Ethics of Boeing in the Design of the 737 MAX

STS Research Paper
Presented to the Faculty of the
School of Engineering and Applied Science
University of Virginia

By

Jack Shea

April 22,2020

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: Jack Shea ____________________

Approved: ____________________ Date ____________________
Benjamin J. Laugelli, Assistant Professor, Department of Engineering and Society

Introduction

In 2011, The Boeing Company announced a new iteration of the extremely popular 737 aircraft called the 737 MAX. It aimed to increase the range and efficiency of the current version, the 737 Next Generation, to compete with the newly announced Airbus A320neo. In October 2018, a 737 MAX 8 operated by Lion Air crashed in Jakarta killing all 189 passengers and crew. In March 2019, a 737 MAX 8 operated by Ethiopian airlines crashed in Ethiopia killing all 157 passengers and crew. Investigations by Indonesia’s Komite Nasional Keselamatan Transportasi (KNKT) and the Aircraft Accident Investigation Bureau (AIB) of Ethiopia revealed that both crashes were caused by uncommented activation of the Maneuvering Characteristic Augmentation System (MCAS) (AIB, 2020; KNKT,2019). This software was designed to prevent dangerous flight conditions, but was found to cause an aircraft to go into a dive if given incorrect angle of attack (AOA) information.

Most have viewed this issue as a simple example of bad software implementation. However, while this assessment is useful to correct future design deficiencies, it fails to acknowledge if the actions taken by Boeing the design of this aircraft were moral. If students continue to ignore the moral implications of Boeing’s actions, they may be unable to understand how ethical mindsets affect safety-critical designs. I will argue that the actions taken by Boeing in the design of the 737 MAX were immoral using the virtue ethics framework. I will demonstrate this by showing that Boeing failed to adhere to several virtues including a commitment to quality, seeing the big picture, and a habit of thorough documentation. The lack of these virtues can be determined by examining the decisions which Boeing made in the design of the 737 MAX.

Background

The Boeing 737 is a narrow-body twinjet airliner that was originally introduced in the late 1960s. One of the most recent iterations of the aircraft is the 737 MAX, which succeeded the 737 Next Generation (737NG). The 737 MAX aimed to greatly increase the fuel efficiency of the 737 through aerodynamic changes and the installation of new high-bypass turbofans. This aircraft was marketed to airlines and regulators as a minor upgrade to the existing 737NG to avoid expensive and time-consuming aircraft certification and pilot training. To maintain similar handling characteristics to 737NG, Boeing engineers created the MCAS software (Johnston & Harris, 2019).

The MCAS software would activate during manual (non-autopilot) flight when the angle of attack (AOA) exceeded a certain limit based on the aircraft Mach number. High AOA in aircraft can lead to the aircraft's wings stalling. This is accompanied by a large decrease in lift, an increase in drag, and can lead to the plane losing altitude or crashing. The MCAS software controlled the elevator trim and would command an aircraft nose down (AND) trim movement to avoid stalling the aircraft when the AOA limit was exceeded.

On October 29, 2018 a Boeing 737 MAX 8 crashed into the Java Sea killing all189 passengers on board. Analysis of the digital flight data recorder (FDR), which records a variety of data from an aircraft's system, showed repeated AND trims commanded by the flight computer (KNKT, 2018). On March 10, 2019 a second Boeing 737 MAX 8 crashed in Ethiopia killing all 157 passengers on board. Again, repeated AND trims, partially countered by crew efforts, were found on the FDR (AIB, 2020). The repeated AND trims in both flights resulted in the loss of altitude and eventual ground collision.

Literature review

A number of different authors have published papers on how the design of the 737 MAX was flawed. However, these articles primarily focus on the design decisions which lead to the crashed and why those decisions were made. The current work largely fails to address or investigate the morality of the decisions made by Boeing.

In the article The *Boeing 737 MAX Saga: lessons for Software Organization* the authors Phillip Johnston and Rozi Harris investigate the crashes from software engineers' perspective. They make the argument that the crashes were not a result of a software engineering problem, but instead was caused by poor implementation of a software patch into a complex system. They identified several compounding variables which all contributed to the crashes including poor documentation, a rushed release schedule, aerodynamic changes, and an elimination of humans from the decision-making loop. The crashes then occurred when real-life situations including poor training and maintenance issues exacerbated these factors. An important distinction this article makes is that "there was not an entire organization whose individuals decided to collectively disregard safety" and that Boeing's decisions weren't malicious (Johnston & Harris, 2019, p. 11). However, this article fails to consider the morality of the decisions made by Boeing in the design of this aircraft. While they do touch on several issues that could have ethical implications, this paper falls short of making ethical conclusions regarding the decisions to use the MCAS program and instead mainly focuses on why the system failed.

In the IEEE article *Lessons Must be Learned – But are they?* Hatton and Rutkowski examine the issues which lead to the 737 MAX crashes and the implications brought about by Boeing's software design choice. They believe that the designers ignored a number of standard practices used during safety-critical software including a reliance on a single sensor, selling additional safety features for safety-critical systems, and failing to adequately prepare for computer failure. They also note that the design process of modern safety-critical software, such as MCAS, is merging with agile development practices to decrease costs. This is in contrast with previous methods that had “a testing regime that is rigorous and exhaustive as possible” (Hatton and Rutkowski, 2019, p. 91). Although this article highlights the abnormalities of Boeing’s software design, they don’t consider the morality of those involved in the design and certification of the aircraft.

Conceptual Framework

My analysis of the morality of the Boeing in designing the 737 MAX draws on virtues ethics. This is a normative ethical framework that focuses on the character or nature of an actor. This ethical framework was originally defined by the ancient Greek philosopher Aristotle who believed that true happiness could be achieved through the use of reason and moral behavior. In order to live morally, people would need to act in accordance with moral virtues. These virtues are personal characteristics that balance between two extremes. For example, a commitment to quality would be the balance between carelessness and perfectionism. Aristotle believed it was within a wise person’s capacity to develop then based on practical wisdom. The virtues defined in this framework are not innate and an actor can learn or develop virtues over time (De Poel & Royakkers, 2011). This framework can be used to evaluate actor morality based on how well they follow these virtues.

The virtues which an actor should follow are dependent on the situation they are faced with. To analyze the morality of Boeing’s decisions I will use virtues defined by Michael Pritchard in his paper *Responsible Engineering: The Importance of Character and Imagination*. In his paper, Pritchard develops a list of virtues by surveying engineers for what characteristics would define a highly responsible engineer. Prichard argues that these virtues themselves are not enough to ensure an actor acts morally, but a lack of any of these virtues "detracts from responsible engineering practice in general, and exemplary practice in particular." (Pritchard, 2001, p. 395).

In this paper I will use virtue ethics to show that the actions taken by Boeing in the design of the 737 MAX were immoral. I will do this by proving that Boeing failed to adhere to several of the virtues created by Pritchard including a commitment to quality, seeing the big picture, and a habit for thorough documentation.

Analysis of Evidence

It can be shown that Boeing engineers did not adhere to several of Pritchard's virtues for engineers. Specifically, Boeing lacked a willingness to compromise, and commitment to quality, and a habit for documenting work thoroughly. This can be proven by observing the decisions made in the design of the MCAS software, the system level design of the 737 MAX, and the information provided by Boeing to airline companies, pilots, and regulators. Pritchard says that engineers that have all of these virtues are not certainly ethical and that an engineer could have all of the virtues and still act in unethical ways. However, he states that "lacking any of them detracts from responsible engineering practice in general" (Pritchard, 2001). Therefore, finding that Boeing lacked any of these virtues is enough to say it acted unethically.

It most likely isn't possible to state a single employee or group at Boeing was morally responsible for the flawed decisions made in the design of the 737 MAX. To be held responsible a single employee would have to be proven to have committed wrong-doing, have a causal contribution to the problem, knowledge of the problem, and freedom to act and prevent the problem (De Poel & Royakkers, 2011, p. 254). However, using the problem of many hands I can instead evaluate the morality of Boeing to determine if it meets these requirements as a whole. The problem of many hands is defined as “The occurrence of the situation in which the collective can be held morally responsible for an outcome, while none of the individuals can be reasonably held responsible for that outcome” (De Poel & Royakkers, 2011, p. 253). Although Boeing was subject to external regulations, it implemented the MCAS system and had the final say in the 737 MAX design. Therefore, it had a causal contribution to the crashes and freedom to act to prevent the problem. Boeing engineers did recognize the possibility of an uncommanded MCAS activation in their risk analysis, but failed to realize how the system could fail and contribute to a crash. However, internal Boeing communications did show that employees of the company believed the plane was not ready to undergo certification (Kitroeff, 2020). This can be implied as Boeing having knowledge of the problems with the aircraft. Based on these assumptions, I will argue that Boeing had a moral responsibility for its actions and that it acted immorally in those actions.

Commitment to quality

The first virtue ignored by Boeing is a commitment to quality. To understand why, I will discuss why the MCAS software was included in the aircraft’s design. The inclusion of this software was the result of pressure placed on Boeing to quickly bring a product to market.

In 2011 Airbus, the primary competitor of Boeing, announced an updated version of its flagship single-aisle airplane: the A320. This new design would be referred to as the A320neo and would incorporate new engines and minor aerodynamic changes to improve per-seat fuel efficiency. Boeing was surprised by the amount of interest airlines expressed in the increased efficiency and launched a project to compete with it. By the time Boeing launched a competing project, Airbus had a large lead in getting its product to market. To reduce development time, Boeing decided to update the 737NG aircraft which allowed them to reduce the certification and pilot training requirements (Johnston & Harris, 2019). The elimination of simulator training was one of the primary selling points presented to the airliners to increase interest and Boeing had offered considerable discounts to airlines if regulators required it. This increased pressure on Boeing to limit the apparent differences in the 737 MAX (Kitroeff, N. (2020). It is important to note that this reduction in training would only be possible if Boeing demonstrated that the 737 MAX controlled similarly to the 737NG.

The 737 MAX was fitted with larger engines to achieve an increase in efficiency comparable to the A320neo. The engine mounting location was moved up and forwards to limit the risk of ground strikes during landings. This introduced a pitch up moment when the aircraft was flying at high angles of attack which could lead to stalling the aircraft (Johnston & Harris, 2019). This situation is significant for two reasons: stalling an aircraft could lead to loss of control and it represented a significant difference between the 737NG and the 737 MAX. If this had been left unchanged, it was likely the Federal Aviation Administration (FAA) would require the aircraft to be re-certified and pilots would have to go through more rigorous training. This would delay the aircraft's release and Boeing would fall even further behind Airbus’s timeline. This is important because it shows that MCAS was a software solution aiming to patch what was a hardware problem.

If Boeing had been concerned with delivering a quality product instead of keeping a timeline, it would have re-designed the hardware to resolve the underlying aerodynamic issues. Most aircraft are designed to settle at a certain AOA given a certain airspeed and trim setting, this is referred to as being statically stable. Any perturbations to the aircraft’s AOA results in a pitching moment that returns the aircraft to its stable state. The 737 MAX would instead diverge from a stable state when at high AOA. Boeing was not able to fix this flaw in the aircraft design within its schedule, so its engineers introduced a software patch to fix the problem (Johnston & Harris, 2019).

Seeing the big picture

Boeing failed to keep the bigger picture in focus during the creation of the 737 MAX which resulted in unexpected behavior. The NTSB report *Assumptions Used in the Safety Assessment Process and the Effects of Multiple Alerts and Indications on Pilot Performance* points out several instances of design issues that had unexpected or unobserved effects on the aircraft as a whole. The issues discovered include the unannounced expansion of the MCAS operating range, the failure to properly asses the risk level of an MCAS system failure, the MCAS system use of 1 AOA sensor. The designers were able to anticipate the possibility of the MCAS system giving erroneous commands to the elevator trim, but they were not able to observe the big picture and accurately model how the system would fail in the real world.

To investigate if pilots could safely respond to “uncommanded MCAS activation” an engineering flight simulator was used. Boeing induced a trim input that would simulate the rate and duration of the MCAS activating in flight. This method resulted in the motion of the stabilizer trim wheel, a forward force on the pilot’s controls, and AND movement (NTSB, 2019). This scenario did not account for why the MCAS software was activating erroneously and ignored its context in real world scenarios.

In both aircraft that crashed, the MCAS activated after the single AOA sensor which fed it data began giving higher than actual AOA readings. The MCAS software believed that the aircraft was stalling and adjusted the elevators trim AND by 2.4 degrees. In addition to the conditions observed in the Boeing simulator testing the FDR recorded activation of the IAS

DISAGREE alert, the ALT DISAGREE alert, pilot sides stick shaker (where the control yoke shakes to indicate stall), the MASTER CAUTION alert, and an overspeed warning (The Federal Democratic Republic of Ethiopia Ministry of Transport, 2019). Multiple warnings would have made troubleshooting difficult for the pilots. This is important because it shows that Boeing failed to accurately represent and plan for realistic failure scenarios when it implemented the MCAS system.

<u>Habit for thorough documentation</u>

Boeing failed to provide accurate documentation to the users of its aircraft in the form of omitting information for the airplane flight manual (AFM) and the pilot training material. An airplane flight manual is created to provide any information "that is necessary for safe operation because of design, operating, or handling characteristics" and is required for all aircraft certified by the FAA as defined in the US Code of Federal Regulations (1990). The AFM will include information needed to fly the aircraft and emergency procedures if a problem occurs with the aircraft in flight.

According to the Lions Air crash report released by the Komit Nasional Keselamatan Transportasi of Indonesia, Boeing did not include information regarding the MCAS system or emergency procedures to use if it failed in the original 737 MAX AFM (KNKT, 2018). The FAA released an airworthiness directive following the crash requiring that airlines in the US to update the AFM section on runaway stabilizer to include the conditions witnessed by the pilots preceding the crash (FAA, 2018). Only after this airworthiness directive did pilots become aware of the existence of the MCAS software.

This documentation was important to include because the MCAS software did not behave like other electronic trim systems in Boeing aircraft, which would turn off if the pilot started placing opposite control inputs. Instead, the MCAS software would continue to apply AND trim and apply forward force on the control yoke unless the electronic trim system was disabled. These factors placed the pilots of the 737 MAX into a situation which they believed they were prepared for, but who's attempts to rectify a problem would be ineffective.

Some might say that providing pilots information on the MCAS software would have been superfluous and that, with modern aircraft, pilots will not be able to know everything about an aircraft. This argument holds some weight and providing too much information to pilots can also be a problem. This can lead to a situation called "information overload" where pilots are suddenly barraged by several warnings or alarms making it difficult to determine the root cause of an issue. However, this situation would not have been created had Boeing included MCAS information and failure mode in the documentation provided to pilots. While countering an unintended MCAS software activation is solved in the same way as a stabilizer trim runaway, the symptoms are not. To troubleshoot an emergency, pilots need to have information on their starting point or they could make mistakes that unintentionally worsen a situation.

Conclusion

I have argued that actions taken by the Boeing Company in the design of the 737 MAX aircraft were immoral. This can be shown through the use of the virtue ethics frameworks which focuses on determining if an actor's actions are moral through their adherence to desirable characteristics. To judge the morality of Boeing, I selected virtues for responsible engineering developed by Michael Pritchard. I believe that Boeing lacked several of these virtues including a commitment to quality, being able to see the big picture, and a habit for thorough documentation. Any actor who lacks the qualities can be said to be immoral.

This case study demonstrates how immoral engineering decisions can have dangerous effects on the safety of the public. Even companies without malicious intent can undertake immoral actions due to outside pressures with unintended consequences.

Word count: 3113

References

14 C.F.R. § 25.1581 (1990)

De Poel, I. V., & Royakkers, L., (2011). *Ethics, technology, and engineering: An introduction.* Wiley-Blackwell

Federal Aviation Administration. (2018). *Emergency airworthiness directive 2018-23-51*. https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgad.nsf/0/83ec7f95f3e5bfbd8625833e0070a070/$FILE/2018-23-51_Emergency.pdf

Hatton, L., & Rutkowski, A. (2019). "Lessons must be learned" - But are they?. *IEEE Software,* 36(4), 91 – 95. https://doi-org.proxy01.its.virginia.edu/10.1109/MS.2019.2909330

Johnston, P., & Harris, R. (2019). The Boeing 737 MAX saga: Lessons for software organizations. *Software Quality Professional*, *21*(3), 4-12.

Kitroeff, N. (2020, January). Boeing employees mocked F.A.A. and 'clowns' who designed 737 MAX. *The New York Times.*

Republic of Indonesia Komite Nasional Keselamatan Transportasi. (2018) *KNKT.18.10.35.04 aircraft accident investigation report*

National Transportation Safety Board. (2019) *Assumptions used in the safety assessment process and the effects of multiple alerts and indications on pilot performance*. https://www.ntsb.gov/investigations/AccidentReports/Reports/ASR1901.pdf

Pritchard, M. (2001). Responsible engineering: The importance of character and imagination. *Science and Engineering Ethics, 7. 391-402.* https://doi.org/10.1007/s11948-001-0061-3

The Aircraft Accident Investigation Bureau of Ethiopia. (2020). *Interim investigation report on accident to the B737-8 (MAX) registered ET-AVJ operated by Ethiopian Airlines.*