Photo Illustration by Kelly Caminero/The Daily Beast/Getty /Lion Air 610, Boeing 737 Max, Ethiopian Airlines 302

# Boeing's Grounding: Catastrophic Crashes and Questions About Boeing's Liability and 737 MAX Aircraft Viability

By Vaughn Cordle, CFA and Don McGregor, USAF Maj Gen (ret)

**Bottom Line Up Front: UPDATE / March 23, 2019**

**Contributing Factors** – Pilot error, insufficient training, inadequate MCAS information (insufficient description/data to FAA, carrier maintenance, and training manuals), faulty AOA sensors, cultural issues, and a deficient Boeing and FAA safety review process all contributed to the Lion Air and Ethiopian Airlines 737 Max 8 crashes.

**Culpability** – Carriers responsible for inadequate training (Both Carriers) and proper maintenance practices (Lion Air). Boeing responsible for not disseminating MCAS information (prior to Lion Air crash), safety-review process, and withholding certain MCAS technical data to FAA during 737 Max series certifications. FAA responsible for over-delegating certification reviews to Boeing. Lastly, Boeing (and suppliers) quality control of AOA sensors.

**Outcome Scenarios:**

**Worse case** – Boeing found criminally negligent (highly unlikely in our view). Boeing key senior management relieved. Manufacturer directed to institute changes based off investigation findings and recommendations. Additionally, DOT directs internal review of FAA certification process and incorporates findings and recommendations. Financial impact to 737 Max fixes, production, orders and delivery for both Boeing and operators.

**Best case** – Lion Air and Ethiopian Airlines share blame with Boeing. Carriers found negligent in training program. Manufacturer found negligent of withholding MCAS data to FAA resulting in a hefty fine. Boeing management retained but company performs internal review of production and certification processes and procedures. FAA performs internal audit of safety-review process. Minimal impact in terms of 737 Max fixes, production, orders and delivery.

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March 21, 2019

By Vaughn Cordle, CFA and Don McGregor, USAF Maj Gen (ret)

**Executive summary**

On October 29, 2018, Lion Air Flight 610 crashed into the Java Sea twelve minutes after takeoff with 189 passengers and crew on board. On March 10, 2019, Ethiopian Airlines Flight 302 crashed six minutes after takeoff with 157 passengers and crew. In March 2019, the Boeing 737 MAX passenger airliner was grounded by airlines and governments worldwide following the two crashes, which occurred less than five months apart, killing all 346 people aboard both flights.

The 737 is the best-selling airliner in history, and the MAX, its newest version with more fuel-efficient engines, is a central part of Boeing's strategy to compete with European rival Airbus.

On March 11 Ethiopian Airlines announced it had grounded its 737 MAX 8. On March 11, the China Civil Aviation Administration, citing its zero-tolerance policy for any safety hazards, became the first government authority to ground the 737 MAX 8. Shortly after, the aircraft was grounded in the European Union (EU), Indonesia, Mongolia, Singapore and other countries, either voluntarily by airlines or by order of their respective governments. In the U.S., the Federal Aviation Administration (FAA) initially stated that it had “no systemic performance issues and provides no basis to order grounding the aircraft [737 MAX series].” But on March 13 the FAA updated their position stating, “The agency made this decision [grounding] as a result of the data gathering process and new evidence collected at the site and analyzed...” The FAA further explained the grounding decision describing the similarities of the two crashes (Lion Air and Ethiopian Airlines) and the "possibility of a shared cause" for the accidents.

The U.S. Department of Transportation (DOT) Office of Inspector General (OIG) opened an audit and evaluation of the FAA's 737 MAX series certification process and a criminal investigation looking into the aircraft's safety-review process. As part of the criminal investigation, the federal grand jury, based in Washington D.C., issued a subpoena on behalf of the U.S. Justice Department for documents related to the development of the 737 MAX series. The FBI has also joined the criminal probe in a support role.

**Bottom Line Up Front**

**Problem definition:** Bad sensors (AOA and/or airspeed) + erroneous data (sensor inputs) + MCAS inputs (nose down trim correction) + incorrect pilot reactions (lack of training) = Crash

**Worse Case Solution:** Hardware + Software + Training procedures/manuals + DOT Investigation = Fix

**Best Case Solution**: Software + Training procedures/manuals = Fix

**Worse Case Timeline:** [Hardware: 3-6 months to fix (Boeing + Vendor)] + [Software: 2-3 weeks to fix (Boeing + FAA)] + [Training: additional 1-3 months to fix (carrier dependent)] + [DOT Investigation: 1-3 months (results, penalties, and fixes) = 5-13 months

Best Case Timeline: [Software: 2-3 weeks to fix (Boeing + FAA)] + [Training: additional 2 weeks to 3 months to fix (carrier dependent)] = 1-4 months

**Milestone Announcements**

1. Boeing software fix (done)
2. FAA approval
3. Software Implementation
4. Training Completion
5. 737 MAX back in the air (could occur before training completion)
6. DOT Investigation completion

Probability: 100% certainty if our assumptions are correct.

**Contributing Factors**

**Largest** — Pilot error is likely the largest contributing factor. The pilots at Lion Air and Ethiopian Airlines had the means to control the aircraft using existing emergency equipment and procedures (*liability on carriers*).

**Next Largest** —Boeing's omission in terms of disseminating critical MCAS characteristics to FAA and carriers prior to the Lion Air crash and during aircraft certification (*liability on manufacturer*).

**Least** — The least contributing factor is faulty sensors that provided erroneous data to flight control computers which activated MCAS (*liability on manufacturers—not just Boeing*).

**Unknowns:** Investigation + Liability + Litigation = Manufacturer, vendors, carriers, and FAA value. Regardless, secondary to fixes and getting aircraft flying again. The ongoing investigations may result in liability to Boeing, but aircraft will be back flying well before they finish. Ongoing crash investigations could find negligence on foreign carriers to properly carry out Boeing's recommended training and software fix. Regardless of these unknowns, aircraft will get fixed.

**Why did Boeing Continue with the 737 Aircraft?**

MCAS system and its flight control shortcomings

When Boeing developed the 737 MAX series, a new system called Maneuvering Characteristics Augmentation system (MCAS) was added to counter changed flight characteristics due to the addition of new more powerful CFM Leap 1 engines. The MCAS system uses a trimmable horizontal stabilizer, along with the elevators, to prevent a stall (nose high and slow airspeed) by controlling the aircraft's pitch (nose down).

The MAX's larger Leap 1 engines create more lift (nose up) at higher Angles of Attack (AOA) generating a greater pitch-up moment than the older CFM56-7 engine of the 737 NG. The MCAS was added as a certification requirement to minimize the handling difference between the MAX and NG.

To allow for larger, more fuel-efficient engines on the 737 MAX wing, the engines were moved forward. This forward movement also moved the aircraft Center of Gravity (CG) 8 inches forward. By moving the engine slightly forward and higher up and extending the nose landing gear by eight inches, Boeing was able to squeeze another 14-16% improvement in fuel consumption out of a continuously improved fleet type. The relocated engine—much larger with a refined nacelle shape—caused an upward pitching moment, especially in high thrust conditions (i.e. climb-out thrust). Basically, the nose would move upward. The only purpose of the MCAS is to trim the stabilizer nose down and to offset the tendency of the aircraft to pitch up.

During high AOA and slow airspeed flight situations, this pitch up bias from the new Leap 1 engines can aggravate impending stall conditions. To compensate, Boeing added a new MAX flight-control law which changed from normal speed trim to a more aggressive MCAS trim authority because the MCAS reacts more quickly to AOA changes. **MCAS activates automatically (unknown to pilots)** under four flight conditions: (1) nose is high or high AOA sensed by AOA airspeed and altitude sensors, (2) the autopilot is off, (3) when flaps are up, and (4) steep turns (highly unlikely condition in either the Lion Air or Ethiopian Airlines accidents). An important note is that the MCAS system is activated only when the pilots are manually flying, which is normal on climb-out, and cannot be disengaged by manual stabilizer movement (pulling on the yoke).

**Faulty angle of attack indicator identified**

It appears that an AOA sensor may have sent erroneous signals to the aircraft's new MCAS software that automatically pushes the plane's nose down to prevent a stall. Boeing's chief executive Dennis Muilenburg said Sunday (March 17, 2019) that his company is finalizing software updates and pilot training protocols to address problems that have emerged "in response to bad sensor inputs." He did not specify which sensors but indications from Lion Air crash results lean toward an AOA sensor.

Over the past five years, AOA sensors have been identified as problems more than 50 times on U.S. commercial airplanes, although no accidents have occurred over millions of miles flown, according to reports made to FAA's Service Difficulty Reporting database.

The FAA reports include 19 reported cases of sensor problems on Boeing aircraft, such as an American Airlines flight last year that declared a mid-flight emergency when the plane's stall-warning system went off despite normal airspeed. The Boeing 737-8 landed safely. *Maintenance crews replaced three parts, including the angle-of-attack (AOA) sensor*, according to the FAA database.

The AOA sensors on the fatal Lion Air flight were made by Minnesota-based Rosemount Aerospace, a subsidiary of United Technologies. The model is commonly used on commercial aircraft but "appear to have a greater susceptibility to adverse environmental conditions" than sensors made by a third company, the FAA reports.

**All signs point to pilot error and inadequate training as the largest contributing factor, but there are also serious design flaws with the 737 Max series MCAS system**

The [MCAS-activated] runaway stabilizer trim event that occurred during the Lion Air flight was most likely triggered by a faulty AOA sensor (the 737 Max series use only a single-source AOA input out of two available probes). In normal flight conditions like climb-out, the pilots are flying manually and at high thrust settings. Inaccurate AOA signals sent to the aircraft flight control computers may have contributed to the aircraft believing it was in a stalled situation (high AOA and slow airspeed), automatically triggering the MCAS system. The high thrust and airspeed condition on climb-out may have magnified the MCAS movement of the stabilizer creating an aggressive nose-down flight change or what pilots refer to as a "startled moment." In other words, the action most likely lifted them of their seats (negative G forces) making it even more difficult for the pilots to control the aircraft. The combination of an unexpected aggressive aircraft movement, low altitude and the startled effect may have heightened the need to correct the problem.

Pilot reactions were most likely quick using either counter [yoke-mounted] electric trim to help pull out of a dive or just brute force overcoming MCAS nose-down inputs by pulling back on the yoke. Regardless, once the pilots recovered to level (or a climb) flight attitude, the erroneous sensor data, still feeding MCAS, forced it to reactivate (after five seconds if countering with yoke mounted trim) or continue as the pilots eased up on the yoke.

## Most likely accident scenario and design flaws

The repeated actions mentioned above can create an oscillation or battle between the aircraft and the pilots producing hazardous results, but both flight profiles provided by satellite information show that that the pilots of Lion Air and Ethiopian Airlines successfully fought off the unwarranted MCAS trim ranging from five to ten minutes—at times maintaining some semblance of level flight. The question is why did they eventually end up in such a severe nose down position that even brute force could not overcome?

The 737 has three trim systems that may have had a contributing (combining) effect in the accidents; MCAS, Speed Trim (STS), and Elevator Feel Shift (EFS). Each system is designed to improve flight characteristics during takeoff, climbs, ago arounds, and stall situations. They work automatically and together, depending on flight parameters. As mentioned, MCAS was added to account for bigger engines, more thrust and changes in a forward center of gravity. Combined, these new factors give the MAX series aircraft a stronger tendency to pitch up. In a stall position, the MAX automatically transitions from STS to MCAS to account for its nose up tendency since it reacts quicker to faster AOA changes from the larger Leap engines.

Here’s an important point, and possibly at the heart of the design flaw, as the pilots were fighting for control they most likely used the yoke trim switches to help pull the nose back up thus cutting off MCAS. However, MCAS not only resets after five seconds (starts again, assuming the same erroneous data is being received) but also the trim position goes back to pre-MCAS activation. If the pilots did not fully trim out the MCAS trim position (nose down) then when it reactivates it starts from that spot, which may have been a nose down position. This would compound the problem each time the MCAS activates and a new more severe nose down position develops. At some point, the control column presser is so great that neither the manual trim or brute force could overcome the nose down movement. And unlike STS, where the movement of the control column (yoke) shuts off the automatic trim, the control column does not shutoff for MCAS. Each accident occurred around the five to six-minute point meaning that the difficulty to keep the nose up was so great the pilots eventually lost the battle with the aircraft system, plunging straight down at excessive speeds (remember the auto throttles are probably still at a high-power setting thinking the aircraft is stalled). Under these circumstances, we are not sure that any pilot could have saved these aircraft.

## Pilot Error and Training Factors

Regardless of software and/or hardware failures or flight conditions, the outcome would have been very different if the pilots had deactivated the stabilizer trim—an already established emergency action procedure in the 737 MAX series aircraft. This is a simulator trained procedure on all Boeing and Airbus aircraft, by all operators worldwide. It’s a “memory item” or “time critical” procedure and because the phase of flight (e.g., low altitude) may not allow enough time to research the problem or go through a set of lengthy checklists. Therefore, these types of emergencies are quick reaction memory requirements and routinely trained to.

Considering the reaction time required and severity of an uncommanded trim situation, pilots can quickly deactivate the MCAS in two ways: via the yoke-mounted electric trim switches or by using the STAB TRIM CUTOUT switches on the center console. The trim switches interrupt the MCAS for 5 seconds and establish a new stabilizer trim reference point, but as described in the previous paragraph, does not de-power the MCAS and the speed-trim system.

In defense of the pilots, the urgency (or startled moment) of the manual maneuver at low altitude would be exceptionally challenging given the unexpected and increasingly larger swings in the nose-down pitches. Another important point is that since MCAS is part of the augmentation system and the fact that it operates automatically may have been the reason Boeing did not put out descriptions and an associated MCAS emergency procedure—not being delinquent but because severe high AOA flight conditions or uncommanded trim would be covered in other existing emergency procedures. By this we mean that the emergency procedure to handle MCAS issues already exist in airline checklist procedures, like runaway trim or unreliable airspeed emergency procedures. Without a specific checklist to deal with an [unknown] MCAS fault could lead pilots to misidentify the problem and thus miss the correct checklist procedures or not identify the problem at all which may have been the case with the Lion Air crash. As such, the pilots in both crashes likely followed the wrong checklist (or no checklist) procedure which may have led them to battling the aircraft. An easy fix would have been to switch off the stab trim cutout switches.

One of the possible corrections to this problem, as suggested by the FAA, is to mandate changes in the system to make it less likely to activate in unwarranted stalled conditions. The agency and Boeing said that in addition to software fixes they will reiterate already prescribed (or new) emergency procedure training and references to it in flight manuals.

**Boeing's Bulletin and FAA's emergency order defines the problem and updates flight manuals**

After the Lion Air crash**,** Indonesian investigators identified a faulty AOA sensor**.** To address, Boeing's Bulletin number TBC-19 directive stressed that pilots should follow procedures in the fight manual when erroneous data is present. The bulletin lists 9 indicators that would alert the pilot to an erroneous AOA sensor. Increasing nose down control forces is one of the indications—runaway stabilizer trim—and clearly, the one that must be addressed immediately by flipping off the STAB TRIM CUTOUT switches.

The FAA followed up with an emergency directive requiring U.S. airlines to follow Boeing recommendations and add erroneous MCAS activation training and information to pilot manuals. For U.S. carriers, with respect to the Ethiopian accident, the fix was considered already in place and the most likely the rationale for holding off on grounding the aircraft in the U.S.

In addition, and critical to possible liabilities for Boeing, the Ethiopian Airline CEO has verified in a letter to the media, customers and the general-public that they were also provided the above MCAS information, Boeing recommendations and training procedures after the Lion Air accident. Further adding, he stated that all their pilots were informed, and recommended training provided. The similarities of the two accidents (or new evidence of a systemic issue) is why U.S. regulators followed suit and grounded the MAX series aircraft

**Boeing's bulletin provides additional information not provided during the MAX aircraft certification**

During the certification of the 737 MAX, Boeing did not fully disclose the severity of the trim (nose-down pitch) that the MCAS would command. This shortfall did not alert the FAA to possible severe flight conditions that could result from an erroneous MCAS activation which would have highlighted a need for further review and corrections. One other major MCAS shortcoming is that Boeing designed the system to receive input from only one of the AOA sensors during each flight. The left and right sensors alternate between flights, sending AOA data to the Flight Control Computers (FCC) and the MCAS. This only allowed one sensor to send data instead of designing a redundant system where the aircraft would use another AOA sensor in case of faulty data or failure.

Operators and regulatory agencies were supposedly unaware of the severity and degree of the MCAS commanded nose-down trim. Each attempt to stop the pitch down would reset the MCAS resulting in more nose-down trim. Perhaps—and this is only an assumption—Boeing was unaware of the faulty software and how it would impact the flight controls if there was inaccurate AOA sensor input. Or they felt that the system would only be activated in extreme flight conditions and the fact that there were already existing emergency procedures to take care of other than stalled flight situations.

If the degree in which the MCAS commands the trim were known during the safety analysis and certification, the regulatory agencies would have required additional redundancies in addition to updated MCAS software, such as requiring inputs from both AOAs—this in addition to other system safe-guard redundancies may have produced different accident outcomes.

In terms of making sense of the timeline of events, the aircraft gained FAA certification on 8 March 2017, but Boeing did not provide the airlines and regulatory authorities with the critical new information [bulletin TBC-19] until November 6, 2018, eight days after Lion Air flight 610 had crashed (October 29, 2018). This suggests that Boeing was unaware of the seriously flawed MCAS software and its exaggerated stabilizer trim effect (during non-MCAS flight conditions) prior to the Lion Air crash. Or if known, and this is speculation, willingly left out full MCAS trim authority to FAA regulators to quicken the certification process. Anonymous FAA and Boeing sources say that this new MCAS command information would have put the system in a different "catastrophic failure" category forcing Boeing to address the problem and adding significant time and cost to the certification process. The withholding of this MCAS information is at the heart of the current DOT OIG investigations.

**Boeing's Flight Crew Operations Manual Bulletin number TBC-19 dated November 6, 2018**

**Subject line of the bulletin:** 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)

**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 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.

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 the autopilot.
- Automatic disengagement of autopilot.
- IAS DISAGREE alert.
- ALT DISAGREE alert.
- AOA DISAGREE alert.
- 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 position for the remainder of the flight.

Boeing's new service bulletin was sent to all operators of the MAX series aircraft, including Ethiopian Airlines, four months before Ethiopian Airlines Flight 302 hit the ground at 500 mph. In other words, as we have stated, the airline had critical information that should have prevented the crash.

The service bulletin was the prelude to the formal emergency airworthiness directive from the Federal Aviation Administration (FAA) issued the following day on November 7, 2018. The

FAA said the directive was prompted by an "analysis performed by" Boeing that found "an erroneously high angle of attack (AOA) sensor input" can cause "repeated nose-down trim commands of the horizontal stabilizer." The emergency directive calls for U.S.-based 737 MAX 8 and 9 operators to revise operating procedures to flight crew *handling runaway horizontal stabilizer trim* motion.

As a point of emphasis, on the catastrophic Lion Air flight—Boeing issued the new bulletin 8 days later—the angle-of-attack sensor sent erroneous readings indicating the plane's nose was pointed dangerously upward. This signaled the MCAS to activate the horizontal stabilizer to push the nose down to prevent a stall. Unfortunately, the pilots did not have the new flight manual updates.

**Southwest updates its MAX cockpits with AOA indicators**

Because of the Lion Air crash, Southwest added new AOA indicators on the large display screens for its new 737 MAX deliveries from Boeing. With the largest group of trained 737 pilots in the world, Southwest wants its pilots to have a supplemental cockpit panel cross-check in the event there is an erroneous AOA data signal that may activate the stall protection system. Delivery of these newly-equipped aircraft started in late December last year. The new control panel indications provide "continuous visual feedback to the Flight Crew allowing identification of an erroneous AOA that could lead to uncommanded stabilizer trim actuation," according to an internal message provided to the Southwest pilots.

**Deactivating the electric Stab Trim system would have prevented the crashes (further detail)**

The Lion Air and Ethiopian Airlines pilots faced a flight control emergency that is akin to a runaway stabilizer trim scenario trained in simulators by airlines worldwide. This is a widely-known procedure and trained procedure for both Boeing and Airbus aircraft. Tragically, at the time of the Lion Air crash, pilot training and flight manuals did not include the existence of MCAS. However, a runaway stabilizer trim—if uncommanded and unwarranted—is a trained procedure. The pilot's attempt to override the auto trim system would result in the MCAS resetting and retrimming repeatedly until auto-trim hit full trim down. The flawed MCAS software that created the additional problems and distraction—a full nose-down pitch after repeated pilot yoke pullbacks—likely confused and distracted the pilots and is a contributing factor that investigators will consider.

When a triggering AOA threshold is reached, the MCAS commands 0.27 degrees per second of aircraft nose-down stabilizer deflection for 10 seconds—a total of 2.5 units of trim. When the Flight Control Computer (FCC) reads that the AOA is back below the threshold, the MCAS is reset, and the aircraft's trim returns to the pre-MCAS trim position. Inaccurate AOA data will continue to trigger the MCAS (every five seconds after pilot manual trim is used) until the data is corrected or the system is disabled. This unusual trim response may have distracted the pilots from identifying the real problem, a runaway stabilizer trim. Since it was an unwarranted trim input, the proper procedure would be to turn off the STAB TRIM CUTOUT switches to deactivate both the electric trim and the MCAS.

**Foreign carrier training and cultural issues**

We now know that an off-duty pilot was sitting in the cockpit jump seat on an earlier flight [than Lion Air flight 610] whose pilots also fought to control its nose-down pitching shortly after take-off. The deadheading pilot correctly diagnosed the problem and told the crew how to disable the malfunctioning system causing the pitch-down dives—a runaway stabilizer trim. The pilots followed his lead and turned off the STAB TRIM CUTOUT switches. The flight control problem was solved, and the pilots saved the aircraft and the passengers. Turning off the stabilizer trim switches is a checklist item that pilots for most airlines are required to memorize when there is a runaway stabilizer trim.

By contrast, the crew on the flight that crashed the next day didn't know how to respond to the malfunction, said one of the people familiar with the plane's cockpit voice recorder recovered as part of the investigation. They can be heard checking their quick reference handbook, a summary of how to handle unusual or emergency situations, in the minutes before they crashed, Reuters reported, citing people it didn't name.

Further, the Lion Air Captain supposedly handed the aircraft over to the first officer just before the deadly nose dive, highlighting a question, why would the Captain hand over controls during such a critical phase of the emergency. Especially if there were most likely severe control column forces caused by compounding erroneous MCAS trim. Even in a preliminary investigation report it suggests Lion Air needs to "improve safety culture" by training pilots better. This all adds to potential carrier training and culture problems.

The Lion Air challenges don't end with the pilots. The flight control system for Lion Air flight 610 was written up and signed off by maintenance the day before. Investigators were asking about essential flight-control systems on trips before the crash, and why the aircraft was dispatched without first undergoing a test flight without passengers. The company also mentioned that the maintenance performed in the days before the accident failed to fix the problem. Further mentioning that the faulty AOA sensors were not replaced.

Take the above Lion Air challenges and let's compare similar shortfalls with Ethiopian Airlines. The FAA requires U.S. carriers to have pilots with an airline transport pilot certificate, which calls for 1000-1500 hours of flight time. In contrast, the International Civil Aviation Organization (ICAO), which Ethiopian and Indonesian Airlines fall under, requires as little as 200 flight hours. The first officer on Ethiopian Airlines flight 302 had only 200 hours, according to the company…enough said.

Lastly, here is a quote from the Ethiopian Airlines LinkedIn page, "Ethiopian Airlines pilots completed the Boeing recommended and FAA approved differences training from the B-737 NG aircraft to the B-737 MAX aircraft before the phase in of the B-737-8 MAX fleet to the

Ethiopian operation and before they start flying the B-737-8 MAX." The assumption here is that not only were their pilots properly trained on the Max series aircraft, but also the fact that they had received all pertinent information from Boeing about the Lion Air crash.

Further, the company was aware of the MCAS problem and trained to it…i.e. move the STAB TRIM CUTOUT switches to cutout if you suspect runaway trim. If these accidents are similar then why did the pilots of flight 302 not perform the Boeing recommended procedures and use the cutout switches? Do they still have a training issue or is it more cultural?

Remember, Ethiopian Airlines flight 302 crashed on 10 March 2019—116 days after Boeing issued the bulletin.

Just to reiterate, a "runaway trim" emergency procedure is a "memory item" or "immediate action" and must be known cold and acted upon without referencing a checklist. Obviously, both Lion Air and Ethiopian Airline pilots did not recognize the problem or were improperly trained and did not know to execute the already established immediate actions for runaway trim.

The pilots are the last line of defense and because they failed to turn off the trim system, regardless of why it automatically pushed the nose down—pilot error is likely the largest contributing factor for the crashes.

It is reasonable to assume that:

- If the MCAS was properly designed and specified during MAX certification—the two MAX aircraft crashes would not have happened.
- If the pilots had followed established procedure—perhaps not trained—and were aware of how to turn off the electric stab motor (system knowledge), the crashes would not have happened.
- If Lion Air maintenance checked both AOA sensors (one was written up), flight 610 would not have crashed.
- If Lion Air and Ethiopian Airlines were subsidiaries of a US-based airline—using experienced American pilots trained and employed by US airlines—the crashes would not have happened.

Airlines in 3d world countries that are state-owned have different cultures in terms of employee thinking/behavior and how the businesses are managed. Country, employee, and company culture matters when it comes to assessing risk. Safety-related statistics, like the number of air travel accidents in 3d world nations, provide quantitative evidence of the higher risk of flying on 3d world airlines. Still very safe, statistically speaking, but not as safe as flying on a developed nation airline. 8x worse is statistically significant.

**Is Boeing negligent or liable because they did not disclose MCAS's full trim authority and shortcomings during the safety analysis (further detail)?**

It might be argued that Boeing was negligent for not emphasizing the severity of the auto trim swings [commanded by the MCAS software given certain sensor failures] to airline operators and regulatory safety agencies such as the FAA when the new aircraft was being certified. If Boeing knew this information and communicated it to the FAA, the new system should have been classified in the catastrophic failure category, not the less severe hazardous failure or major failure categories during the safety analysis required to certify the new aircraft. This category would have required the FAA to mandate additional redundancy (two channels, more than one sensor source) in the new system. The current MCAS system receives data from a single AOA sensor and we know it was a single AOA sensor failure that contributed to the Lion Air 610 tragedy.

Perhaps Boeing believed the MCAS system was safe and therefore did not think the additional information presented in Bulletin number TBC-19 was necessary during the MAX safety analysis during the certification process. Perhaps they were unaware that a faulty AOA sensor would result in a runaway stabilizer trim event that would be exacerbated by pilots trying to manually override the auto nose-down trim. MCAS commanded the horizontal tail 2.5 degrees, not the originally disclosed limit of 0.6 degrees. That number was new to FAA engineers who had seen 0.6 degrees in the safety assessment. Both the FAA and foreign regulatory authorities were not aware of the larger down-pitch that would occur if MCAS commanded the stabilizer trim without pilot input. As such, MCAS can move the tail more than four times farther than was stated in the initial safety analysis document. This likely was considered critical information in the assessment of the hazard involved in the failure of the sensor. The higher limit meant that each time MCAS was triggered, it caused a much greater movement in the tail than specified in the original safety analysis document. A subsequent report suggested that a faulty sensor might have triggered the automatic flight control system into a series of 26 dives at under 5,000 feet.

The pilots were unaware of the automatic features of the new MCAS system because it wasn't in their manuals. Even U.S. airline pilots said they were unaware of the MCAS prior to the Lion Air disaster. So, it could be argued that Boeing was negligent by not informing the airlines about the MCAS and not incorporating the required fail-safes into the system.

**Did Boeing cut corners to sell more aircraft that require less training time?**

If Boeing did know about the full swing in pitch that would occur during certain failures and did not provide the correct information to the FAA or operators, this suggests culpability on its part. If so, it could be argued that Boeing cut corners to speed the certification process and meet key production timelines (increase sales and profits) of the MAX aircraft. This would also save the operators time and money because the 737 MAX requires less simulator training. It's a difference training course for a common fleet type that has some changes in systems, but not the full-blown course required for a new aircraft type which carries significant costs for the operator. However, even if true, what would be the liabilities for not disclosing this information to the FAA when the aircraft was undergoing safety analysis?

Much of this problem could have to do with the FAA delegating too much of the safety review to Boeing. Thus, putting into question the accuracy and needed detail to properly certify the aircraft. This could have allowed Boeing to provide much of the engineering input and analysis that resulted in the aircraft's new MCAS system to be mischaracterized as less than catastrophic in the safety analysis.

**What is the longer-term viability of Boeing's fix to be rolled out in April?**

**Very high**—although the accidents are not completely Boeing's fault, they may be at liable for withholding information from the FAA during the safety review process. How this affects their overall credibility and future viability is unknown, but historically aircraft manufacturers, especially one the size and importance of Boeing, usually work through these problems quickly acknowledging their error or negligence and fixing the problems.

Most airlines will incorporate the initial software fix in place within weeks. A short-term fix maintains viability. If it also involves a hardware issue, such as a faulty AOA sensor, then viability is still the same, but it will take longer to get the 737 MAX flying again because the full fix will take longer. Additionally, delays will most likely occur due to FAA and carriers recertifying fixes and adding additional simulator training. Meanwhile, airlines will adjust schedules to work around the grounded aircraft, and most already have.

**Is Boeing too important to fail?**

There are currently 350 MAX 8s in operation (though many are grounded) worldwide. There are over 5000 orders for MAX series aircraft still pending (in a worldwide total of over 25,000 airline type aircraft). In China alone they are one of Boeing's biggest customers for the aircraft with 96. Therefore, the present number of MAX 8s, current and pending, represent over 20% of all airline aircraft. If you look at just U.S. carriers, American Airlines operates 24 MAX aircraft out of 995 aircraft or 2% of its total mainline fleet. Southwest has 34 MAX aircraft out of 760 or 5%. United has 9 MAX aircraft out of 755 or 1%. Alaska has 32 orders out of 155 total aircraft (6% of the fleet but a June delivery). WestJet 13 MAX aircraft out of 121 or 10%.

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