Boeing 737 MAX Aircraft Accident Reports: Determining the Costs of Culpability and Aircraft Groundings

Preliminary Summary and Conclusions for Why the Crashes Occurred

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A Boeing (BA) 737 Max operated by Ethiopian Airlines crashed shortly after takeoff on March 10, killing all 157 people on board. Lion Air Flight 610 of the same model plunged into the Java Sea off the coast of Indonesia on Oct. 29, killing 189 passengers and crew. As a result, all 737 MAX aircraft were grounded by operators worldwide.

Airlines with large market capitalizations (Figure 1) and MAX 737 fleets (Figure 2) include Southwest Airlines (LUV), the largest U.S. customer, American Airlines (AAL), United Airlines (UAL), Ryanair (RYAAY), Air China (SHA: 601111), China Southern (ZNH), China Eastern (CEA), Norwegian Air (NWARF), Air Canada (ACDVF), GOL Linhas Aéreas (GOL) and WestJet (WJAFF). Both Boeing and the airline operators will be financially impacted by the accidents and MAX groundings.

The 737 is the best-selling airliner of all time

The MAX variant quickly became the fastest selling plane in Boeing's history and 15,000 737s have been sold since the 1960s—nearly a third being the MAX variant (this includes future Max orders). In total, 376 737 aircraft have been delivered to airlines and leasing companies worldwide. Boeing has 5,012 outstanding orders for the 737 MAX which represents 80% of the company's backlog. Future Boeing MAX orders are worth more than $600 billion—a single aircraft type that, according to Goldman Sachs, "makes up 33 percent of Boeing's total revenue for the next five years."

Boeing's 20-year forecast, published in July 2018, projects a long-term average growth rate of 4.7% per year for passenger traffic and 4.2% for cargo traffic. Based on long-term global economic growth projections of 2.8% average annual GDP growth, Boeing projects a $6.3 trillion market for 42,700 new airplanes over the next 20 years. As of the nine months ending September 2018, commercial aircraft accounted for 60% of Boeing's total revenue. Boeing (BA) will report Q1 earnings this coming Wednesday morning.

The outcome of software fixes, safety investigations and potential litigation against the manufacturer will have an impact not just on the company but also on the global airline market. For example, Chinese airlines flew 97 of the 371 MAX jets in service prior to the groundings, more than any other country excluding the U.S., which accounted for a quarter of the total number. China alone has 200-plus orders with Boeing worth over $25 billion. Countries in the European Union (EU) have ordered close to 280 MAX aircraft worth over $35 billion.

Other countries and regions have similarly large orders with Boeing, but it is important to highlight China and Europe because of their sometimes-fractious relationship with the United States. Both are in trade disputes with the U.S., to include World Trade Organization (WTO) rulings over subsidy disputes between the U.S. (Boeing) and the EU (Airbus), which makes any tangential incident, such as these accidents, possibly aggravate their trade negotiations.

The question of culpability will determine liability and costs

Our 26-page report "The Boeing 737 MAX 8 Crashes: The Case for Pilot Error" has received over 650 comments, many critical of our conclusion that pilot error was the largest contributing factor in the accident. In our previous 21-page report "Boeing's Grounding: Catastrophic Crashes and Questions About Boeing's Liability and 737 MAX Aircraft Viability" we identified the critical issues and addressed culpability (based on preliminary reports), and roughed out a timeline of when the MAX aircraft would be back in the air.

The purpose of the reports was to answer the critical question of why the accidents occurred and then estimate the market value impact on Boeing and key operators of the MAX aircraft. While the tragic loss of life is everyone's first concern, the question of culpability for the crashes is important for investors because it gets to the issue of liability and costs for both Boeing and the operators of the MAX aircraft.

China Daily reports that Shanghai-based China Eastern has already raised its demands for claims with Boeing because of the aircraft's grounding. According to a senior executive with the airline, **"The final decision will depend on the cause of the MAX aircraft grounding, whether it is a result of a design flaw or an operational problem."** We believe this will be the case for all operators of the grounded MAX aircraft and sets the stage for claims against the various parties, including operational (i.e., pilot) errors, design flaws, inadequate system integration—or all of the above.

Thus far, the grounding of the aircraft has had little impact on China Eastern, and likely most other affected airlines that rescheduled around the grounded aircraft, as the grounding has not coincided with the peak travel season. In addition, these delays and lost revenue must be weighed against future orders and their impact across their fleets. For example, China Eastern has 14 MAX aircraft, a small number relative to its 700-aircraft fleet. However, in contrast—and a major concern for Boeing—China Eastern operates the world's second largest and Asia's largest fleet of Airbus Aircraft.

China was the first country to ground the aircraft following the two crashes. The Civil Aviation Administration of China (CAAC) suspended the airworthiness certificate application of the 737 MAX for Chinese airlines, which means that no new deliveries of this model will take place in China until the jet is certified airworthy (design and integration issues resolved).

The CAAC is not alone in its concern for the aircraft's airworthiness. Since 12 March, the European Aviation Safety Agency (EASA) has suspended all 737 Max 8/9 flight operations within the European Union (EU) as well as 737 Max series aircraft flying into, within or outside the EU. Further, the EASA has discussed convening its own airworthiness certificate, so it's critical for Boeing to have its software fixes recognized by all global aviation safety regulators.

Lawsuits and potential liabilities

For Boeing, its liability will be much higher if the primary cause of the accident is determined to be a design flaw and/or integration problem. Families of those who perished in the fatal aircraft accidents in Indonesia and Ethiopia are seeking payouts from Boeing in U.S. courts. With the federal investigations into whether Boeing provided incomplete or misleading information to regulators and customers, aviation lawyers believe there is a higher chance of a U.S. court accepting the lawsuits.

The Maneuvering Characteristics Augmentation System (MCAS) was a flight control law [mode] designed and certified for the 737 MAX aircraft to enhance the pitch stability of the airplane—so it feels and flies like the previous 737s. Boeing's design and integration of MCAS, as well as the FAA's certification, are at the heart of the accident (s) controversies.

However, Boeing insists that the accidents were caused by a series of events, including pilot action. There have been more than 30 lawsuits filed over the Lion Air crash and U.S. lawyers are proceeding with litigation on behalf of the plaintiffs over the Ethiopian crash. Some of the lawsuits also name the airline and Rosemount Aerospace Inc., a unit of United Technologies Corp. (UTX) that made the AOA sensor. The sensor is currently being examined by air-safety investigators.

Final reports on the official investigations into the crashes are usually issued within 12 months of an accident. Once completed, the plaintiff's lawyers will seek details from the probes to support their case.

Valuation Framework

To rough out the potential cost of culpability to Boeing and its impact on shareholder value, we develop a valuation framework that identifies the biggest drivers of revenue and costs to the company. Revenue will be impacted by industry fundamentals and various macroeconomic factors and forces. We also include political forces that have collided in tit-for-tat trade skirmishes/wars and congressional hearings/investigations that could increase safety compliance costs and result in heavy fines.

Costs will include ballpark estimates of legal costs and operator claims against the manufacturer.

Here is a possible list of potential valuation factors and how they might be shaped within the larger context of legal suits/claims, the economy, and airline industry fundamentals.

Legal suits/claims

- Operational—operators demand Boeing cover the costs of the MAX groundings and perhaps the additional cost of pilot training
- Integration/design flaw—inadequately or poorly integrated/designed MCAS

Macroeconomic factors and forces

- Changes in economic growth—greater than 1 multiplier effect on earnings
- Trade issues— WTO rulings, negotiations, tariffs, and leverage
- Aircraft orders—deferred vs. canceled

Boeing's valuation drivers

- Revenue and costs
- Future earnings/cashflows
- Balance sheet/liquidity
- Share repurchases/dividends

CONTEXT AND CONTRIBUTING FACTORS

We understand that what happens in an aircraft during an emergency cannot be fully duplicated after the event. We also recognize the complexity and difficulty of the situation presented to the pilots of LA 610 and ET 302, especially during a critical phase of flight, such as climb-out.

Contributing to the pilots' predicament was an integrated Maneuvering Characteristics Augmentation System (MCAS) that, after each MCAS activation, the pilots had to aggressively re-trim the aircraft back to a level or nose-up trim setting. The MCAS auto nose-down (AND) activation was the result of a faulty AOA signal, which falsely indicated that the aircraft was in a high (approaching stall) angle of attack flight condition

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

After each subsequent MCAS trim activation, if the pilots did not properly retrim to a level or nose-up trim, the nose-down trims became additive. In other words, the nose-down trim position moved further down and this resulted in the aircraft flying mistrimmed. We believe this contributed to the crew's distraction because it forced the pilot in control to pull back repeatedly on the yoke and retrim. Unfortunately, after several MCAS actuated AND trims—given the mistrimmed state of the aircraft and after full nose-down trim was reached—the result was an aircraft in an unrecoverable dive.

However, as our previous articles support, across the accidents it is our conclusion that mismanaging the airspeed, misdiagnosing the problem, and deviating from company and Boeing procedures as well as poor aircraft handling that ultimately led to these unrecoverable dives—***in other words, pilot error.***

Boeing's MCAS design and integration contributed to the crashes

First, *MCAS lacks AOA sensor redundancy*. The aircraft has two AOA vanes, but only one feeds MCAS, alternating between AOA sensor sources on the ground and after each flight. One of Boeing's solutions is for the flight control system to compare inputs from both AOA sensors. If the sensors disagree by 5.5° or more with the flaps retracted, MCAS will not activate. Hence it might be argued that Boeing was culpable for not adequately designing a safer redundant system.

Second, *MCAS can activate repeatedly*. Each time either the yoke-mounted electric trim switches or manual trim wheel (STAB TRIM switches NORMAL) are used by the crew to stop MCAS auto nose down trim, the trim moves (i.e., resets) to a new position.

Five seconds after the pilot releases the yoke-mounted electric trim switch (or manual trim wheel), MCAS commands another nose-down trim. This will continue as long as the autopilot is disengaged, the flaps are up, and the aircraft senses a high angle of attack (AOA)—real or false.

The MCAS-actuated electric stabilizer trim motor moves the horizontal stabilizer at a force and rate that requires a sustained pilot-initiated (yoke-mounted) electric trim actuation or an aggressive physical movement of the manual trim wheel. If the pilots do not trim-out the MCAS commanded nose-down trim, after several resets the additive nose-down trim can result in a hard-to-recover-from full nose-down trim setting.

Note: the yoke-mounted trim switches are active when the STAB TRIM CUTOUT switches are in the NORMAL (on) position and pilots use the manual trim wheel to move the horizontal stabilizer during the *runaway trim procedure* after the STAB TRIM switches are positioned to CUTOUT (off). The manual trim wheel moves the horizontal stabilizer through cables.

Both LA 610 and ET 302 reached full nose-down trim, which ultimately led to a severe unrecoverable nose-dive. A Boeing solution is to limit the system to one MCAS trim input, which allows the stabilizer a maximum nose-down movement of only 2.5 units.

Third, *elevators have limited effectiveness if nose down trim is excessive.*

The control yoke moves the smaller elevator that is attached to the horizontal stabilizer. When the aircraft's horizontal stabilizer is properly trimmed for phase of flight, the elevator is used to control aircraft pitch. If the pilots do not trim out the MCAS-actuated nose-down trim, the system can trim the stabilizer beyond the ability of the control column (yoke) to counteract. It is important to note that the elevators are capable of taking out at least 1-2 units of stabilizer trim.

One solution is for MCAS to command a stabilizer force that can be counteracted by the flight crew pulling back on the control column (yoke) or by limiting MCAS to only one nose-down input, allowing at most a 2.5-unit nose-down trim position. Pilots should be able to overcome an auto nose down trim by just pulling back on the control column (yoke).

Pilot error and training issues were the primary factors in both accidents

Without new evidence from the final investigation reports, our analysis of the flight control parameter statistics, from the Flight Data Recorder (FDR), leads us to believe that it was **pilot error and training issues—compounded by Boeing's MCAS design characteristics—that were the primary factors in the accidents.**

Our report "The Boeing 737 MAX 8 Crashes: The Case for Pilot Error" presents the four major arguments and two critical errors that support the conclusion that pilot error was the largest contributing factor in the two MAX crashes.

ET 302

Summary: The pilots mismanaged engine thrust, allowed the aircraft to accelerate to dangerous speeds, and deviated from company and Boeing procedures.

Supporting description: The aircraft's excessive speed (past the aircraft's max certified speed limit or VMO) exerted extreme pressure (force) on the horizontal stabilizer and tension on the jack screw (the mechanical component that physically moves the stabilizer) making it very difficult—if not impossible—to use the manual trim wheel. Even Boeing's bulletins recommend neutralizing the stabilizer trim (identified on the STAB TRIM indicator) before using the manual trim wheel.

The last and fatal mistake was deviating from Boeing's and the company's emergency procedures by turning the electric stab trim motors back on. This action activated MCAS, still being fed faulty AOA signals, which commanded nose-down trim to the stabilizer. Combine the excessive speeds, the increasing aerodynamic forces on the stabilizer, and not aggressively trimming out the MCAS nose-down trim, pulling back on the yoke (elevators) could not overcome the severe nose-down trim position of the stabilizer—putting the aircraft into an unrecoverable dive.

Results: ***By action and definition, the pilots were in error.***

LA 610

Summary: The accident was the result of misdiagnosing the emergency, executing the wrong checklist, and poorly-handled aircraft control.

Supporting description: Faulty AOA signals, which caused a master caution light, stick shaker alert, and erroneous airspeed and altitude indications, created a time-compressed and event-saturated situation. This led to misdiagnosing the problem and executing a lesser priority checklist. But what likely determined the aircraft's fate was handing over control during a critical point in the flight control emergency. This likely surprised the first officer, delayed his pulling back on the yoke and limited the trim inputs, which contributed to an unrecoverable nose-low condition.

Results: ***By action and definition, the pilots were in error.***

FINDINGS

The following is a summary of our analysis of the preliminary accident reports and Flight Data Recorder Data. We divide our findings of Ethiopian Airlines Flight 302 (ET 302) and Lion Air Flight 610 (LA 610) crashes into critical arguments that identify key pilot errors and conclude with common arguments and errors across the accidents.

ET 302

Critical Arguments

1. The pilots (crew) mismanaged engine thrust and airspeed
2. Excessive airspeed rendered manual trim ineffective
3. The crew deviated from the emergency procedure
4. Crew competence and experience a major contributing factor

Pilot Errors

1. Mismanagement of engine thrust and airspeed

2. Deviation from company and Boeing procedures

LA 610

Critical Arguments

1. Previous Lion Air Flight 43 did not pass on critical aircraft information

2. Previous Captains or Maintenance did not ground the aircraft

3. The pilots (crew) identified the wrong checklist

4. The pilots misdiagnosed the runaway trim problem

5. Inappropriate transfer of aircraft control during a critical phase of the emergency

Pilot Errors

1. Misdiagnosed runaway trim

2. Inappropriate transfer of aircraft control

CONCLUSION

Common Critical Arguments

1. Pilots misdiagnosed runaway trim

2. Pilots lost control of the aircraft

Common Pilot Errors

1. Mismanagement of emergencies

2. Deviations from normal procedures

Based on our assessment, the crash of Ethiopian Airlines Flight 302 (ET 302) and Lion Air Flight 610 (LA 610) were preventable had the crews followed company procedures and maintained control of the aircraft.

CONDITIONAL STATEMENTS

It is reasonable to conclude that:

If the pilots had followed (or not deviated from) established procedures (perhaps because of incomplete training), the crashes might have been prevented.

If Lion Air pilots and maintenance had properly addressed previous aircraft system problems and effectively communicated them to follow-on crews, Flight 610 might not have crashed.

If the MCAS was properly integrated and specified during MAX certification, the two MAX aircraft crashes probably would not have occurred.

If Lion Air and Ethiopian Airlines pilots', generally speaking, had the same average years of experience and entry qualifications as US-based airlines, perhaps the accidents would not have occurred.

Other Factors: Africa and Indonesia aviation accident rates and blacklisting

Africa: According to the International Civil Aviation Organization (ICAO), a U.N. agency, Africa had an air accident rate of 7.9 in 2011, versus a global average of 4.2 and 3.5 for North America. Another organization, the International Air Transport Association (IATA), shows a 2012 accident rate of 3.71 in Africa versus .15 in Europe and .2 globally. (http://planecrashinfo.com/rates.htm) (https://www.icao.int/safety/iStars/Pages/Accident-Statistics.aspx)

Indonesia: In June 2018, Indonesia received the all-clear from the European Union, which removed all of the country's airlines from the EU's safety blacklist. This was supposed to mark a major moment for Indonesia's fast-growing aviation industry, which had suffered from a poor safety record for years. In 2007, the EU had blacklisted all of the country's airlines. The U.S., having similarly barred flights from Indonesian airlines that year, raised the country's safety rating in 2016.

Boeing 737 MAX software upgrade 'operationally suitable': FAA panel

A review by a U.S. Federal Aviation Administration panel into Boeing Co's grounded 737 MAX aircraft found a planned software update and training revisions to be "operationally suitable," the agency said Tuesday, an important milestone in getting the planes back in the air.

The draft report from the Flight Standardization Board (FSB) appointed by the FAA, which includes pilots, engineers, and other experts, said additional training was needed for MCAS, but not required to be done in a simulator. The board said ground training "must address system description, functionality, associated failure conditions, and flight crew alerting."

The panel evaluated the software update to MCAS for "training and checking differences determination," the report said. "The MCAS system was found to be operationally suitable."

The FAA still must approve the software package and training once Boeing formally submits them to the agency, an FAA spokesman said.

Boeing said earlier this month it planned to submit a software upgrade and additional training for the anti-stall system known as Maneuvering Characteristics Augmentation System (MCAS) on the planes to the FAA in the coming weeks for approval.

Pilots publicly criticized Boeing for not giving them sufficient information about new safety software on the plane. The Justice Department, Congress, and other federal investigators are examining Boeing's actions while developing the 737 MAX.

CLOSING REMARKS

Airline pilots are trained to the highest standards. In fact, the bulk of recurrent training involves difficult emergencies and problem-solving scenarios that include multiple warnings, alerts, and emergency indications occurring simultaneously. Because systems and components fail quite often, pilots must fly the aircraft and then properly identify and address the problems. Failure to do so can be fatal. Pilots train to exacting standards to ensure they can prioritize their problems and address them accordingly. Every pilot is taught to control the aircraft first—*everything else is secondary.*

To summarize: pilot error is the most significant factor in both accidents.

REFLECTION

After carefully examining and analyzing these accidents, we believe that pilot ground training (computer-based training) is not enough. Carriers should incorporate at least one simulator dedicated to reviewing accident scenarios, building confidence in MCAS and ensuring that pilots understand the sequence of events that led to the accidents and can correctly handle the aircraft under similar conditions.

The public expects safe and reliable transportation and every responsible airline tries to deliver on that promise. Flying, it needs to be said, is still the safest form of travel —by a large margin. But people and systems sometimes fail, and accidents happen. We may have lost some confidence in the airline industry, and understandably so, but we owe to flights 610 and 302 and to every airline passenger the promise to use all of our resources —across manufacturing, carriers, and regulatory oversight—to ensure that the cause, causes or sequence of events that led to these accidents never happen again.

Vaughn Cordle, CFA has 40 years of experience in the airline industry, including 20 years as an airline analyst for (and founder of) AirlineForecasts and Ionosphere Capital, LLC. He is currently a senior B787 captain for a major airline, with 34 years / 27 years as Captain and 25,000+ flight hours. Ratings, licenses, and awards include LRJET, CE500, A320, B727, B737, B747, B757, B767, B777, B787. CFII/MEI/Gold Seal Instructor, Flight Engineer.

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