

FDR data validation

The binary file was synchronized with the BEA software used for FDR analysis (LEA). It was a 1024 WPS, UPK, and Teledyne. In total there was 18 synchronized zones and a total of 264 569 seconds were synchronized, corresponding to more than 73 hours. The synchronization rate was 99.9807%.

Validation of parameters

The FDR data were decoded using the Boeing data frame described in the document *Digital flight data acquisition unit 737 MAX Data frame interface control and requirements* document, reference D226A101-6, rev E dated 10th January 2019. NTSB provided this data frame document on March 13th, 2019.

The validation of the data extraction was made using the following parameters

- Altitude 101325mb Left & Right / Radio height Left & Right
- Computed airspeed Left & Right / Ground speed
- CMD A / CMD B
- Control Column Position Capt & FO
- Control Column Force Pitch Capt & FO
- Elevator Position Left & Right
- Angle of Attack Indicated Left & Right
- Stick Shaker Left & Right
- Pitch Trim Position
- Trim up Manual / Trim up AP / Trim Down Manual / Trim Down AP
- Flap Handle Position
- Pitch angle right
- Inertial Vertical Speed
- Vertical Acceleration
- Longitudinal Acceleration

Description of the validation

The validation focus was made on the last 10 minutes of recorded data. All parties agreed that the events of the accident flight were present in the FDR.

As the validation process, a focus was made on the angle of attack parameters. The left and right angle of attack parameters showed significant differences during the accident flight. Those two parameters showed similar values during the end of the previous flight (and were within coherent range).

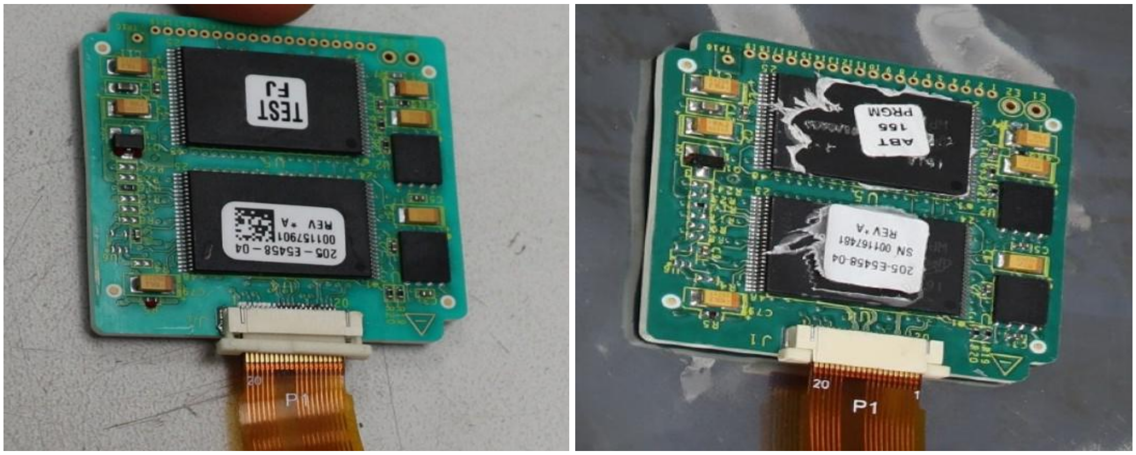


FIGURE 7: ET-AVJ FDR MEMORY BOARD WITH INTERFACE BOARD CONNECTOR FROM BEA SURROGATE RECORDER (LEFT), BEA SURROGATE RECORDER MEMORY BOARD WITH ORIGINAL CONNECTOR (RIGHT), BOTH MOUNTED WITH FLEX CABLE PIN VISIBLE AND "P1" WHEN PERFORMING READOUT

CVR EXAMINATION

2.1. Opening

The CVR CSMU was already separated from its chassis when it was brought to the BEA facilities. There was no ULB attached to it and no identification plate was found on the CSMU.

The isolated chassis was damaged and still partially attached to the Airplane rack on which it was mounted. There was no identification plate on it. Wires were visible on the back side.

FIGURE: 8 CVR CSMU AND CHASSIS WHEN BROUGHT BY ETHIOPIAN EAIB

The CSMU case showed an opening. The hole on the side opposite to the ULB fixation allowed seeing the internal insulation material

FIGURE 9: CVR WHEN OPENING THE SUITCASE BROUGHT BY ETHIOPIAN EAIB

The interface board that is supposed to be located under the CSMU was missing and the flex connecting it to the memory puck was damaged.
It was decided to open the CSMU to extract the memory puck. The first 3 screws were removed but it was not possible to remove the last one due to deformation of the screw head. The cover was slid to allow the removal of the memory puck. The insulation material inside the CSMU was no longer compact and it was scooped out.

The memory board identification was P/N 205-E5458-04, S/N 001158641 and the flex identification was 024-E5675-20 REV, 1809-1.

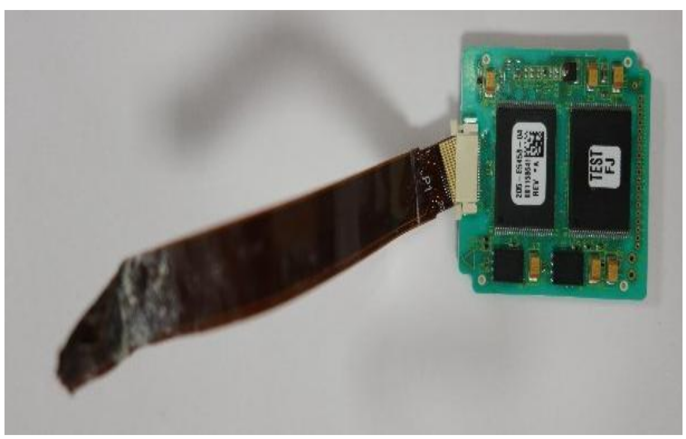


FIGURE 10: CVR MEMORY BOARD AND FLEX

The CVR memory board and flex were visually inspected with the Keyence microscope. There was no damage on the board and the connector was in good condition.
A second observation with the X-ray was made, which confirmed that the connector soldering were in good condition.

APPENDIX K: BOEING RESPONSE

***Boeing Response to Recommendation*1**

FSBR-B737-Rev-17

PILOT TRAINING

9.1 Airman Experience. Airmen receiving initial, differences, upgrade, or transition training are assumed to have previous airman experience. Applicable previous experience may include multiengine transport turbojet airplane, new generation avionics, high altitude operations, military, or flight management system (FMS). Pilots without this experience may require additional training.

9.2 Special Emphasis Areas.

***Note*:** References to "pilots" in this section include both pilots in command (PIC) and seconds in command (SIC) unless otherwise specified.

9.2.1 Pilots must receive special emphasis on the following areas during ground training:
9.2.1.1 Multiple flight deck alerts during non-normal conditions. Training must include instances where a single malfunction results in multiple flight deck alerts, and flight crew alert prioritization and analysis of the need to conduct additional NNCs. This training must be included in initial, upgrade, transition, and recurrent training.

9.2.1.2 Automatic landings. When an operator is authorized for autoland operations, ground training is required during a preflight briefing prior to flight training. This item must be included in initial, upgrade, transition, differences, and recurrent training. The 737NG and 737 MAX autoland systems are identical and do not require differences training unless transitioning between the Fail Passive system and the Fail Operational system.

9.2.1.3 Enhanced Digital Flight Control System (EDFCS). When an EDFCS that supports Fail Operational autoland operations with a Fail Passive Rollout system is used, ground training is required during a preflight briefing prior to flight training. This item must be included in initial, upgrade, transition, differences, and recurrent training. The 737NG and 737 MAX autoland systems are identical and do not require differences training unless transitioning between the Fail Passive system and the Fail Operational system.
9.2.1.4 737 MAX flight control system. The Elevator Jam Landing Assist system and the Landing Attitude Modifier (LAM) ground training must address the system functions and associated flight spoiler deployments. These items must be included in initial, transition, differences, and recurrent training.
9.2.1.5 737 MAX FCC. MCAS ground training must address the latest FCC system description, functionality, and associated failure conditions to include flight crew alerting. This training must be included in initial, transition, differences, and recurrent training.

9.2.1.6 HUD. Training must address appropriate ground training elements for both HUD and non-HUD operations as specified in Appendix 5, Head-Up Guidance Training. This item must be included in initial, upgrade, transition, differences, and recurrent training.
9.2.1.7 737 MAX gear handle. Gear handles operation to address normal and non-normal procedures. This item must be included in initial, transition, differences, and recurrent training.
9.2.2 Pilots must receive special emphasis on the following areas during flight training.
9.2.2.1 Automatic landings. When an operator is authorized for autoland operations, flight training must occur with the appropriate autopilot (AP) autoland systems (e.g., Fail Operational vs. Fail Passive). This training can occur in either a full flight simulator (FFS) or airplane. Flight training must ensure appropriate AFM limitations are addressed and complied with. This item must be included in initial, upgrade, transition, differences, and recurrent training. The 737NG and 737 MAX autoland systems are identical and do not require differences training unless transitioning between the Fail Passive system and the Fail Operational system.
9.2.2.2 EDFCS. When an EDFCS that supports Fail Operational autoland operations with a Fail Passive Rollout system is used, flight training can occur in either an FFS or airplane and should address dual channel AP approaches. This item must be included in initial, upgrade, transition, differences, and recurrent training. The 737NG and 737 MAX autoland systems are identical and do not require differences training unless transitioning between the Fail Passive system and the Fail Operational system.
9.2.2.3 HUD. When HUD is installed and an operator is authorized HUD operations, training must address appropriate flight training elements for both HUD and non-HUD operations as specified in Appendix 5. This item must be included in initial, upgrade, transition, differences, and recurrent training.
9.2.2.4 Stabilizer trim.
9.2.2.4.1 Training must emphasize the following during electric and manual stabilizer trim operations:
a) Manufacturer recommended procedures for the proper use of main electric stabilizer trim during normal and non-normal conditions, and manual stabilizer trim during normal and non-normal conditions;

b) The different manual trim techniques recommended by the manufacturer; and

c) The effects of airspeed and aerodynamic loads on the stabilizer and the resulting trim forces in both the nose-up and nose-down directions during operations at low and high airspeeds.

d) Use of manual stabilizer trim during approach, go-around, and level off.

9.2.2.4.2 Electric and manual stabilizer trim operation during normal and non-normal conditions. This item must be included in initial or transition training and must be accomplished at least once every 36 months during recurrent training.
9.2.2.5 Runaway stabilizer. Training must emphasize runaway stabilizer recognition and timely pilot actions required by the Runaway Stabilizer NNC. Demonstrate control column functionality and its effect on a runaway stabilizer condition. Emphasize the need to attempt to reduce control column forces with main electric

stabilizer trim prior to selecting STAB TRIM cutout. This item must be included in initial or transition training and must be accomplished at least once every 36 months during recurrent training.
9.2.2.6 Multiple flight deck alerts during non-normal conditions. Training must include scenario-based training where a single malfunction results in multiple flight deck alerts that require timely pilot actions to include recognition and interpretation of the non-normal condition and prioritization of the required pilot actions. This training must be included in initial, upgrade, transition, and recurrent training.
9.2.2.7 Unreliable airspeed. This training applies to pilots flying the 737NG, 737 MAX, or conducting 737NG/737 MAX Mixed Fleet Flying (MFF). Training must include erroneous high angle of attack (AOA) malfunctions. This training must also include a demonstration of Flight Director (FD) behavior (biasing out of view) during a go-around or missed approach. This item must be included in initial, transition, and differences training and must be accomplished at least once every 36 months during recurrent training. Either pilot may serve as pilot flying (PF) for this training task. Recurrent training may be accomplished in either a 737NG or 737 MAX FFS.

***Boeing Response to Recommendation* 2**

APPENDIX 7- BOEING 737 MAX SPECIAL TRAINING FOR FLIGHTCREWS

The purpose of this appendix is to describe ground and flight training requirements associated with pilot qualification on the 737 MAX. The MDR Table makes reference to this appendix with the use of an asterisk (shown as E*).
No pilot may operate the 737 MAX unless the ground and flight training documented in this appendix has been completed. References to “pilots” in this section include both PICs and SICs unless otherwise specified. These Special Training segments can be standalone or embedded into another training curriculum. Some tasks outlined in this appendix are purposely omitted from Section 9.2, Special Emphasis Areas. The required training is as follows:

1. GROUND TRAINING

1.1 Training on the following NNCs:

- Runaway Stabilizer.
- SPEED TRIM FAIL.
- STABILIZER OUT OF TRIM.
- Stabilizer Trim Inoperative.
- Airspeed Unreliable
- ALT DISAGREE
- AOA DISAGREE

1.2 Training in this section emphasizes the design differences associated with FCC software version P12.1.2 for the 737 MAX. This training also emphasizes necessary ground training between the 737NG and 737 MAX with FCC software version P12.1.2 or later. Pilots may complete this training by accomplishing the applicable 737 MAX CBT provided by Boeing or an FAA-approved equivalent.

1.2.1 ATA 22 – Autoflight – FCC – MCAS:
- MCAS function description.
- Conditions for operation.
- Erroneous FCC trim commands.
- Flight deck alerting of the failure of the MCAS function.

1.2.2 ATA 22 – Autoflight – FCC – AFDS:
- Automatic AP disengagement.
- Temporary FD removal.
- AFDS pitch mode changes following stick shaker.
- Inhibiting of AP nose up trim.

1.2.3 ATA 22 – Autoflight – FCC – STAB OUT OF TRIM:
- Alert illumination logic (ground vs. flight).
- Revised NNC.

1.2.4 ATA 22 – Autoflight – FCC – SPEED TRIM FAIL:
- Function of the SPEED TRIM FAIL light.
- Revised NNC.

1.3 Training on the following bullet points that emphasize Boeing-recommended procedures. Pilots may complete this training by accomplishing the applicable 737 CBT provided by Boeing or an FAA-approved equivalent.

1.3.1, 737 Manual Trim Operation
- Manual stabilizer trim operation.
- Manual stabilizer trimming techniques.
- Effects of airspeed and aerodynamic loads on manual stabilizer trim operation.

1.3.2, 737 Unreliable Airspeed – Determining a Reliable Airspeed
- Recognition of flight deck effects of an unreliable airspeed condition.
- Memory pitch and thrust settings associated with the NNC.
- Determination of reliable airspeed indication.

2. FLIGHT TRAINING

Training is required to be conducted in a 737 MAX Level C or D FFS. The following bullet points emphasize the objectives of each maneuver. This training applies to pilots flying the 737 MAX, or conducting 737NG/737 MAX MFF. A 737NG Level C or D FFS may be used for some conditions where noted below.

2.1 Demonstration of MCAS activation accomplished by each pilot acting as PF.

2.1.1 MCAS activation during an impending stall (or full stall) and recovery demonstration during manual flight in a clean configuration.

2.1.2 Demonstrate MCAS activation stabilizer trim responses:
- Stabilizer trim in the nose down direction when above threshold AOA for MCAS activation during stall.

- Stabilizer trim in the nose up direction when below threshold AOA for MCAS activation during recovery.

2.2 Runaway stabilizer condition requiring use of manual stabilizer trim accomplished by each pilot acting as PF.

2.2.1 Runaway stabilizer training as described in subparagraph 9.2.2.5.

2.2.2 Operation of each manual trim technique (as defined by Boeing).

2.2.3 This training can be completed in a 737 MAX or 737NG FFS.

2.3 Use of manual stabilizer trim during approach, go-around, and level off accomplished by pilot acting as PF.

2.3.1 Use of manual stabilizer trim as described in subparagraph 9.2.2.4.

2.3.2 This training can be completed in a 737 MAX or 737NG FFS.

2.4 A Cross-FCC Trim Monitor activation demonstration accomplished by either pilot acting as PF.

2.4.1 Condition must terminate in a landing in order to demonstrate the updated STAB OUT OF TRIM light functionality.

2.5 Erroneous high AOA during takeoff that leads to an unreliable airspeed condition accomplished by either pilot acting as PF.

2.5.1 Demonstrates flight deck effects (i.e., aural, visual, and tactile) associated with the failure.

2.5.2 Fault occurring during the takeoff procedure.

2.5.3 Must include a go-around or missed approach flown with erroneous high AOA condition.

2.5.3.1 Special emphasis placed on FD behavior biasing out of view upon selecting takeoff/go-around (TO/GA).

***Boeing Response to Recommendation* 3**

737 RTS summary (11-18-2020)

13.1 Safety Issue #1: Use of Single Angle of Attack (AOA) Sensor

In the original design, erroneous data from a single AOA sensor activated MCAS and subsequently caused airplane nose-down trim of the horizontal stabilizer. In the new design, Boeing eliminated MCAS reliance on a single AOA sensor signal by using both AOA sensor inputs and through flight-control law changes that include safeguards against failed or erroneous AOA indications. The updated FCC software with revised flight-control laws uses inputs from both AOA sensors to activate MCAS. This is in contrast to the original MCAS design, which relied on data from only one sensor at a time, and allowed repeated MCAS activation as a result of input from a single AOA sensor. The updated FCC software compares the inputs from the two sensors to detect a failed AOA sensor. If the difference between the AOA sensor inputs is above a calculated threshold, the FCC will disable the STS, including its MCAS function, for the remainder of that flight and provide a corresponding indication of such deactivation on the flight deck. Other safety issues are also included in 737RTS summary (11-18-20).

Boeing Response to Recommendation 4

737 RTS summary (11-18-2020)

The Cross-FCC Trim Monitor is a new feature to address Safety Item #6: OTHER POSSIBLE FCC STABILIZER RUNAWAY FAILURES and provides additional protection against erroneous FCC trim commands caused by postulated failures in the FCC Lane 2 CPU or I/O chips. Boeing implemented cross FCC Trim Monitor, which can effectively detect and shut down erroneous stabilizer commands from the FCCs. This makes continued safe flight and landing for this type of failure not dependent on pilot reaction time.This monitor is implemented in Lane 2 of the FCC.

While the FCCs are powered, each FCC continuously monitors the other FCC channel, except during dual-channel autopilot operation or when a Fail-operational configured airplane is performing an Autoland or automatic Go-Around. The FCC channel in which the autopilot or CWS is engaged, or which is the STS selected channel, is referred to as the operational FCC channel. The other FCC channel is referred to as the standby FCC channel.

The monitor compares the trim-up and trim-down command outputs from both FCCs with its own trim command calculation. The operational channel performs its normal stabilizer trim-command calculations for use by the monitor. The standby channel switches its data sources to use the same data as the operational channel to perform its stabilizer-command calculations for use by its monitor.

Boeing Response to Recommendation 5

737 Summary (11-18-2020)

Boeing completed individual safety assessments on the Enhanced Digital Flight Control System (EDFCS) and Stabilizer to show that those systems' designs meet the reliability and integrity safety requirements for the737MAX. Assessments include Failure Mode Effects Analysis, Functional Hazard Assessments and Fault Tree Analysis. In addition to the individual safety assessments, Boeing developed an integrated System Safety Analysis (SSA) for the Speed Trim System with an emphasis on MCAS, including upstream and downstream interfaces. The integrated SSA was developed to aid in the showing and finding of compliance based on the integration of the systems noted above and their relation to each other. This decision meant the FAA had to review and cross reference systems without relying on Boeing's computer-aided design tools. The integrated SSA enabled the FAA to trace systems and make safety determinations using a single document that integrated the analysis, rather than simultaneous tracing through multiple documents.

Reliance on Pilot Mitigations the FAA's review of the integrated SSA included an evaluation of Boeing's STS design changes to determine if any STS failure modes rely on pilot reaction times to maintain safe operation of the airplane . The FAA's review of the integrated SSA and validated through extensive failure modes testing in simulators, the FAA concluded that no STS failure modes rely on exceptional piloting skills, and do not rely on immediate pilot actions. (See 8.3.2, 8.5, 8.6, and 9.1 of this report)

Single Point Failures

The FAA's review of the integrated SSA included an evaluation of Boeing's STS design changes. The FAA's review determined that there is no evidence that STS functionality is vulnerable to any other single-point failures, which can result in a catastrophic outcome.

***Boeing Response to Recommendation* 6**

737 RTS summary (11-18-2020)

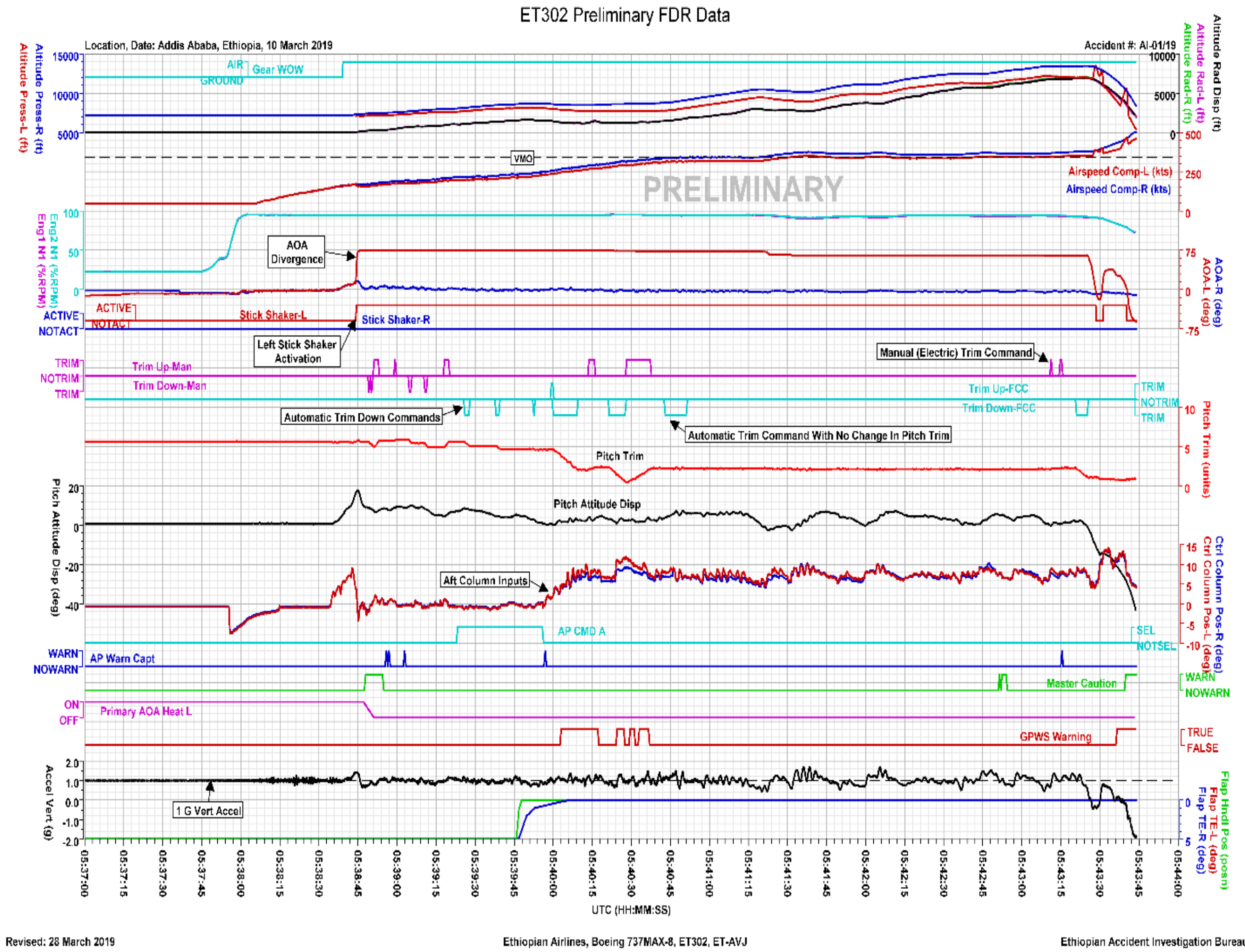
In the original design, when a continuous erroneous high AOA sensor value existed, the MCAS control law used pilot release of the electric trim switch to reset MCAS activation. Once reset, the MCAS system would makeanother airplane nose-down stabilizer trim command after five seconds. This scenario would repeat each time the MCAS made a command and the pilot made an electric trim command of any duration and released the trim switch. In the new design, Boeing included flight-control law changes to ensure that MCAS will not command repeated movements of the horizontal stabilizer. The revised flight control laws allow only an activation of MCAS per sensed high-AOA event. A subsequent activation of MCAS is only possible after the airplane returns to a low AOA state, below the threshold that would cause MCAS activation.

ATTACHMENT1: NTSB, BEA

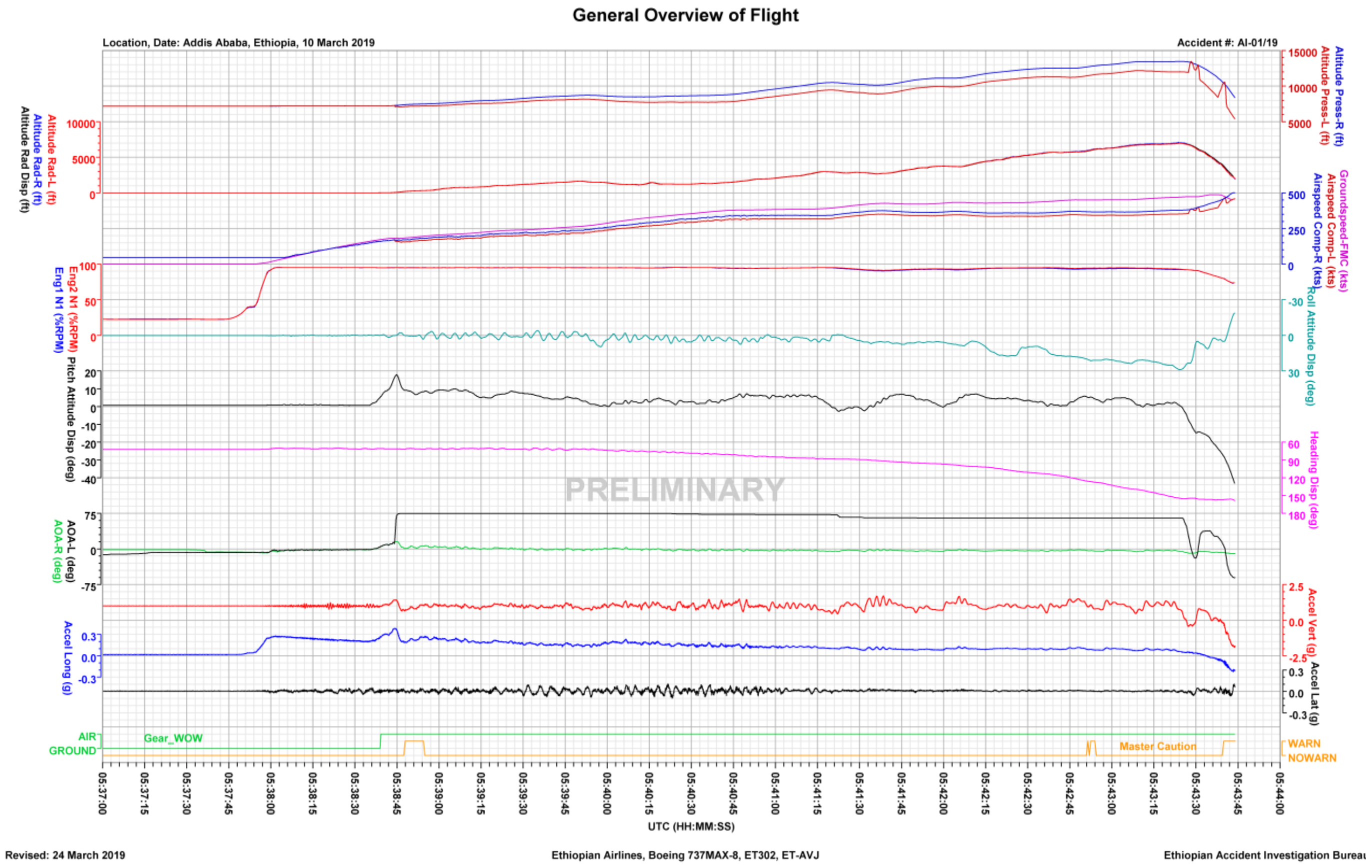
Comments by US National Transportation Safety Board and French Bureau D'enquêtes Et D' Analyses Pour La Sécurité De L'aviation Civile (BEA),

http://aib.gov.et/wp-content/uploads/2020/documents/accident/ET302_NTSBcomments_21June_final.pdf

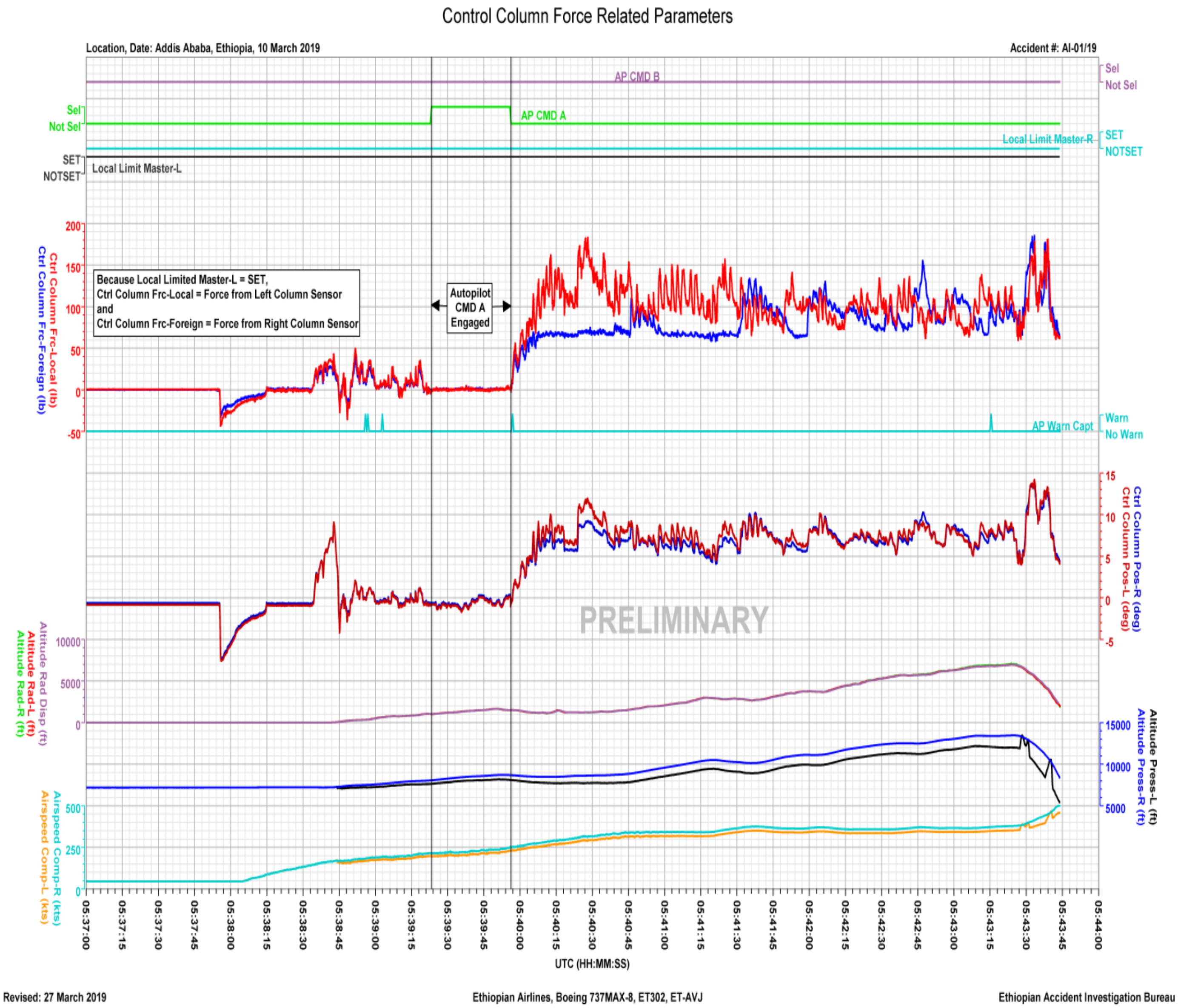
http://aib.gov.et/wp-content/uploads/2020/documents/accident/BEA-Comments-to-append.V-Finale.pdf



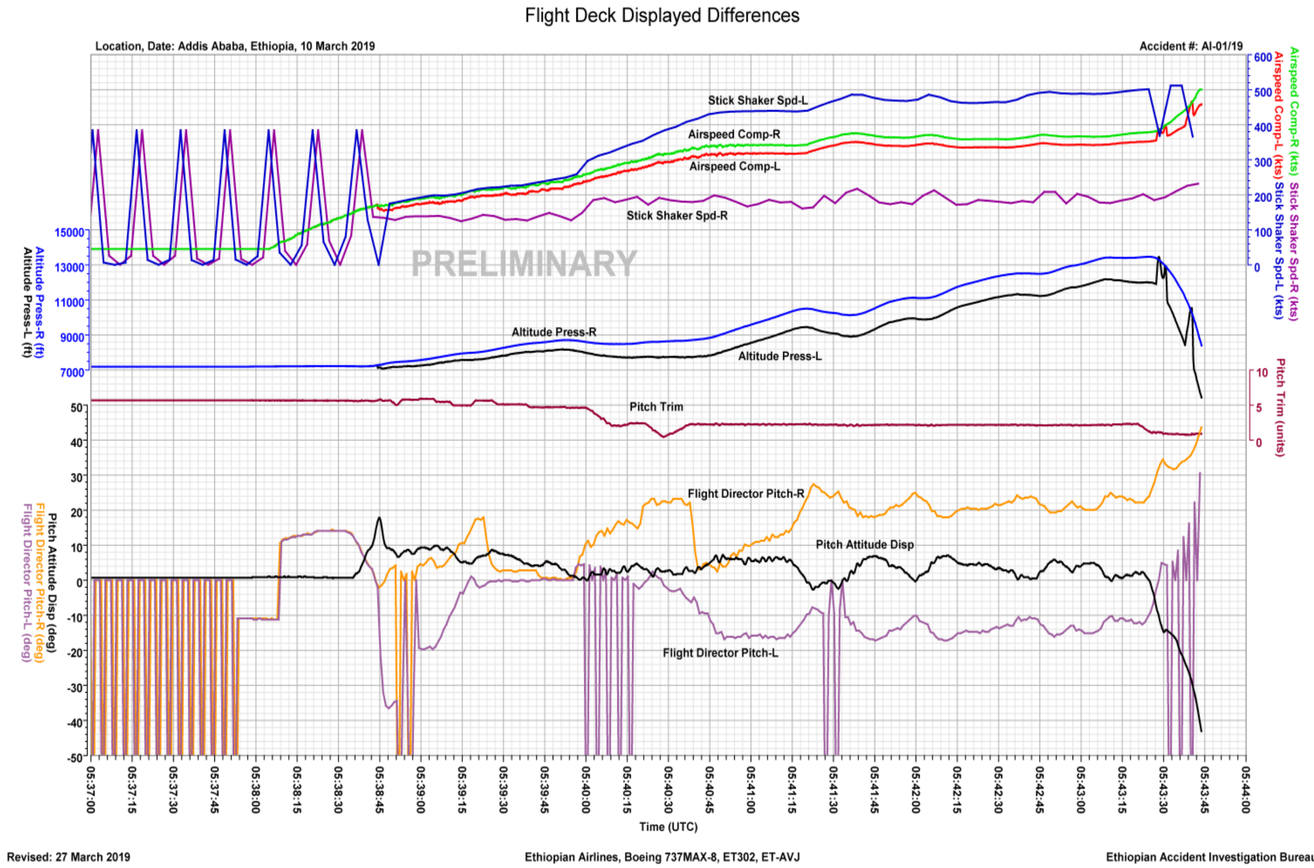
ATTACHMENT2: ET -AVJ GENERAL VIEW OF FDR DATA



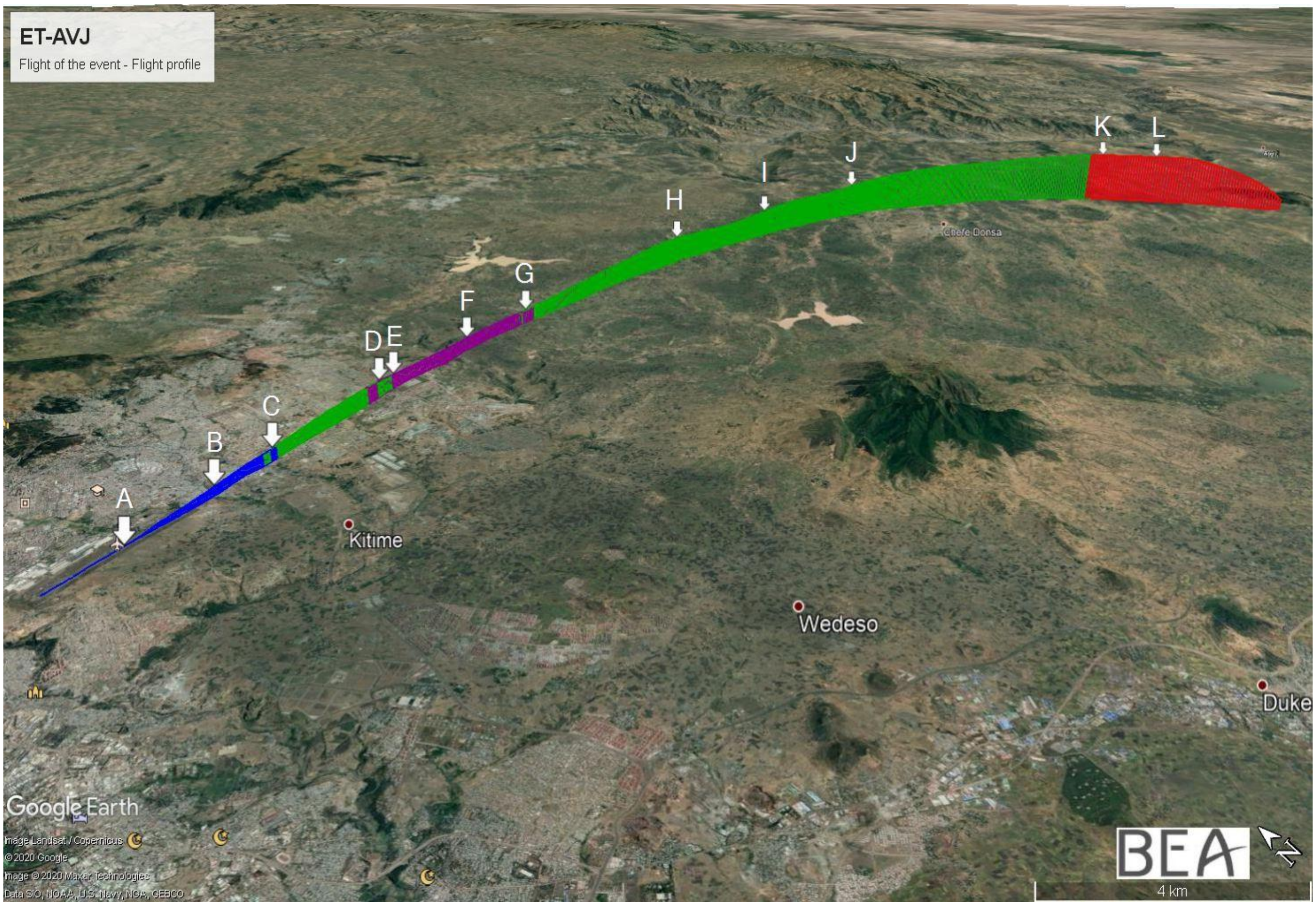
ATTACHMENT3: GENERAL VIEW OF FLIGHT



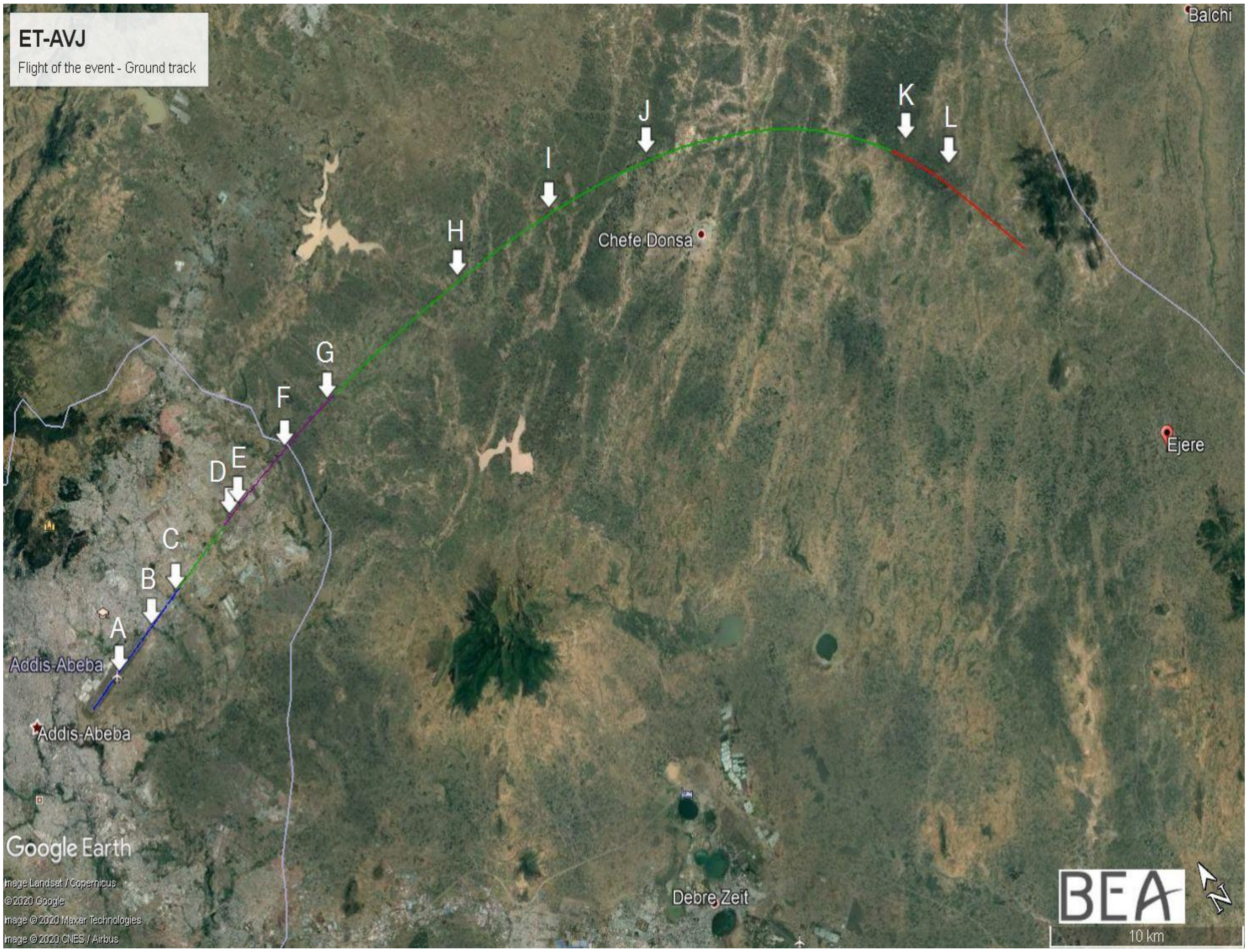
ATTACHMENT4: CONTROL COLUMN FORCE RELATED PARAMETERS



ATTACHMENT5: FD DISPLAYED DIFFERENCES



ATTACHMENT6: ET- AVJ FLIGHT PROFILE



ATTACMENT 7: ET –AVJ GROUND TRACK