Complex System Failures: Analysis of the Boeing 737 MAX Accidents using Actor-Network Theory

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

By

Katherine Fogarty

April 23, 2021

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: ____

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

Introduction

Lion Air flight 610 crashed into the Java Sea in Indonesia on October 29, 2018. Less than a year later, Ethiopian Airlines flight 302 crashed in Ejre, Ethiopia on March 10, 2019 (Federal Aviation Administration [FAA], 2020b). Both accidents occurred on a Boeing 737 MAX. There were no survivors of either accident. On March 13, 2019, the Federal Aviation Administration (FAA) signed an Emergency Order of Prohibition, grounding all Boeing 737 MAX aircraft (FAA, 2019). This order remained in effect until November 18, 2020, when the order was rescinded. At this point, Boeing 737 MAX aircraft could return to service in the United States assuming operators met additional requirements (FAA, 2020c). In January 2021, the European Union Aviation Safety Agency (EASA) approved the Boeing 737 MAX to fly again in European airspace (European Union Aviation Safety Agency [EASA], 2021). Boeing 737 MAX aircraft are now returning to the skies after being grounded for over a year. American Airlines began flying their 737 MAX fleet again in December 2020 (American Airlines, n.d.b).

Initial media coverage after the accidents frequently highlighted the Maneuvering Characteristics Augmentation System (MCAS) as the cause of these accidents. Designed to provide “smooth handling characteristics in all flight conditions,” this flight control law was activated in “a very specific set of unusual flight conditions” (Boeing, n.d.c). Initial scholarship tends to attribute fault primarily to the Boeing Company. However, as the aerospace system becomes more complex and autonomous technologies are given more responsibility, the importance of considering the entire system increases exponentially. These accidents did not occur because of one failure at either the technological or company level. Focusing on finding a single-point failure may obscure and prevent necessary changes from being implemented to improve system safety and performance overall. Multiple factors ranging from pilot training, misunderstandings regarding duties and roles between Boeing and the airlines, and the initial design of the aircraft all contributed to these tragic accidents. To support this argument, I will use documents such as the "Summary of the FAA's Review of the Boeing 737 MAX" and the NTSB accident report.

Using the Boeing 737 MAX accidents, I will use Actor-Network Theory (ANT) to provide greater understanding of the system breakdown leading to the accidents. ANT will allow the reader to understand the flaws in selecting a specific factor or actor as a single-point failure. The breakdown of a system or network, not of one technology, caused these system failures/accidents involving the Boeing 737 MAX.

An Overview of the Boeing 737 MAX Accidents

After the tragic accidents, initial media coverage highlighted the Maneuvering Characteristics Augmentation System (MCAS) as the root cause. MCAS was deployed multiple times before both accidents (National Transportation Safety Board [NTSB], 2019). However, the development of MCAS had to follow a thorough and detailed aircraft certification process. To comply with certain Federal Aviation Regulations requirements, catastrophic failure conditions must occur with a probability of 1×10^{-9} or less. Catastrophic failure conditions are classified as "failure conditions that would prevent the continued safe flight and landing of the airplane" (FAA, 1988).

Before the Boeing 737 MAX grounding on March 13, 2019, the 737 MAX 8 had approximately 8,600 successful flights a week (Lu et al., 2019). Southwest Airlines pilots alone logged over 89,000 flight hours in 737 MAX aircraft before the grounding, successfully completing almost 40,000 flights (Southwest, n.d.). The aircraft was certified by the FAA with an Amended Type Certificate as it was deemed a derivation of the Boeing 737 Next Generation

(NG) aircraft. The FAA does not allow companies to certify their aircraft themselves (FAA, 2021).

Although the 737 MAX has returned to service and has been recertified by the FAA, it is still important to analyze and determine the root causes of these tragic accidents. The causes of this system failure will be analyzed in the following sections.

Literature Review

Although the Boeing 737 MAX accidents occurred relatively recently, some research exists analyzing the root causes of these tragic accidents. Current research regarding these accidents frequently focuses on the shortfalls of The Boeing Company. Although decisions made at the design level did propagate throughout the system, these works tend to classify the cause as a single-point failure at the company level.

Analysis of the causes of complex system failures is not new. In 1990, J. Reason proposed that complex systems fail because of “latent failures” that “combine with local triggering events to breach the system’s defenses.” Reason recognizes the importance of the “interaction between the technical and social aspects of systems.” However, he ascribes system failures primarily on human decisions. Potential misunderstandings between the expected behavior of a human and the programmed actions of a machine are not addressed (Reason, 1990).

Henkert, Borenstein, and Miller examine potential causes of the accidents in “The Boeing 737 MAX: Lessons for Engineering Ethics.” The authors also recognize the role of human decisions on systems failure, arguing that a dearth of ethical obligations at The Boeing Company ultimately caused these accidents. This analysis also attributes the accidents to design flaws, the long-standing rivalry with Airbus, perceptions of internal company culture, and the relationship with the FAA. Although this article acknowledges that multiple factors played a role in the Boeing 737 MAX accidents, this article primarily focuses on the role of The Boeing Company (Henkert et al., 2020).

Analysis of system failures is extremely important. The Boeing 737 MAX accidents should be analyzed to determine how to prevent tragic accidents from happening in the future. Current research regarding the Boeing 737 MAX accidents focuses primarily on The Boeing Company, while prevailing systems engineering scholars state that system failures often occur due to latent and active human failures. This paper will use Actor-Network Theory to show how decisions can propagate throughout a system with disastrous consequences. This paper will also show that as autonomous systems are given more responsibility, it becomes significantly more important to consider the entire system. The rise of automation has introduced a new latent failure: a misunderstanding between how the human is expected to act and what the machine is supposed to do.

Conceptual Framework

The airplane itself is an incredibly complex system. The process of designing, certifying, and flying an airplane is even more complicated. Multiple heterogeneous entities, from the engineers to the various technological elements, must interact and work together to successfully and safely design, certify, fly, and land an airplane. This system, or network, is not composed of only technical parts. There are also sociological elements. Actor-Network Theory (ANT) provides a method to analyze different heterogeneous entities, which is effective for analyzing the complex system of the Boeing 737 MAX accidents. This paper will utilize Michel Callon's methodology for Actor-Network Theory.

At its core, ANT provides a method to compartmentalize a system into a series of heterogeneous entities that must work together and accept their assigned role. Recognizing that the associations between these entities could extend far beyond the initial system, ANT allows simplification. Although in practice systems are interconnected with other systems, this reduction creates a "black box" and a stable network that can be more easily analyzed. However, as the network is simplified, the relationships between the network members, or juxtaposition, becomes even more critical. Each entity in a network is composed of its own sub-network (Callon, 1987).

The initial formation of the network is extremely important. Callon's theory of translation provides a method to examine the process of network formation around the primary actors. Callon partitions translation into four moments: problematization, interessement, enrolment, and mobilisation. In problematization, the actors are defined and their motives are analyzed. The primary actor defines an "obligatory passage point" (OPP) and identifies other actors to join the network. In interessement, the "allies are locked into place." Actors recruit and solidify their alliance with the other entities. During this phase, each entity can choose to either assimilate into the original planned network, or define themselves differently. Successful interessment validates the original problematization and implied alliance. In enrolment, the primary actors assign roles which are accepted by the actors in the network. Negotiations of responsibilities occur between the actors. Once the roles have been assigned, the actors perform their roles. In mobilisation, the spokesperson is defined. The primary actors assume the role of representing the other actors and encourage action. Once mobilisation has successfully occurred, the network has been defined and can cohesively work together (Callon, 1986).

I will use ANT to determine the points of failure within the socio-technical network of the Boeing 737 MAX. Callon's theory of translation will allow me to determine areas where the network broke down and deviated from the original definition.

Analysis

Network Formation

Constructing the Boeing 737 MAX network will provide a framework for the following analysis. I have identified the following human and/or organizational entities as key actors: Boeing, government regulatory agencies, engineers, pilots, and airlines. I have identified autonomous technology and the Boeing 737 MAX as non-human actors.

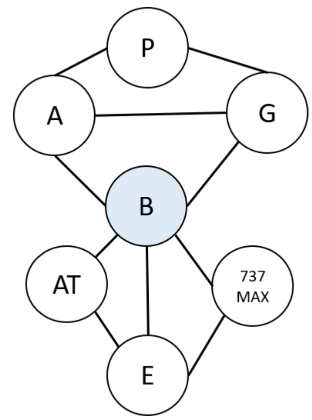

Figure 1 - The Boeing 737 MAX actor-network. *P is pilots, A is airlines, G is government regulatory agencies, B is Boeing, AT is autonomous technology, 737 MAX is the 737 MAX, and E is engineers.*

Due to the scale and complexity of the global aerospace network, simplifications and assumptions have been made regarding these actors. I will focus on the Boeing Commercial Airplanes business unit in my analysis of the factors leading to the Boeing 737 MAX accidents. Government regulatory agencies will be generally limited to the FAA. The FAA will be simplified to the sections focusing on the Boeing 737 MAX return to service, airline certification, and aircraft certification process. I will also focus on long-range aircraft and airlines.

To determine the Boeing 737 MAX actor-network, the associations of these actors must be defined. These associations will be revealed through the formation of the network using Callon's process of translation. Boeing determines growth markets for new aircraft or aircraft variants. Boeing engineers then design and develop the aircraft according to FAA standards (Boeing, n.d.a). The FAA certifies airworthy aircraft to fly in U.S. airspace (FAA, 2021). The

FAA also certifies airlines for operation (FAA, 2018). Airlines purchase the aircraft for their airline pilots to fly (Boeing, n.d.a). Due to the central role Boeing plays in the development of new aircraft or aircraft variants, I assume that Boeing is both the primary actor and network builder.

The translation process begins with the problemization phase. During this phase, Boeing decides that there is a market for a new variant of the Boeing 737 NG. Boeing identifies that engineers are needed to develop the aircraft and any accompanying technologies. This aircraft is developed with commercial airlines in mind. Boeing also identifies that the new aircraft must comply with government regulations. As illustrated in Figure 1, Boeing creates the network by centering and connecting themselves with the three other human/organizational entities. Boeing becomes the OPP.

Once the problem definition has solidified, the network moves into the interessement phase. Boeing begins to recruit other actors into the network. Identifying airlines that are in the “single-aisle market”, Boeing determines desired features, such as fuel efficiency and range, that would attract more orders if implemented (Boeing, n.d.b). Engineers are then recruited to design and implement these features into the new aircraft. Boeing then determines which regulatory agencies must certify the aircraft for flight. For the purpose of this analysis, I will focus on the FAA, which is the government agency that regulates commercial airspace and aircraft in the United States (FAA, 2016a). It should be noted that Boeing does not directly work with airline pilots. The pilots are trained by their airline to fly certain planes. Pilots must have the appropriate licenses as well.

Once all necessary actors have been recruited into the network, the translation process moves into the enrolment phase. In the ideal scenario, Boeing, the engineers, the FAA, the airlines and by extension the pilots all accept and successfully perform their assigned roles. The engineers design the Boeing 737 MAX and determine what, if any, autonomous technologies should be implemented. The government agencies review the aircraft and decide if it is airworthy. The government-certified airlines order the aircraft and provide appropriate training for their pilots. The airlines also follow all proper maintenance procedures.

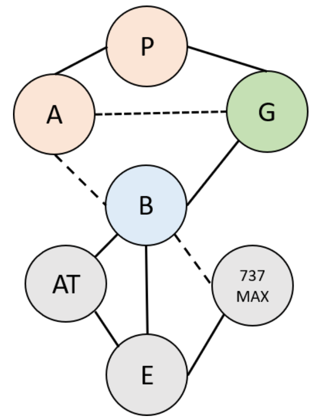

Figure 2 - The 737 MAX network in practice. *Similar to Figure 1, P is pilots, A is airlines, G is government regulatory agencies, B is Boeing, AT is autonomous technologies, 737 MAX is the Boeing 737 MAX, and E is engineers.*

Unfortunately, the ideal scenario did not occur. The accidents in 2018 and 2019 revealed the flaws in the Boeing 737 MAX network. I propose that this network collapsed during the enrolment phase at three key junctions: between Boeing and the airlines, between the government regulatory agencies and the airlines, and the initial design of the Boeing 737 MAX. The faulty associations are shown in Figure 2 and are indicated by the dashed lines. The colors indicate the actor groupings. Blue represents the primary actor. Gray and orange represent isolated groups of actors. Green represents government oversight. I will now describe the three faulty associations in more detail.

Regarding Pilot Training and the Role of the Airline (reproduce evidence for readers, explain it with show and tell, do this at least once in each section)

Earlier in this paper, I mentioned the licenses that commercial pilots must hold. Pilots in the U.S. must have an ATP license to fly multi-engine aircraft such as the Boeing 737 MAX (FAA, 2020a). However, pilots in the European Union must have an ATPL license to fly similar aircraft (L3Harris, n.d.). These licenses are usually acquired through airline-specific training.

American Airlines partners with over 50 flight schools for their Cadet Academy (American Airlines, n.d.a). One of these schools is ATP Flight School. At this school, individuals interested in flying for American Airlines must enroll in their Airline Career Pilot Program to earn their FAA certification. A "FAA commercial multi-engine pilot certificate and instrument rating" is required. Once completing the program, individuals then work as a flight instructor. After earning "1,500 hours of flight experience," individuals transition into a first officer position for a regional airline. Once they gain more experience in the cockpit, individuals then become captains at Envoy Air (a regional airline). This generally takes two years (ATP Flight School, n.d.). After gaining more experience at the captain level, pilots can fly for American Airlines. British Airways has a similar program, directing potential pilots to their "preferred flying schools." (British Airways, n.d.) Each airline has its own training programs and requirements, which are approved by government regulators (Boeing, n.d.e). These different flight schools across different airlines may introduce differences between how pilots are trained. Pilots may have trained on different aircraft, experienced different weather conditions, and encountered different geographical features and runways.

Training is not the only differentiator between pilots. Prior experience also widely varies amongst pilots and airlines. Approximately 50% of pilots for Delta Air Lines have experience flying military aircraft (Delta, n.d.). These former military pilots would have experience flying in a variety of different conditions, different aircraft, and would join the commercial airline with significant training and experience. Delta also has a program to select future pilots directly out of college (Simmons, n.d.). It is more likely that pilots joining Delta directly out of college would have less training and experience than former military pilots. The variety in experience and training both within and across airlines introduces new vulnerabilities and potential rogue actors in the Boeing 737 MAX network. Training and pilot experience are significant factors contributing to pilot response during an emergency, which unfortunately became clear on Lion Air flight 610.

Acknowledgement & Response

I have shown that pilot training by the airlines contributed to the accidents. Some may argue that the pilots should not be considered as a factor in these accidents. After all, MCAS was deployed multiple times before the crash occurred (NTSB, 2019). However, this argument does not consider expected pilot response. On Lion Air flight 610, pilot response to the MCAS alerts differed from what was expected.

Boeing and the FAA assumed that pilots would take "immediate action" and follow "trained flight crew memory procedures." However, this did not occur (NTSB, 2019). The flight crew of Lion Air flight 610 referred to a printed manual instead of following memorized procedures (Baker, 2019). This unexpected response contributed to the accident.

Additionally, airline pilot training has been identified as a key factor in the Boeing 737 MAX return to service. The "Summary of the FAA's Review of the Boeing 737 MAX" specifically mentions additional training requirements for Boeing 737 MAX pilots (FAA, 2020b). New mandatory training requirements are also listed in the "Rescission of Emergency Order of Prohibition" (FAA, 2020c). Boeing "collaborated with pilots, engineers, and safety experts" to encourage "pilots to complete additional training, thoroughly review technical documentation, and demonstrate their knowledge in a regulator-qualified, full-motion flight simulator." Government regulators must approve pilot training proposals before "setting the final protocols for their jurisdictions" (Boeing, n.d.e). Assumptions made by Boeing and the FAA were not met by the airlines or their pilots. A breakdown between the associations between the airlines, Boeing, and the pilots significantly contributed to the accidents.

Regarding Airline Operations

Airlines must also follow regulations set by government agencies. In the United States, airlines that operate large aircraft, such as a 737 MAX, must follow the regulations set in AC 125-1A (FAA, 2016b). These rules ensure compliance with safety rules (FAA, 2018).

Airline operations are extremely complex. Airplanes must be maintained, modified, repaired, replaced, and upgraded as needed. Airlines can purchase new aircraft directly from the manufacturer or lease old and new aircraft. They can also purchase used aircraft from a third-party seller. Flight planning, pilot training, navigating, and other flight operations are also important (Boeing, n.d.d).

The aircraft used for Lion Air flight 610 provided faulty data for both the speed and altitude on its previous flight (Gröndahl et al., 2018). Data from the digital flight data recorder (DFDR) reveals a discrepancy of approximately 20 degrees between the left and right angle of attack sensors that was present until the end of the recording (NTSB, 2019).

If aircraft are not properly maintained, it can lead to devastating consequences. If the faulty DFDR reported in the previous flight had been repaired prior to take off, the discrepancy could have been fixed. The association between the airlines and the regulatory agencies broke down as aircraft maintenance did not occur as expected, contributing to the accidents.

Regarding the Initial Design of the Boeing 737 MAX Aircraft

Decisions made by Boeing also contributed to the accidents. Initially, the Boeing 737 MAX was developed as a variant of the Boeing 737 NG design, instead of as a new aircraft. This decision was made because the changes to the original 737 NG design were determined to be minor. Because of this, the 737 MAX was certified by the FAA under an Amended Type Certificate. The certification process for an Amended Type Certificate is shorter than the certification process for a new design. The process took approximately 5 years (FAA, 2021).

One difference between the Boeing 737 MAX and the Boeing 737 NG is the engine type. The Boeing 737 MAX has “larger and more powerful” engines than the Boeing 737 NG. These engines are “installed higher and farther forward than the engines on the 737 NG.” Both aircraft have a Speed Trim System (STS) that “automatically moves the horizontal stabilizer in response to changes from trimmed airspeed while in manual flight”. This STS system “provides increased aircraft speed stability,” providing pilots with “required control force feel” mandated by the FAA.

However, the “737 MAX was designed to handle and feel the same to the pilot as the 737 NG.” Because the new engines are more powerful, certain edge cases would cause the “control column [to feel] lighter in the 737 MAX than the regulations allow.” It was assumed by both Boeing and the FAA that these circumstances would rarely occur. These cases, such as stalls, “are not areas of the flight envelope in which the airplane normally operates.” The 737 MAX STS included “an additional flight control law” called MCAS, which “enhances the feel of the column forces in manual flight and is only operative with flaps up.” MCAS is deployed based on the angle of attack and airspeed. It “provides signals to move the horizontal stabilizer at elevated angles of attack to compensate for the aerodynamic effects” of the new engines. Interestingly, installation of MCAS was necessary to meet FAA certification standards and provide 737 MAX pilots with a similar experience to flying a 737 NG aircraft (FAA, 2020b).

The decision to develop a variant of the 737 NG with more powerful engines led to the development of MCAS. The certification standards and requirement for the flight experience to be identical to the Boeing 737 MAX were also significant towards development of MCAS. These factors contributed to the accidents. Decisions and assumptions embedded in both the design and certification of the aircraft propagated throughout the system.

Network Deconstruction

It is an oversimplification to attribute the tragic accidents to simply one actor. The separate actor groups made different assumptions and accepted different roles than the other expected. The faulty associations are most clear regarding the relationship between Boeing and the airlines, airlines and the government regulators, and Boeing and the development of the 737 MAX.

I propose that the association between Boeing and the airlines, as well as the association between government regulatory agencies and the airlines are the most critical to network success. I mentioned earlier that Boeing does not work directly with airline pilots. Instead, "each airline [works] directly with its regulator to determine their training approach and receive approval for their training course." (Boeing, n.d.e) Unsuccessful enrolment of either the airlines, their pilots, and/or Boeing can weaken the network.

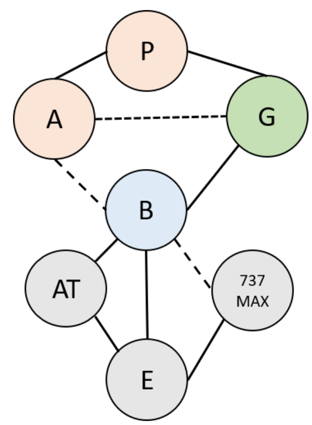

Figure 3 - The 737 MAX network in practice. *Similar to Figure 1, P is pilots, A is airlines, G is government regulatory agencies, B is Boeing, AT is autonomous technologies, 737 MAX is the Boeing 737 MAX, and E is engineers.*

Figure 2 shows that the operators and developers of aircraft are two isolated groups. Clear communication in addition to clearly assigned and accepted roles is critical for a stable actor-network. The Boeing 737 MAX accidents did not occur due to a single-point failure at either the technological or company level. Rather, they occurred due to separate actor groups assigning and accepting different roles than expected. Successful enrolment requires all actors to both accept and take appropriate action regarding their roles. Without successful enrolment, the network is destabilized and is vulnerable to collapse (Callon, 1986).

Conclusion

Throughout this paper, I have used ANT to analyze why the Boeing 737 MAX network failed. Through an analysis of the associations between Boeing, the airlines, and government regulatory agencies, it reveals that the Boeing 737 MAX accidents were not caused by a single-point failure, but rather through a multi-part breakdown at various points in the network. The two isolated groups of the aircraft developers and the aircraft operators accepted different roles than the other expected.

Ultimately, more complex systems are more error prone. Assigning blame of a system failure to a single actor may seem like the simplest solution. However, system failures are rarely caused completely by a single-point failure. Searching for a single-point failure can hinder analysis, preventing potential necessary changes from being discovered and implemented. Incorporating autonomous technologies further complicates the network. Considering the entire system and ensuring all actors fully understand and accept their roles will help make systems safer and increase network stability.

Word Count: 3944

References

American Airlines. (n.d.a). *Know exactly what to expect.* Cadet Academy. http://www.aacadetacademy.com/CadetAcademy/career_progression/1

American Airlines. (n.d.b). *737 max return to service.* https://www.aa.com/i18n/travel-info/737-MAX-return-to-service.jsp

ATP Flight School. (n.d.). *American Airlines Envoy Air cadet program*. https://atpflightschool.com/airlines/american-airlines-cadet-pilot-training.html

Baker, S. (2019, October 29). *This timeline shows exactly what happened on board the Lion Air Boeing 737 Max that crashed in less than 13 minutes, killing 189 people.* Business Insider. https://www.businessinsider.com/lion-air-crash-timeline-boeing-737-max-disaster-killed-189-2019-10

Boeing. (n.d.a). *About Boeing commercial airplanes.* https://www.boeing.com/company/about-bca

Boeing. (n.d.b). *About the Boeing 737 Max.* https://www.boeing.com/commercial/737max/

Boeing. (n.d.c). *MCAS.* https://www.boeing.com/737-max-updates/mcas/

Boeing. (n.d.d). *StartupBoeing.* https://www.boeing.com/company/about-bca/startupboeing.page

Boeing. (n.d.e). *737 Updates.* https://www.boeing.com/737-max-updates/

British Airways. (n.d.). *Future pilots.* https://careers.ba.com/future-pilots

Callon, M. (1986). Some elements of a sociology of translation: domestication of the callops and the fishermen of St. Brieve Bay. In J.Law, *Power, action and belief: a new sociology of knowledge?* London: Routledge, 196-223.

Callon, M. (1987). Society in the making: the study of technology as a tool for sociological analysis. In W. Bijker, T. Hughes, & T. Pinch (Eds.), *The Social Construction of Technical Systems* (pp. 83-103). Cambridge, MA: The MIT Press.

Delta. (n.d.). *What it takes to be a Delta Air Lines pilot.* https://news.delta.com/what-it-takes-be-delta-air-lines-pilot

European Union Aviation Safety Agency. (2021, January 27). *EASA declares Boeing 737 Max safe to return to service in Europe.* https://www.easa.europa.eu/newsroom-and-events/press-releases/easa-declares-boeing-737-max-safe-return-service-europe

Federal Aviation Administration. (2016a, June 27). *What we do*. https://www.faa.gov/about/mission/activities/

Federal Aviation Administration. (2018, September 27). *Commercial Operations branch part 125 operations.* https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/afx/afs/afs800/afs820/part125_oper/

Federal Aviation Administration. (2020a, August 7). *Pilot Training ATP Certificate.* https://www.faa.gov/pilots/training/atp/

Federal Aviation Administration. (2020b). *Summary of the FAA's Review of the Boeing 737 MAX.* https://www.faa.gov/foia/electronic_reading_room/boeing_reading_room/media/737_RTS_Summary.pdf

Federal Aviation Administration. (2021, March 5). *Airworthiness Certification.* https://www.faa.gov/aircraft/air_cert/airworthiness_certification/

Gröndahl, M., McCann, A., Glanz, J., Migliozzi, B. & Syam, U. (2018, December 26). In 12 minutes, everything went wrong. *The New York Times.* https://www.nytimes.com/interactive/2018/12/26/world/asia/lion-air-crash-12-minutes.html

Henkert, J., Borenstein, J., & Miller, K. (2020). The Boeing 737 MAX: Lessons for Engineering Ethics. *Science and Engineering Ethics, 26*, 2937-2974. https://doi.org/10.1007/s11948-020-00252-y

L3Harris. (n.d.). Integrated ATPL course. https://www.l3commercialaviation.com/uk/airline-academy/easa-pilot-training/easa-pilot-training-courses/integrated-atpl/

Lu, D., McCann, A., Wu, J., & Lai, R.K.K. (2019, March 13). From 8,600 flights to zero: Grounding the Boeing 737 Max 8. *The New York Times*. https://www.nytimes.com/interactive/2019/03/11/world/boeing-737-max-which-airlines.html

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

Reason, J. (1990). The Contribution of Latent Human Failures to the Breakdown of Complex Systems. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *327*(1241), 475-484. https://doi.org/10.1098/rstb.1990.0090

Simmons, C. (n.d.). Delta propels next generation of pilots through innovative career paths. Delta News Hub. https://news.delta.com/delta-propels-next-generation-pilots-through-innovative-career-paths

Southwest. (n.d.). 737 max news. https://www.southwest.com/737-max/

United States Department of Transportation Federal Aviation Administration. (1988). *Advisory Circular 25.1309-1A.* https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_25_1309-1A.pdf

United States Department of Transportation Federal Aviation Administration. (2016b). Advisory Circular 125-1A. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_125-1A.pdf

United States Department of Transportation Federal Aviation Administration. (2019). Emergency order of prohibition. https://www.faa.gov/news/updates/media/Emergency_Order.pdf

United States Department of Transportation Federal Aviation Administration. (2020). Rescission of emergency order of prohibition. https://www.faa.gov/foia/electronic_reading_room/boeing_reading_room/media/737_MAX_Rescission_of_Grounding_Order.pdf