THE BOEING 737-MAX DISASTERS

On October 29, 2018, 181 passengers and 8 crew were killed when Lion Air Flight 610, crashed approximately 13 minutes after takeoff. On March 10, 2019, Ethiopian Airlines Flight 302 crashed 6 minutes after takeoff, killing 149 passengers and 8 crew. While initially it may not seem that two airline crashes on different continents would be related, what these incidents had in common was that both planes were Boeing 737 MAX airliners. Within days of the second incident the US Federal Aviation Administration (FAA) became the 52nd regulatory agency to ground the planes. Just over a week later, all operating 737 MAX aircraft were pulled from service. In order to understand how a well-respected aircraft manufacturer like Boeing could be directly responsible for the deaths of 346 people, it is necessary to explore the history of decisions that lead to these events.

I. BACKGROUND

A. History of Boeing 737

The first Boeing 737 was designed in 1965 to help Boeing catch up to other aircraft manufacturers, including the American company McDonell Douglas and a number of European manufacturers. New generations of the 737 were released in 1979 and 1993. Within each generation were a number of variants with subtle improvements or alterations for different functions (e.g., military, cargo). In 2006, Boeing began to seriously consider a replacement for the 737 (Flight International, 2006). However, this design was postponed when Airbus announced a more fuel-efficient plane, the A320neo (Airbus, 2010). When American Airlines decided to purchase a number of new Airbus planes instead of only Boeing planes (AMR

Corporation, 2011), Boeing decided to reengineer the 737 to compete with the new Airbus planes (Boeing, 2011).

B. Development of 737 MAX

The new generation of the 737 was called the 737 MAX. In order to compete with Airbus, Boeing chose to use basically the same body as the previous 737 but add new fuel-efficient engines (Cusumano, 2020). By early 2016, Boeing had received over 3,000 orders for the new generation, putting pressure on the company to deliver (Gates, 2016). The Boeing 737 MAX was certified by The Federal Aviation Administration (FAA) on March 8, 2017 (FAA, 2017). By May of 2017, Boeing had over 5,000 orders for the plane (Herkert et al., 2020).

C. MCAS

One of the systems that became important as a difference between the 737 MAX and older generations of the 737 was the Maneuvering Characteristics Augmentation System (MCAS). Because the 737 MAX needed new engines in order to achieve the desired fuel efficiency, the aerodynamics of the plane changed. This meant that at certain angles and speeds, the plane could enter an aerodynamic stall, causing the lift of the plane to decrease, meaning the plane would begin to fall (Cruz & Dias, 2020). For trained pilots, this is a relatively straightforward challenge to overcome, but can create a stressful situation that has lead to major airline crashes in the past (Wendel, 2019). On the front of the 737 MAX, engineers added a single sensor of the angle and speed called the Angle of Attack (AOA) sensor (Collings et al., 2022). MCAS would respond to input from the AOA sensor and bring the nose of the plane down, which is the common fix for an aerodynamic stall. Originally, the MCAS was designed to take input from two sensors (the AOA sensor and one to detect G-forces) and had less power overall in controlling the plane. Boeing calculated the risk of “hazardous failure” of the

sensor/MCAS combination at one failure per 223 trillion flight hours (Gates & Baker, 2019). However, during the design phase, the decision was made to give MCAS more control as issues arose in simulation training and use only the single sensor for AOA as the single sensor was easier to implement and more cost-effective. Additionally, the G-force sensor would not activate at low speeds, but pilots were experiencing issues in the simulator at low speeds (Gates & Baker, 2019). Boeing designated this AOA sensor as part of the speed trim instead of what is called a "safety-critical system" (Collings et al., 2022). This allowed the MCAS system to avoid scrutiny.

D. Decision to Not Train Pilots

One major reason for reengineering a current model rather than creating a brand new one is that it is significantly cheaper. Some of that cost savings comes from not having to start from scratch, but an additional savings comes from not having to train pilots on flight simulators if there are not too many new changes. If the changes were more significant, the pilots would all need to be trained. Boeing had guaranteed a $1 million per plane rebate to airlines like Southwest if the pilots needed to undergo simulator training, and Southwest had ordered 280 planes, which would cost Boeing $280 million if training were needed (Collings et al., 2022). Boeing's goal was to ensure that pilots needed no more than 16 hours of computer-based (not simulator) training to learn about the new features of the 737 MAX when compared to the previous generation (Collings et al., 2022).

E. Lion Air Crash

On October 29, 2018, Lion Air Flight 610 crashed approximately 13 minutes after takeoff, killing all 189 aboard. Just over a week after the accident, the Indonesian National Transportation Safety Committee (NTSC) described that in the days prior to the crash, crews flying the same plane reported issues with AOA sensors. The sensors were replaced, but the

flight before the fatal flight also experienced significant issues, including a dive that the crew was able to recover from. On that flight, the left and right AOA sensors were off by 20 degrees (Thaiger, 2018). The NTSC released a second report about a month after the accident describing that there were concerns with the maintained of the AOA sensors, training of the pilots, and the MCAS (though it was not yet known by that name), though the report did not list a cause of the accident. The cockpit voice recorders were found in early January of 2019, but the NTSC decided to not release the recordings until a final report was complete (Reuters Staff, 2019).

F. Response After the First Crash

After the preliminary report from the NTSC, the FAA released what is called an "Emergency Airworthiness Directive". This directive described that Boeing showed the potential for loss of control of the airplane if the AOA malfunctioned. The directive required Boeing to add information on what to do in this situation to the flight manuals for the 737 MAX (Spangenberg, 2018). Boeing denied hiding anything about MCAS from the FAA or from pilots, but did agree to hold calls with various airlines to better educate pilots on the differences between the 737 MAX and the previous 737 generation (Koenig, 2018). Boeing officials did meet with pilots' unions about one month after the Lion Air crash and said there would be a software fix within 6 weeks. The FAA estimated that, without a fix, the MCAS would lead to a fatal crash once every 2 years (Hemmerdinger, 2019). Boeing thought they would be able to fix the MCAS before another fatal accident occurred (Kennedy, 2022).

G. Ethiopian Airlines Crash

On March 10, 2019, Ethiopian Airlines Flight 302 crashed 6 minutes after takeoff, killing all 157 aboard. Almost immediately after takeoff, the AOA sensor malfunctioned. This led to activation of the MCAS. The pilots were aware that the MCAS had turned on due to

communications following the Lion Air crash, however in their panic, they did not appropriately react to regain control of the aircraft. The MCAS should not have activated at the speed at which the plane was traveling but did so anyway (Wise, 2019). Ethiopian authorities placed the blame solely on the MCAS, but the US National Transportation Safety Board (NTSB) indicated the crew and airline bore some responsibility for insufficient training and crew performance (NTSB, 2022).

H. Response to Second Crash

By early March 13, 2019, three days after the crash of the Ethiopian Airlines plane, 51 countries had grounded the 737 MAX. The US was not among those countries (Frost, 2019). Later that day, then-US President Trump announced that the US would be grounding all 737 MAX aircraft after consultation with the Transportation Secretary, CEO of Boeing, and acting head of the FAA (Haslett & Phelps, 2019).

II. BOEING FAILURES

A. Design Defects

By changing the number of sensors from two to one (removing the G-force and leaving only a single AOA), Boeing engineers made it far more likely that the MCAS would activate in situations that may not have necessitated its use. This was not necessarily done maliciously, but this was a significant design flaw in the MCAS system (Cioroianu et al., 2021). Boeing felt that it would be uncommon for aircraft to encounter conditions that would activate the MCAS (Wendel, 2019). Additionally, Boeing felt that experienced pilots would be able to quickly and accurately correct any issues that arose from the malfunction or activation of the MCAS (Cioroianu et al., 2021; Collings et al., 2022). By Boeing's own calculations, pilots needed to recognize an issue within 4 seconds and respond to it within 10 seconds in order to

override the MCAS (Cusumano, 2020). This short time to recognize the issue is approved by the FAA (Gates & Baker, 2019).

Based on the Restatement (Second) of Torts (Bagley, 2019), this is a design defect because switching from two sensors to one made the planes "dangerous to an extent beyond that which would be contemplated by the ordinary consumer who purchases it, with the ordinary knowledge common to the community as to its characteristics." Put more simply, the airlines purchasing these planes had no way of knowing that switching the number of sensors could cause a catastrophic cascade of events, potentially leading to significant loss of life.

With the Restatement (Third), to describe something as a design defect requires that whoever is bringing a suit is able to identify there "was, or reasonably could have been" an alternative design that may not have been defective (Bagley, 2019). Since the original designs for the 737 MAX included a second sensor (G-force) to provide input to the MCAS, plaintiffs likely could meet the standard in the Restatement (Third). Another consideration is that all planes have two AOA sensors (one on each side of the fuselage), but only one was connected to the MCAS (Gates & Baker, 2019). If the second had also been connected, damage to or improper input from one sensor would likely not have led to activation of the system.

These design defects did worry some of the engineers in charge of the project. In a complaint filed in late 2019, one Boeing engineer described that as early as 2014, he and others wanted to institute a backup system to MCAS. A similar system is used on other Boeing airlines but had not been used on 737s previously. The whistleblower alleged that managers refused to consider the addition of the backup system because of the cost, including potentially pilot simulator training (Kitroeff et al., 2019).

An additional major design defect occurred in the way pilots were warned of issues in the cockpit. The FAA had made new regulations for how cockpit warnings should occur, but in 2014, Boeing successfully received a waiver allowing them to keep the old system. Boeing argued that implementing the new system required by the FAA would cost in excess of $10 billion and cited the 737's long safety record as justification for the waiver for the new generation of the 737. Unfortunately, the confusing warning notifications received in both crashes were major contributing factors to the catastrophic failure (Gates et al., 2019).

B. Failure to Warn

Internal communications released by Boeing and cited in numerous publications, including the New York Times (Kitroeff, 2020) paint a picture of a team that knew the AOA sensor/MCAS combination was deeply flawed and leadership who actively sought to cover up that fact. Employees said the 737 MAX was "designed by clowns, who are in turn supervised by monkeys." Others questioned whether or not they would allow their families to fly in these aircraft, with the common answer being "no." Even a pilot who was testing the 737 MAX discussed his issues with controlling the plane in a flight simulator due to the MCAS and admitted to having deceived the FAA about the plane, though he said it was unintentional.

In another email, that same pilot talks about how he "just jedi mind tricked this fools (sic)…to make them feel stupid about trying to require any additional training requirements." It is unclear whether this was a reference to questions by an airline or the FAA, but does paint the picture of a company hiding information. In June of 2017, Lion Air inquired about possible simulator training and a Boeing employee emailed a colleague about the question, stating "…and maybe because of their own stupidity. I'm scrambling trying to figure out how to unscrew this now! Idiots (Baker, 2020)."

As far back as 2013, memos and other communications detail that the MCAS should be treated as an enhancement to the "speed trim" rather than a completely new function because the company wanted to avoid increased certification scrutiny or training requirements. In some of these same memos, there is a discussion to use the MCAS name internally but to remove it from the manual. The MCAS abbreviation was unintentionally left in the glossary of the manual, but there was no other mention of the system provided to the airlines or pilots (Kitroeff, 2020).

When modifications were made to MCAS, including removing the G-force sensor and providing more power to the MCAS, no information regarding these changes was submitted to the FAA so the FAA certification was actually based on the safety data of a less powerful MCAS triggered by two sensors (Gates & Baker, 2019). The FAA was aware of the MCAS system, but not what it was truly capable of, so the FAA approved removing MCAS from the manual as they assumed it was more like code running the flight-control system rather than a powerful tool that could eventually cause catastrophic failure of the plane.

III. CONSEQUENCES

A. Groundings and Production Stoppages

All Boeing 737 MAX aircraft were grounded within a week of the Ethiopian Airlines crash. By December of 2019, Boeing announced a pause on the production of new 737 MAX planes and the resignation of the CEO, Dennis Mullenberg. Production of new 737 MAX planes resumed in May of 2020 (Hemmerdinger, 2020). Nearly two years after the second crash, in December of 2020, at least three airlines, Gol, Aeromexico, and American Airlines, had resumed flights with the 737 MAX, however the company lost billions of dollars in canceled orders of hundreds of planes (Koenig, 2020).

B. Criminal Charges

Boeing was charged with a single criminal count of Conspiracy to Defraud the United States in violation of Title 18, United States Code, Section 371 (Cox & Kahn, 2021). On January 7, 2021, Boeing entered a deferred prosecution agreement. The company admitted that they hid issues with the 737 MAX, specifically the MCAS, to deceive the FAA. As part of the agreement, Boeing agreed to pay $2.5 billion distributed to the families of victims, airlines who lost money, and as fines, though Boeing did place the majority of the fault for deceiving the FAA on two pilots (Department of Justice, 2021). One of the pilots, Mark Forkner, was originally charged with 6 counts: 2 of Fraud Involving Aircraft Parts in Interstate Commerce and 4 of Wire Fraud (Meacham & Beemsteoboer, 2021). Eventually, the 2 counts of Fraud Involving Aircraft Parts and 2 of the Wire Fraud counts were dropped. Mr. Forkner was acquitted of the remaining two counts of Wire Fraud (Reuters Staff, 2022). Provided Boeing were not to commit additional crimes in the three-year period following the agreement, the case against them would be settled with no further prosecution.

The families of the crash victims were very upset by the deferred prosecution agreement and in October of 2022, a federal judge in the US District Court of Northern Texas found that the crash victims were in fact that victims of a crime under the Crime Victims Rights Act and that their representatives (i.e., family members) theoretically should have been consulted regarding the agreement, which they were not. However, in February of 2023, the same judge found that court did not have the authority to revisit the deferred prosecution agreement (Bodine, 2023). The families are appealing that decision to the Fifth Circuit Court of Appeals.

IV. ANALYSIS AND INTERPRETATION

In my opinion, one of the more important ethical principles a company must follow is to do no harm, either intentionally or through negligence. Boeing failed on both counts. The negligence was in the design defect of the single AOA sensor and the overpowered MCAS. The intentional harm was hiding the MCAS from the airlines and pilots who would rely on the system and the FAA who was supposed to approve any major changes to the design of the plane. Boeing hid the significant changes it made to the 737 MAX in order to save money for the company. It had promised Southwest Airlines $1 million for every plane if pilots had to be simulator trained. Boeing also requested exemptions from the newest FAA regulations about pilot warning lights and sounds because the company estimated compliance would cost them $10 billion. Boeing did not think its product was truly flawed, but it did know the plane was so different from the previous generation that simulator training should have been required.

Boeing believed it was doing its fiduciary duty to its shareholders because it was trying to maximize profits on sales of the 737 MAX by not requiring simulator training or having to invest in costly upgrades to the notification system. However, the money saved through these measures does not compare to the cost of the fines and compensation imposed by the Department of Justice, the lost sales of the 737 MAX, and the decreased trust in the company to be honest about what products it is actually producing.

Boeing was charged with Conspiracy to Defraud the United States. This charge came from Boeing's deception of the FAA to get certification for the 737 MAX. Judicial interpretation of the original statute (Title 18, United States Code, Section 371) has found that the intent to deceive the government and interfere with the function of the government meets the definition of "defrauding" the government (Department of Justice, 2015). Because the FAA is the

government agency with the authority to regulate aviation in the United States, by hiding material information from the FAA, Boeing was defrauding the United States.

In hindsight, I do not believe Boeing employees and executives were malicious in hiding information from the FAA. I believe that if Boeing actually knew the planes could fail catastrophically (i.e., leading to loss of the plane and high numbers of fatalities), it would not have designed the system the way it was designed and would have made sure information about the MCAS was available for pilots. However, if I had been in a position at Boeing to be involved in the design of the system, I would have made sure to not make something like MCAS dependent on a single sensor that would fail. I would also work to ensure that a backup system was in place, like on other aircraft, so that if MCAS failed, it would not necessarily be catastrophic. Finally, if I had been a Boeing executive or manager, I would have insisted that information about the MCAS be presented to the FAA and included in the pilot manual so that the FAA could have made the final determination about certification.

In terms of the regulatory environment, I would like to see the FAA do a thorough approval process even for new variants and to not grant exceptions of waivers for safety-critical systems. I think it would also be important to have an independent FAA employee embedded with the airlines to do their own testing and flight simulations. Perhaps an FAA employee would have experienced the same issues that Mr. Forkner did with the simulation and could have halted the development process. The internal culture of Boeing needs to promote open discussion of problems with any system and allow for people to bring concerns without fear of retaliation. The FAA should likely develop a set of guidelines for more stringent inspections and reporting to ensure Boeing complies with all relevant statutes for a certain period of time. The FAA should also continue to more critically evaluate modifications Boeing proposes to its aircraft.

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