

Boeing 737 MAX – Still Not Fixed

Introduction

The world has heard the basic explanation given for why two new 737 MAX airplanes crashed killing 346 people. The Angle of Attack (AOA) Sensor sent faulty data to the Maneuvering Characteristics Augmentation System (MCAS) software, which caused the horizontal stabilizers to repeatedly pitch the airplanes down, overwhelming the pilots causing them to lose control. People that have been following these tragedies a little closer know the original, Boeing-installed AOA Sensor on the Lion Air airplane had been replaced the day before the crash. But there is more to the story.

Important facts involving the Lion Air Flight 610 and Ethiopian Airlines Flight 302 accident investigations have gone unnoticed leading to many unanswered questions. Several factors appear to have played a direct role in the accidents—specifically, the failure of the AOA Sensors, unexplainable electrical anomalies, and the production of the airplanes—the details of which seem to have been largely ignored. There are at least three other plausible accident scenarios that have not been investigated.

Background

The Lion Air Final Aircraft Accident Investigation report concluded the replaced AOA Sensor was miscalibrated by 21 degrees and this miscalibration activated MCAS triggering the accident sequence.¹ Ethiopia's Ministry of Transport has not issued their final investigation report or determined the cause of their AOA Sensor failure, although a critical piece of the puzzle seems to exist. Instead they have issued two interim reports and have stated their analysis is still in progress.²

The AOA Sensor is not an algorithm in a piece of software, it is a physical part that weighs approximately three pounds. The part manufacturer is Collins Aerospace (formerly Rosemount Aerospace). The 737 MAX has two AOA Sensors. One on each side of the airplane's nose. The model # is 0861FL1 and the part is electrically de-iced by an internal solid-state heater. Inside the AOA Sensor there are two internal resolvers that independently measure the rotation angle.³

The Lion Air Final Accident Investigation Report is 318 pages long. The most recent Ethiopian Airlines interim report is 136 pages. Much of the following information is buried deep in these reports. Key events have been selected from these reports and arranged in chronological order to assist readers in understanding the sequence of events.

Sequence of Key Events

August 15, 2018 – Boeing delivered a 737-8 MAX, Production Line Number 7058 to Lion Air

October 9, 2018 – 55 days after delivery, the Lion Air airplane began experiencing intermittent problems with the flight control system.⁴ The Air Data Inertial Reference Unit (ADIRU) detected a problem with the Angle of Attack system and generated an “Angle of Attack is Out of Range” message.

¹ Indonesia KNKT, [Final Aircraft Accident Investigation Report](#) (Oct 25, 2019), pgs. 207, 209, 214, 215

² Ethiopia Ministry of Transport, [Aircraft Accident Investigation Bureau Interim Report](#) (Mar 9, 2020), pg. 130

³ Indonesia KNKT, [Final Aircraft Accident Investigation Report](#) (Oct 25, 2019), pg. 43

⁴ IBID, pg. 33

The new airplane had other technical problems described in the accident investigation report besides the flight control system. For example, the Aircraft Flight and Maintenance Log (AFML) has an entry regarding an electrical system abnormality that resulted in the illumination of the aircraft's STANDBY PWR OFF light followed by the tripping of six circuit breakers.

“During parking in Jakarta the aircraft’s STBY PWR OFF (stand by power off) light illuminated and followed by the Circuit Breakers (CBs) tripped out on the following components; DC battery, APU GCU (Auxiliary Power Unit Generator Control Unit), GCU 1 (Generator Control Unit of left engine) and GCU 2 (GCU right engine), and GEN DISC 1 (Generator Disconnect of the left generator) and GEN DISC 2 (Generator Disconnect of the right generator)”.⁵

Over the course of several weeks leading up to the accident, Lion Air maintenance personnel performed troubleshooting using the airplane’s Onboard Maintenance Function (OMF). They were faced with a multitude of maintenance messages including: “AD DATA INVALID”, “STALL WARNING SYS L”, “ADIRU-L ADR DATA SIGNAL IS INVALID”, “ANGLE OF ATTACK SIGNAL IS OUT OF RANGE”, “AIR DATA SIGNALS FROM THE ADIRU-L ARE INVALID”, “AIR DATA INVALID” and “AOA SIGNAL FAIL”.⁶

In addition to all the maintenance messages, on October 26th the AFML notes problems on the Captain’s Primary Flight Display (PFD). Over the next few days, instead of the normal speed and altitude indications, the pilots encountered several intermittent faults including SPD (speed) and ALT (altitude) flags; illumination of SPEED TRIM and MACH TRIM lights; and the disconnection of the Auto-Throttle on takeoff. Pilots depend on accurate speed and altitude information especially during takeoffs, landings, and while flying in instrument meteorological conditions. These repetitive faults are telltale signs of system failures.⁷

Clearly, this brand-new airplane already had major flight control system problems going on before the AOA Sensor was replaced, but the significance of this fact fades away as the investigation continued.

October 28, 2018 – In an effort to resolve the repeat faults involving the flight control system, Lion Air replaced the original, Boeing-installed AOA Sensor on the left side of the airplane the day before the accident with a refurbished AOA Sensor from Xtra Aerospace in Miramar, Florida.⁸

- Boeing as the original equipment manufacturer, is responsible for the design and quality of all parts on the 737 MAX. Boeing relies on hundreds of suppliers worldwide. Boeing is also responsible for inspecting, installing, and testing the AOA Sensors in accordance with the FAA approved production process at the 737 Factory located in Renton, Washington. The Renton site is where all 737 variants are produced (737 MAX, 737 NG, and P-8 Poseidon).

The Boeing-installed, AOA Sensor that was removed is referenced in the Lion Air Final Aircraft Accident Investigation Report as the “removed AOA Sensor” and the refurbished sensor from Xtra Aerospace that was installed in its place is referred to as the “installed AOA Sensor.”⁹ This differentiation is important to keep in mind, because the accident report and the ensuing AOA Sensor discussion is rather confusing.

⁵ IBID, pg. 33

⁶ IBID, pgs. 33, 34, 35

⁷ IBID, pgs. 33, 34, 40

⁸ IBID, pg. 38

⁹ IBID, pg. 37

October 28, 2018 - On the flight immediately following the replacement of the sensor, the newly “installed AOA Sensor” on the left side recorded an approximate 21-degree difference with the sensor on the right and the pilots almost lost control of the airplane due to MCAS activation. They transmitted two urgent emergency communication messages (PAN-PAN radio calls).¹⁰

October 29, 2018 - Lion Air Flight 610 crashes into the Java Sea killing 189 people. The plane was two months old.

November 1, 2018 - The Digital Flight Data Recorder (DFDR) is located.¹¹ The AOA Sensors that were on the airplane at the time of the crash were not recovered.

Early November 2018 - Accident investigators interviewed the Lion Air engineer who removed and replaced the AOA Sensor. After the installation, the engineer performed an “alternative method” installation test to confirm the sensor was working properly. He used the alternative method because he did not have access to the recommended AOA test fixture. A test fixture is a tool or device designed to hold a test specimen in place while it is subjected to controlled test signals. The engineer failed to record the results after the installation. He provided the investigators with some photos claiming they were from the accident aircraft, but the investigators later determined the photos were from another airplane.

November 15, 2018 – Boeing and the NTSB conducted testing in Seattle, Washington to determine if the “alternative method” test performed by the Lion Air engineer could detect a bias in an AOA Sensor. They concluded the alternative method could detect such a bias. Hence if the Lion Air engineer had performed the test properly, he should have noticed the 21-degree difference noted on the first flight after the sensor was replaced. The investigators could not prove the engineer failed to conduct the test properly. On the other hand, the engineer could not prove he did the test correctly either because he failed to record the results.

At this point in the Lion Air investigation it appears accident investigators are leaning towards a miscalibrated sensor scenario. They understandably see a possible connection to the replacement work performed by the engineer. The DFDR also shows the 21-degree difference did not occur on previous flights, but did occur on both flights after the sensor replacement.

Be that as it may, it is essential to highlight that a miscalibrated part installed the day before the accident on October 28th, could not be blamed for the flight control system problems that were occurring in the weeks prior to the accident. Something else was going wrong with the Lion Air airplane.

On this same day, Boeing delivered a 737-8 MAX, Production Line Number 7243 to Ethiopian Airlines.

December 3-6, 2018 - Accident investigators from Indonesia and the U.S. traveled to Seattle, Washington to participate in flight simulations to gain a better understanding of the Lion Air accident flight. During the simulations, the pilots had difficulty flying the airplane under the conditions that occurred on the accident flight.¹²

¹⁰ IBID, pg. 166

¹¹ IBID, pg. 67

¹² IBID, pg. 91

The flight simulations were challenging, but they were nowhere near as challenging as what the Lion Air pilots faced. Boeing's highly experienced test pilots entered the flight simulators knowing they were going to be challenged. They were certainly prepared, at the very least mentally, for what they would face. They also knew no one was going to die no matter how bad the simulations went. Yet they still had difficulty controlling the aircraft while also managing the workload with all the alarms going off in the simulator. It sounds like it was a humbling experience for the pilots involved.

*"Altitude was not able to be maintained with aft control column force if short activations of electric trim result in an accumulation of mis-trim from MCAS nose down trim commands."*¹³

If they did not know it beforehand, the Boeing and FAA test pilots involved in these flight simulations certainly learned about the awesome power, and potential dangers, of MCAS.

Dec 10, 2018 – U.S. accident investigators traveled to a Collins Aerospace facility (formerly Rosemount Aerospace) to test the "removed AOA Sensor." The sensor is subjected to several tests. The test results were not good. In fact one resolver failed every test including the Vane Travel Test, the Resolver Accuracy Test, and the Resolver Accuracy Test with Operation of the Heater Element.¹⁴

*"Examination of the AOA Sensor revealed an intermittent open circuit in the resolver #2 coil wiring. At temperatures above approximately 60°C, the resolver functioned normally, but did not function below that temperature."*¹⁵

The original, 737 Factory installed AOA Sensor failed. This revelation should have sparked numerous quality control questions back in December 2018:

- Why did a new part fail?
- Did this AOA Sensor failure create all the other problems that were going on in the weeks leading up to the accident?
- Why would the sensor have an open circuit?
- Why would the resolver inside the sensor only work when the temperature was above a certain point (60°C = 140°F) and not work below that point?
- What is the resolver's required operating range?
- What is going on with the electrical wiring?
- Are there any other 737 airplanes flying around with potentially similar defective parts?
- What is the potential impact of another AOA Sensor failure?

Apparently Southwest Airlines also had problems with AOA Sensors on their new 737 MAX aircraft just weeks before the Lion Air crash, according to a November 2018 Wall Street Journal article.

*"During the three weeks before Lion Air Flight 610 plunged into waters off Indonesia, Southwest Airlines Co. replaced two malfunctioning flight-control sensors of the same type that has been publicly implicated in the crash, according to a summary of Southwest maintenance records reviewed by The Wall Street Journal."*¹⁶

¹³ IBID, pg. 93

¹⁴ IBID, pgs. 284, 285

¹⁵ IBID, pg. 284

¹⁶ [Southwest Replaced Flight-Control Sensors of the Kind Implicated in Lion Air Crash](#), Wall Street Journal, Andy Pasztor & Andrew Tangel, (Nov 15, 2018)

The 737 MAX airplane was not the only version of the 737 jet being produced in Renton, Washington in late 2017 and 2018. 737 Next Generation (NG) airplanes were being phased out, but the 737 Factory was still producing large numbers of NG airplanes. In an adjacent building, the military variant of the 737, the P-8 Poseidon airplane, was also being produced. Both the 737 NG and the P-8 have the same model AOA Sensor as the MAX built by the same supplier. Why was an Emergency Airworthiness Directive (EAD) requiring operators to inspect, test, and if necessary, replace defective AOA Sensors not issued at this point? Federal Aviation Regulations require an EAD to be issued when an unsafe condition exists that requires immediate action by an owner/operator.¹⁷

Dec 12, 2018 – U.S. representatives from the NTSB, FAA, Boeing, and Collins Aerospace traveled to Miramar, Florida to review and document the maintenance records of the “installed AOA Sensor” at Xtra Aerospace’s facility. They observed an Xtra technician demonstrating the procedures used during the refurbishment process. Someone on the investigation team noticed the technician using an Angle Position Indicator (API) tool that was not approved in the company’s maintenance manual. However, the FAA had previously approved Xtra Aerospace’s request to use this tool.¹⁸ The team watched the technician continue to perform the repair tasks. There was no mention of the technician making any mistakes during the repair work.

The investigators then developed “a procedure” to determine if a 25-degree bias could inadvertently be introduced into the resolvers inside the sensor. The report makes it sound like the procedure was developed on the spot.¹⁹

It is unclear who on the investigation team thought to develop this procedure. Presumably, the procedure was developed by the representative that had the most knowledge of the AOA Sensor part and the company’s maintenance manual.

The procedure is successful in creating the 25-degree bias.²⁰ What is important to note here, is that although the investigators did not see the Xtra Aerospace technician make a calibration mistake when the technician performed the repair work, based on the procedure developed by the U.S. investigators, they conclude a miscalibration “could” have happened and it was “a possibility”.

*“The test demonstrated that an AOA Sensor calibrated and tested with a Peak API in relative mode **could result in an equal bias introduced** into both resolvers.”²¹*

The investigation goes on to conclude:

*“These test results suggest that **there was a possibility** of differences or a bias if the REL/ABS toggle switch was inadvertently selected to REL position.”²²*

It appears this testing in Florida becomes the major pivot point in the investigation, effectively shifting the spotlight away from Boeing and Collins Aerospace towards Lion Air and Xtra Aerospace.

¹⁷ https://www.faa.gov/aircraft/air_cert/continued_operation/ad/type_pub/type_emerg/

¹⁸ Indonesia KNKT, *Final Aircraft Accident Investigation Report* (Oct 25, 2019), pg. 90

¹⁹ IBID, pg. 90

²⁰ IBID, pg. 91

²¹ IBID, pg. 91

²² IBID, pg. 91

The miscalibration scenario takes root, and over the course of the investigation, somehow transforms itself from something that “could” have occurred and was “a possibility” to numerous definitive conclusive statements incorporated into several sections of the report—including arguably the three most read sections of the report (Synopsis, Findings, and Contributing Factors):

*“The installed left **AOA Sensor had a 21° bias** which was undetected during the installation test in Denpasar.”²³*

*“During the accident flight erroneous inputs, **as a result of the misaligned resolvers**, from the AOA Sensor resulted in several fault messages (IAS DISAGREE, ALT DISAGREE on the PFDs, and Feel Differential Pressure light) and activation of MCAS that affected the flight crew’s understanding and awareness of the situation.”²⁴*

*“The replacement AOA Sensor that was installed on the accident aircraft **had been mis-calibrated** during an earlier repair. This mis-calibration was not detected during the repair.”²⁵*

*“The investigation could not determine that the installation test of the AOA Sensor was performed properly. **The mis-calibration was not detected.**”²⁶*

*“Replacement of AOA Sensor proved to be the solution to rectify the SPD and ALT flags that were reported to have appeared on the Captain’s PFD, **however the installed AOA Sensor was misaligned by about 21°** and resulted in different problems.”²⁷*

At this point in the investigation, it appears investigators are quite comfortable with the *miscalibrated AOA Sensor triggering MCAS software scenario* based on the digital flight data recorder information and the testing in Florida. There is nothing in the report indicating they pursued any additional electrical systems forensics testing into whether some other cause might have produced the erroneous sensor readings, or alerted anyone to the December 10, 2018 examination results of the Boeing-installed defective AOA Sensor.

Alternative scenarios might have explained some otherwise inexplicable events. As previously noted, the miscalibration scenario does not explain why this new airplane had flight control system problems in the weeks leading up to the defective sensor replacement. Nor could a maintenance action involving the installation of a miscalibrated sensor be blamed for the next catastrophe.

Ethiopian Airlines Flight 302

March 10, 2019 – Ethiopian Airlines Flight 302 crashes in a field outside Addis Ababa, Ethiopia killing 157 people. The plane was 4 months old.

Like the Lion Air airplane, the Ethiopian airplane experienced an AOA Sensor fault right after takeoff.

“At 05:38:44, shortly after liftoff, the left and right recorded AOA values began deviating. Left

²³ IBID, pg. xviii

²⁴ IBID, pg. 207

²⁵ IBID, pg. 215

²⁶ IBID, pg. 215

²⁷ IBID, pg. 186

AOA decreased to 11.1° then increased to 35.7° while value of right AOA indicated 14.94°. Then after, the left AOA value reached 74.5° in ¼ seconds while the right AOA reached a maximum value of 15.3°, the difference between LH and RH AOA was greater than 59° and continued to be until the final loss of control.”²⁸

March 13, 2019 – The FAA grounded the 737 MAX aircraft following the lead of aviation regulators around the world.

Similar to the Lion Air airplane, the Ethiopian Airlines airplane experienced flight control system abnormalities well before the accident flight. For an airplane that was also fresh out of the factory, it had a troubling history of flight control system problems.

“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 aircraft rolling during autopilot operation and altitude and vertical speed indication on the PFD showed an erratic and exaggerated indication.”²⁹

In “early December 2018” when the Ethiopian Airlines airplane was experiencing these flight control systems problems it was less than one month old.

The Ethiopian Airlines airplane also had intermittent electrical system 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.³⁰ The APU is a backup electrical and pneumatic power source. 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.

Ethiopian Airlines maintenance personnel performed some maintenance on the APU, but the next day the APU Fault Light came on again. They replaced the SCU and after that replacement the APU “successfully started with a limited restart.”³¹

The new Honeywell manufactured APUs on the 737 MAX were touted as having a more reliable starting capability. Yet it appears both airplanes had some electrical quirks related to their new APUs. Another seemingly minor detail that may shed additional light on the quality and stability of the Ethiopian Airlines airplane’s electrical system is the fact the Captain’s personal computer power outlet had no power.³²

Due to the instantaneous failure of the Ethiopian Airlines AOA Sensor, some experts have speculated that maybe the AOA Sensor experienced a bird strike or perhaps the outside assembly just fell off after takeoff. But the Ethiopian Ministry of Transport has not reached that conclusion. Neither of these possibilities were discussed in their interim reports, and more importantly, like the miscalibration

²⁸ Ethiopia Ministry of Transport, [Aircraft Accident Investigation Bureau Interim Report](#) (Mar 9, 2020), pg. 12

²⁹ IBID, pg. 22

³⁰ IBID, pg. 25

³¹ IBID, pg. 25

³² IBID, pg. 26

scenario in the Lion Air crash, neither can explain the earlier flight control and electrical systems problems that were going on with the airplane in the weeks prior.

Late Testing Results in a New Discovery

June 5-6, 2019 - Eight months after the Lion Air crash and three months after the Ethiopian crash, the “removed AOA Sensor” from the Lion Air airplane is finally subjected to additional testing in Blacksburg, Virginia. Findings from the June 2019 testing:

*“Using CT Scans, physical examinations, and Scanning Electron Microscope (SEM) imaging, the open circuit was found to be a broken magnet wire on the rotor coil. **A loose loop in the coil of the magnet wire had been epoxied between two different insulators on the rotor with different coefficients of thermal expansion for each insulator.** As the rotor was exposed to cyclic differences in operating temperature over time, it is likely that the difference in the expansion rates of the two insulators induced a localized stress in the coil wire that led to a fatigue break in the wire that was open or closed dependent on temperature.”³³*

*“As determined by the examination and as seen in the CT images, a loose loop of magnet wire from the primary rotor coil had been trapped with epoxy between the end cap insulator and the rotor shaft insulator. **This epoxy is only meant to hold the end cap insulator in place and is not intended to encapsulate the magnet wire...**”³⁴*

*“Because of the trapped magnet wire attached to two different CTE materials, the thermal cycling of the resolver over time due to the operational environment of the AOA on the aircraft mechanically “worked” the confined magnet wire into a fatigue failure mode. **The magnet wire exhibits a series of ridges or “beach marks” that are indicative of multiple crack growth cycles (i.e. fatigue) before ultimately breaking and arcing multiple times as evidenced in the SEM images.**”³⁵*

This belated testing uncovers a serious production quality defect. These test results are critical to understanding what was going on with the Lion Air airplane before the AOA Sensor replacement. It is also critical to understanding the potential risks other defective AOA Sensors pose. Again, an EAD should have been issued at this point.

Troubleshooting procedures conducted by Lion Air’s maintenance organization also point to the possibility of intermittent electrical system defects as an underlying issue. As maintenance personnel performed troubleshooting to isolate and rectify the problems associated with the AOA Sensor and the Air Data Inertial Reference Unit (ADIRU), the airplane’s onboard maintenance function led them to a task list that directed them to “Repair Wiring” if the repair or replacement of AOA Sensor components failed to resolve the problem.³⁶ Troubleshooting steps also included resetting multiple circuit breakers and guidance to conduct “wiring checks” of the Air Data Module and the ADIRU, although the wiring checks could not be completed due to rainy weather and lightning hazard concerns.³⁷

³³ Indonesia KNKT, [Final Aircraft Accident Investigation Report](#) (Oct 25, 2019), pg. 285

³⁴ IBID, pg. 286

³⁵ IBID, pg. 286

³⁶ IBID, pg. 62

³⁷ IBID, pg. 35

Production Problems and Pressure at the 737 Factory

When these two airplanes were produced in 2018, the 737 Factory in Renton, Washington was under significant pressure. The conditions within the production environment could have easily led to mistakes that affected the airplanes' critical electrical system, among other possibilities.

Production employees were struggling with:

- a huge rolling logjam of unfinished airplanes (upwards of 50 airplanes waiting to be completed)
- a massive backlog of work (thousands of jobs behind schedule, > than 10x the normal amount)
- a vast amount of "out of sequence" work (work performed at a location or time other than what was planned and approved by the FAA as part of Boeing's production certificate)
- chronic part shortages involving hundreds of parts including engines, power panels and wiring
- a shortage of skilled union employees (electricians, mechanics, technicians & quality inspectors)
- an unusually high number of quality defects and functional test failures including extensive rework and retesting of the Electrical Wiring Interconnect System (EWIS)—an airplane's electrical infrastructure which includes wiring, wire bundles, power panels, connectors, etc.
- a limited supply of available test and ground equipment (e.g., test carts and hydraulic carts)
- an overworked workforce that was pushed to work extensive amounts of overtime
- an increase in high hazard worker safety near misses
- and most challenging of all—relentless schedule pressure

The schedule pressure that Boeing's design engineers, Organization Designation Authorization (ODA) employees and test pilots felt during the years of development of the 737 MAX is well documented.³⁸ Once the MAX went into production, this schedule pressure shifted to production workers.

The 737 Factory was in such bad shape in July of 2018 the company ran out of ramp space outside the factory and at Renton Municipal Airport to park all the unfinished airplanes. Boeing had to rapidly convert several employee parking lots (including handicap parking) to airplane parking spots. This was still not enough space. The parking crisis escalated quickly to the point where Boeing had to make an emergency appeal to the City of Renton for additional parking assistance reporting they had "encountered an emergency production challenge that threatened to interfere with their ability to keep their airplane production lines running." City records showed the frustration of city officials including the mayor.³⁹

All the production problems at the 737 Factory worsened throughout the summer, as the Lion Air airplane was being manufactured, and into the fall when the Ethiopian Airlines airplane was being built. The emergency parking of airplanes just happened to be the most visible sign.

In September 2018 (one month before the Lion Air crash) a longtime aerospace reporter for the Seattle Times wrote an alarming report after talking with several production workers who were expressing concern and frustration about the state of the 737 Factory. Excerpts from the article:⁴⁰

³⁸ [Final Committee Report - *The Design, Development and Certification of the Boeing 737 MAX*, Final Committee Report](#), (September 2020), U.S. Congress, House Committee on Transportation & Infrastructure

³⁹ [Boeing 737 Supplier Issues Threatened to Halt Production, Renton Records Say](#), Puget Sound Business Journal (Sep 13, 2018), Andrew McIntosh

⁴⁰ [737 problems have grown in Renton despite Boeing's reassurances](#), Seattle Times, Dominic Gates, (Sep 6, 2018)

“As 53 undelivered jetliners sat parked outside Boeing’s Renton plant this week, up from just over 40 a month ago, workers inside the factory were feeling the pressure of constant overtime and an unrelenting build-up of unfinished tasks. Though Boeing assured Wall Street analysts visiting Seattle Wednesday that the pile-up of 737 jets has peaked and will be sorted out by year end, some frontline workers were less optimistic.”

“Delays in delivering the MAX model’s new LEAP engines, made by CFM International, are just one of the choke points causing the pile-up.”

“Boeing executives told analysts Wednesday that to get a grip on the backlog of work they are adding about 600 employees to the 10,000-strong Renton workforce, with a combination of new hires and workers transferred from Everett and other Puget Sound facilities. Employees are working constant overtime. Many volunteered to work all through the Labor Day holiday weekend and a few have worked as many as nine weekends in a row without a break.”

“‘They have opened the checkbook, letting people work as many hours as they want,’ said one Renton inspector. A high-grade factory mechanic, who like the inspector asked not to be identified because he spoke without management permission, said some employees are burned out, calling in sick just to get days off.

“‘The general sense is that we are so far behind,’ he said. ‘It’s going to be the end of the year before anything is remotely on track.’”

“The Renton inspector said of the parked jets that it’s getting ‘harder and harder to get them flyable because of all the traveled jobs’ and because of the influx of inexperienced workers brought in either as new hires or coming over from other jet programs.”

“He said he’s seeing a lot of rejection tags on wiring modules. ‘We’re ripping apart some of the electronics racks already assembled to replace wire bundles that aren’t right.’”

Not surprisingly every factory metric was getting record low marks and each one was trending in the wrong direction. The terrible metrics showed a dramatic decline in the factory’s health and performance, reflecting the vast number of production issues and associated risks. Despite these warning signs, Boeing continued to produce new airplanes and actually increased the factory’s production rate.⁴¹

Production Quality

Even after the second crash, after the grounding, and as accident investigators were still investigating, the company produced large numbers of MAX airplanes (a “reduction” down to 42 airplanes per month) throughout 2019. Meanwhile production quality problems continued to surface. Since June 2019, several alarming production quality defects have come to light including defective slat tracks, deficient aircraft wiring shielding around the engines, and widespread foreign object debris (FOD) in fuel tanks—a crystal clear sign of an unhealthy and dangerous production environment.

⁴¹ *Final Committee Report - [The Design, Development and Certification of the Boeing 737 MAX, Final Committee Report](#), (September 2020), U.S. Congress, House Committee on Transportation & Infrastructure, pg. 173*

Disturbingly the day after Ethiopian authorities published their initial interim accident report, the FAA received four whistleblower reports on their hotline.

“The FAA tells CNN it received the four hotline submissions on April 5, and it may be opening up an entirely new investigative angle into what went wrong in the crashes of two Boeing 737 Max commercial airliners -- Lion Air flight 620 in October and Ethiopian Air flight 302 in March.

Among the complaints is a previously unreported issue involving damage to the wiring of the angle of attack sensor by a foreign object, according to the source.”⁴²

Only after the December 11, 2019 Congressional hearing, which led to the firing of Boeing’s CEO, did Boeing finally announce it was halting 737 production.⁴³ The shutdown only lasted a few months.

If all of this was not enough evidence that the 737 Factory was under substantial duress when the Lion Air and Ethiopian Airlines airplanes were produced, according to publicly available information, there were at least 13 other reported safety incidents involving new 737 MAX airplanes (in addition to the two fatal crashes) that were all manufactured at the 737 Factory in Renton, Washington during the same period of time.⁴⁴ These incidents are virtually unknown to the public. This is because airplane specific data (like the age of an airplane or its production number) resides in different databases than incident data.

Every airplane involved in these incidents was produced in late 2017 or 2018. The incidents involved an assortment of airplane systems (e.g., engines, hydraulics, flight control instruments). In seven of these safety incidents, the pilots had to execute an emergency divert (landing at an airport other than their planned destination) or had to return immediately to their departure airport. During six of these incidents the pilots transmitted at least one urgent emergency communication message. On average, these incidents occurred within eight months of the relevant aircraft’s first flight. During this timeframe Boeing and the FAA reassured their airline customers and the flying public that the 737 MAX was completely safe. Most shocking of all, 11 of these 13 safety incidents occurred in the five months between the Lion Air crash and the Ethiopian Airlines crash. Thus 2 safety incidents per month.

So at a time when Boeing and the FAA should have been operating at an extremely heightened sense of awareness after the Lion Air crash, the MAX continued to average two safety incidents per month for the five months leading up to the Ethiopian Airlines crash. At this rate, if the MAX had not been grounded in March 2019, there could have been another 42 safety incidents involving airplane systems (other than MCAS) by December 2020—which means a correspondingly higher probability of another fatal accident.

Some aviation professionals might argue these safety incidents are not statistically relevant and they are just “teething” problems from a new model airplane. They might say these incidents represent a tiny fraction of the thousands of Boeing planes that safely fly millions of miles around the world each day. Although impressive, these big numbers are misleading. It is true that before the pandemic, there were

⁴² [Source: Boeing whistleblowers report 737 MAX problems to FAA](#), CNN Politics, Drew Griffin (Apr 27, 2019)

⁴³ [Boeing to Suspend 737 MAX Production in January](#), Wall Street Journal, Andrew Tangel, Doug Cameron & Alison Sider (Dec 16, 2019)

⁴⁴ <https://docs.house.gov/meetings/PW/PW00/20191211/110296/HHRG-116-PW00-Wstate-PiersonE-20191211.pdf>, pg. 33 (for additional information see [Aeroinside](#), [The Aviation Herald](#), and [Airfleets](#) websites)

more than 10,000 Boeing airplanes in service around the world flying millions of miles each day. But when the 737 MAX was grounded in March 2019, there were only 371 MAX airplanes in service around the world. 15 safety incidents represent 4% of the entire MAX fleet (15/371=4%). Thus, 1 in 25 MAX airplanes had already experienced a safety incident within the first year of being in service, two of which happened to be fatal crashes. This track record is unprecedented in modern day aircraft.

An Important Technical Clue

In addition to the flight control system faults AND the electrical system anomalies AND the faulty AOA Sensors AND the hectic production environment AND the production quality defects that have surfaced AND the other safety incidents, these two aircraft seem to share at least one other highly unusual, imbedded hazard associated with the AOA Sensors. It appears to be a crucial technical clue to what may have played a direct role in both accident sequences. Something that ties the two airplane crashes together besides the activation of MCAS.

From the Lion Air report regarding the Dec 10, 2018 testing of the “removed AOA Sensor.”

“A resolver accuracy test was repeated on the AOA Sensor per the test procedure with the additional requirement to operate the internal heaters.”⁴⁵

“The first two measurements taken on Resolver 2 showed that the values were unstable similar to values observed in previous resolver accuracy testing. Once the unit warmed up with the heater operation the unit resolver 2 output stabilized and was within the CMM performance requirements. The remaining Resolver 2 values were found within limits. The first two measurements were re-taken and were found within limits. The vane and case heaters were turned off and the values for Resolver 2 went unstable...”⁴⁶

From the Ethiopian Airlines report. Ten seconds after takeoff the left and right recorded AOA values began deviating. The left AOA Sensor value reaches 74.5 degrees. 4 seconds later the transcript states:

“At 5:38:48 Anti-ice was annunciated, by a master caution. The F/O called out “Master caution/anti ice” and the captain acknowledged the master caution”⁴⁷

The report goes on to say:

“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) switches on*
- 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.”⁴⁸

⁴⁵ Indonesia KNKT, [Final Aircraft Accident Investigation Report](#) (Oct 25, 2019), pg. 285

⁴⁶ IBID, pg. 285

⁴⁷ Ethiopia Ministry of Transport, [Aircraft Accident Investigation Bureau Interim Report](#) (Mar 9, 2020), pg. 12

⁴⁸ IBID, pg. 32

In other words, the original, Boeing-installed AOA Sensor that was replaced on the Lion Air airplane shares an AOA heater peculiarity with the Ethiopian Airlines airplane's AOA Sensor.

The AOA heaters are self-regulated and do not require thermostats.⁴⁹ Why did the sensor signal go unstable when heater power was removed during testing of the "removed AOA Sensor" from the Lion Air airplane? Why did the electrical current suddenly drop, and the vane heater fail on the Ethiopian airplane immediately after takeoff? Is there a relationship between heater power and the stability of the AOA Sensor? Are the sensors being affected by electromagnetic interference (EMI)? Perhaps a power quality issue (e.g., transients, interruptions, voltage fluctuations, etc.)? Another production quality mistake? Resolver electrical errors? DC offset, noise, etc.? Loose or improper connections? Short circuit? Damaged insulation? A bonding or grounding problem? Lots of electrical questions.

The proper installation of an airplane's electrical infrastructure is challenging work necessitating significant attention to detail. Factory workers are frequently required to perform intricate, physically demanding tasks in tight spaces while in awkward physical positions (overhead, bending, reaching, etc.). Over the years lessons learned from accidents and incidents have necessitated the development of EWIS installation best practices.⁵⁰

The failure of an originally installed Boeing part involving an open circuit, wire fatigue and evidence of multiple arcing events, and a factory environment under duress with a shortage of electricians, a high number of quality reports involving EWIS defects and chronic functional test failures is cause for serious concern. The 737 MAX's electrical system is also significantly different than the 737 NG requiring a more complicated build plan—given the new engines, new APU and many miles of wiring infrastructure.

"It may be easier to find a needle in a haystack than to navigate an aircraft's electrical system, which can include miles of wiring and thousands of connectors and plugs."⁵¹

So why did two brand-new airplanes (2 months and 4 months old) have flight control system problems in the weeks leading up to the crashes? Why did both airplanes have unexplainable electrical system faults? Why has there been a rash of production quality problems recently surfacing on new 737 MAX airplanes? Why did 13 other new MAX airplanes have safety related incidents within their first year of service? All signs point back to where these airplanes were produced, the 737 Factory.

Conclusion

The evidence points to at least 3 viable production related accident scenarios:

1. An Electrical Wiring Interconnect System (EWIS) production defect damaged the AOA Sensors OR
2. A production defect in the AOA Sensors damaged EWIS OR
3. An EWIS failure and an AOA Sensor failure occurred simultaneously

In summary, many important questions still remain unanswered. At the top of the list, is whether the 737 MAX, 737 NG and P-8 Poseidon have defective AOA Sensors or electrical system problems that could lead to another preventable tragedy? This question needs to be thoroughly investigated. The FAA's recertification fixes fail to adequately address these issues. How can we trust the airplane is "100% safe" when basic questions arising out of the accident investigation reports remain unanswered?

⁴⁹ <https://utcaerospacesystems.com/wp-content/uploads/2018/04/Angle-of-Attack-AOA-Systems.pdf>

⁵⁰ [FAA Aircraft Electrical Wiring Interconnect System \(EWIS\) Best Practices Job Aid 2.0](#)

⁵¹ [Minding Business, Boeing Frontiers Magazine, December 2009-January 2010](#), pg. 46

Like electricity, Boeing and the FAA have taken the path of least resistance throughout the entire design, development, certification, production, and now recertification of the 737 MAX.

The design of the 737 MAX, MCAS software and the failure to provide vital information and training to pilots did not trigger these accidents. Neither did corporate decision making made years ago, unethical behavior, deceptive marketing, or a misguided leadership culture that prioritized profits over safety. Nor did deregulation, regulatory capture, or a completely broken aircraft certification process. In fact, all of these things contributed mightily to these tragedies. Unfortunately, every MAX airplane ever manufactured shares this same wretched history. The pilots are certainly not to blame. They did everything they could to save the lives of the people who trusted them. The triggering event for these crashes was a defective AOA Sensor part, and quite possibly, a malfunctioning electrical system stemming from a dangerously unstable production environment.

We can either investigate these production problems and fix them, or we can wait for another disaster.

~ Ed Pierson
Jan 20, 2021

To the families and friends that lost loved ones in these preventable tragedies, you are in our prayers and your loved ones will never be forgotten.