AUTOMATION WITHOUT ALIGNMENT: THE ACTOR-NETWORK BEHIND THE CRASH OF LION AIR FLIGHT 610

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science, School of Engineering

Thomas DeCanio

Spring 2025

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

Advisor

Joshua Earle, Department of Engineering and Society

Introduction

At 6:20 AM on October 29th, 2018, a Boeing 737 MAX 8 operating as Lion Air Flight 610 departed from Soekarno-Hatta International Airport in Jakarta bound for Depati Amir Airport in Pangkal Pinang City. 13 minutes later, the flight tragically crashed into the Java Sea, taking the lives of all 189 individuals on board (Komite Nasional Keselamatan Transportasi [KNKT], 2019). The investigation into the underlying reasoning behind the crash was mainly concerned with the Maneuvering Characteristics Augmentation System (MCAS), a software feature designed to improve aircraft handling at high angles of attack after analyzing the aircraft's nose-down commands during flight. It was then discovered that an erroneous sensor delivered inaccurate angle of attack (AoA) data to the system, causing it to repeatedly push the nose of the aircraft down despite counteracting inputs from the pilots (Curran et al., 2024).

Later analyses of the crash found many other factors to be responsible. These include insufficient pilot training, inadequate regulatory oversight, flawed sensor inputs, or Boeing's organizational pressures to deliver a competitive aircraft quickly (U.S. House Committee on Transportation and Infrastructure [T&I], 2020). Other analyses emphasize that pilots were insufficiently informed of MCAS's capabilities and failure modes or that Boeing's assumptions about pilot responses to unexpected trim commands were overly optimistic (KNKT, 2019).

All of these factors were, in part, ultimately responsible for the crash of Lion Air Flight 610. However, the current notion that these factors had a cause-and-effect relationship with the crash misrepresents the crux of the problem and risks setting the stage for a similar disaster in the future. The Boeing 737 MAX's safety depended not just on advanced avionics or aerodynamic refinements but also on how these technologies were introduced, explained, authorized, and maintained within a global aviation system. In reality, all of the factors present were deeply interdependent; attempting to isolate causes overlooks how each element shapes and reinforces the others. Instead of a straightforward chain of events, one must recognize a complex web of relationships that, taken together, created conditions for the tragedy to occur.

An accurate understanding of the underlying issues can be achieved by more closely examining the interconnectedness of the factors related to the crash. As a result, I contend that the interplay of faulty MCAS design, lack of regulatory scrutiny, insufficient pilot training, and Boeing's cost-driven culture, taken in this new light, led to the crash of Lion Air Flight 610. Furthermore, I also argue that weak regulatory scrutiny coupled with market-driven pressures intensified existing flaws in training and system design, ultimately creating the conditions that allowed for the crash to occur.

The Science, Society, and Technology (STS) framework that I will utilize to support my claim is ANT, created and developed by scholars such as Michel Callon, John Law, and Bruno Latour. This theory treats both human and non-human entities as "actors" with the agency to influence outcomes, assembled into a network to fulfill a particular goal (Law, 1992). These actors interact with one another through a process called translation. More specifically, this is where actors take other actors' ideas, needs, or resources, reshape them to fit their own goals, and persuade others to concur with their own interests. (Latour, 1999). Moreover, Callon describes that the strength and resilience of a network depend on how well these actors are aligned and how effectively their interests, information, and responsibilities coalesce to form a network. (Callon, 1986). In my argument, I use this idea to show the incorrect incorporation of actors present within the Boeing 737 MAX network, which led to unstable dynamics that resulted in the crash.

The MCAS

In 2010, Airbus blindsided the commercial flight market with the announcement of the A320neo, a variant of the A320ceo that was largely the same as its predecessor but boasted new fuel-efficient engines and reduced emissions. The commonality between the two models allowed pilots to transition to the A320neo with minimal additional training and, when paired with the increased efficiency of the engines, made the jet an attractive option for airlines (Airbus, 2016). Boeing, feeling the market pressure and fear of losing their customers, decided to forsake making an entirely new model and instead followed suit with Airbus: They re-engineered their best-selling 737-800 Next Generation into what became the 737 MAX 8, introducing new LEAP-1B engines that were four percent more fuel efficient than those on the 320neo (Leeham News & Analysis, 2011).

However, the new engines had a larger diameter, and due to the 737's low landing gear, engineers were forced to mount them higher and farther forward on the wing, which created an unexpected pitch-up moment at high angles of attack. Redesigning the airframe or requiring new pilot training to address this issue would have resulted in a costly and lengthy certification process, discouraging airlines from purchasing the new aircraft. As a remedy, Boeing translated the aerodynamic and fiscal risk into software by crafting the Maneuvering Characteristics Augmentation System (MCAS) to imitate the feel of earlier 737 models by automatically inducing a pitch-down moment at certain angles of attack (Joint Authorities Technical Review [JATR], 2019). In terms of ANT, the MCAS translated the desires of airlines and Boeing's marketing into a single network, promising each what it wanted most with unchanging pilot-type ratings and a quicker time-to-market (T&I, 2020).

The MCAS was originally only meant to activate at high angles of attack at high airspeeds, at a 0.6-degree deflection limit (Gates & Baker, 2019). However, as flight tests and the development of the 737 MAX progressed, the aircraft experienced pitch-up issues at lower flight speeds, leading to the expansion of the MCAS function at lower Mach numbers with a new deflection limit of 2.5 degrees (T&I, 2020). On top of this, to keep the craft within weight limits and its certification on schedule, Boeing engineers removed the earlier safety logic that required agreement from two angle-of-attack sensors and a high-G trigger, leaving MCAS driven by a single angle-of-attack vane (Gates & Baker, 2019). Within the network, the MCAS's increase in agency led to network instability, as these changes in its influence were not realigned with the interests of key human actors such as pilots and regulators. This minimized the ability of those actors to enact changes to the MCAS, led to misalignment, and created the potential for disaster.

The stark disconnect within the network became tragically clear through the Lion Air 610 crash. When the singular angle-of-attack sensor falsely reported higher angle-of-attack values, the MCAS responded as programmed and began producing a pitch-down moment. The pilots then fought back with a pitch-up moment, which was immediately followed by a subsequent pitch-down from the MCAS. Over ten minutes, MCAS issued more than 20 nose-down commands in total (National Transportation Safety Board [NTSB], 2019). This failure in translation left the network susceptible to a machine actor that was insensitive to the broader interests at play, as seen in the relentless reassertion of its authority. At that moment, the misalignment of the network crystallized, and MCAS became an actor that betrayed its network, ultimately leading to the demise of all aboard. Overall, MCAS was an essential actor in the Lion Air 610 tragedy, and it serves as a reminder that all actors in a network must be accounted for for the overall network to succeed.

Weak Regulatory Scrutiny

Established in 2005, the Federal Aviation Administration's (FAA) Organization Designation Authorization (ODA) program was intended to accelerate certification timelines and reduce federal costs by delegating certain FAA oversight tasks to qualified manufacturer employees acting on their behalf called authorized representatives (ARs). This reliance on delegation became increasingly pivotal as the FAA's own engineering workforce in Flight Standards and Aircraft Certification shrank by approximately fifteen percent between 2013 and 2018. With fewer internal engineers, the FAA increasingly directed its staff to concentrate on assessing novel designs and technologies and entrusted a greater share of the certification work for derivative projects to its ODA partners (U.S. House Committee on Transportation & Infrastructure)." Therefore, when Boeing framed the 737 MAX to the FAA in 2012 as a minor derivative of the 737 Next Generation, the administration abnegated its role as an independent supervisor and became an implicit partner in Boeing's schedule-driven project. Boeing's discretion ultimately would cover any changes that would be made in the design of the MAX, including the now-infamous MCAS, allowing them to be trivialized without intensive FAA scrutiny. As the House report states, "on several occasions involving separate incidents, multiple Boeing designated ARs failed to properly inform the FAA of critical information that would have enhanced the FAA's knowledge of key issues and may have altered their certification decisions." (T&I, 2020, p. 76). From the actor-network perspective, the increased reliance on delegation attributed to inadequate oversight proved to be notable in the network's overcompensating for Boeing's time-constrained and cost-driven needs.

The FAA's role as an accessory to Boeing's agenda extended well past its delegation of oversight; its own internal safety processes and handling of experts' advice further entrenched weak scrutiny in the Boeing 737 MAX network. The FAA, aware of Boeing's promised schedule and averse to being seen as the bottleneck in the process, actively undermined the certification's procedural rigor and suppressed any potential complications in the process. In addition to other strategies, the U.S. House reported that "managers on several occasions overruled their own technical experts when those experts raised concerns that might slow the program down" (T&I, 2020, p. 76). These actions heavily swayed the balance of the network in favor of Boeing. In addition, their repression of internal dissent likely fostered an environment that discouraged questioning of any aspects that may prove to be troublesome, damaging the authority's culture of discipline and instead replacing it with one geared toward appeasing the company's schemes. The mutual alignment of Boeing and the FAA as actors left the network vulnerable, paving the way for translation to be skewed and the critical needs of other actors to be neglected.

The manifestation of the FAA's pitfalls as an inspector is seen in the handling of the MCAS implementation. Boeing's Functional Hazard Assessment (FHA) designated a malfunction of the MCAS as a mere "major" hazard: Its effects would be recognized as significant (e.g., physical discomfort to occupants, a slight increase in crew workload) but not catastrophic (implying a large reduction in safety margins, or potential for serious or fatal injuries) (Federal Aviation Administration [FAA], 2019). A more serious classification would have demanded increased design requirements, extensive testing, robust redundancies, and significantly deeper, direct FAA involvement in the system's approval. Even when the MCAS made the jump to the 2.5-degree deflection limit, and issues began to arise, this pivotal safety label remained unchanged. In this way, the FAA's lack of influence as an actor allowed the MCAS to become a black box, described by Latour as a way that technical work becomes taken for granted, and the actors within the network only rely on its inputs and outputs and not on its internal complexity (Latour, 1999). The MCAS became fully decoupled from its technical basis in the eyes of the network and was treated as an independent and automatic unit, failing to address input from other critical actors at play. This imbalance distorted the wider socio-technical relationships in the network and set the stage for failure, a risk magnified by the regulating actors' inability to realign those relationships when warning signs appeared.

Insufficient Pilot Training

When Boeing employed the MCAS to rectify the pitch-up tendencies on the 737 MAX, it served the broader goal of ensuring that the aircraft would be regarded as fundamentally the same as the original model. That continuity was essential to Boeing's marketing promise of a seamless upgrade, and airlines clung to it as a way to sidestep the time and expense of extra pilot training. Southwest Airlines even went as far as negotiating a contract clause entitling the airline to a $1 million rebate per aircraft if full-motion simulator time became necessary for pilots transitioning to the MAX (T&I, 2020). Boeing's internal record echoed this pressure, as it demonstrated that maintaining the rating of Level B Flight Crew Difference Training (FCDT) was a non-negotiable program objective (NTSB, 2019). As a result of these commercial factors, Boeing made the decision to keep the MCAS invisible to pilots, omitting it from the Flight Crew Operations Manual (FCOM), the Quick Reference Handbook (QRH), and the FCDT to protect the vital narrative of operational sameness. The alignment of the interests of Boeing's engineering, marketing, and sales departments with the preferences of regulators and airline customers seeking minimal disruption and cost. However, in achieving this alignment, Boeing effectively excluded pilots from the network's shared understanding. They were expected to operate a new aircraft as if it were identical to the last, unaware that critical automation had been added to manage subtle yet significant aerodynamic changes.

Underpinning Boeing's decision to omit MCAS from training was a set of flawed translations about pilot performance and adaptability. The system safety assessments relied heavily on the premise that pilots, using their existing 737 Next Generation knowledge, would swiftly recognize and counteract any uncommanded stabilizer movement, regardless of its source, within a few seconds. The NTSB heavily criticized this crucial assumption, identifying that it did not reflect the "operational context" of a high-stress, multiple-alert scenario (NTSB, 2019). This created a dangerous potential scenario where the established procedures for a standard runaway stabilizer, which pilots were trained for, were insufficient or even misleading in extraordinary circumstances. In fact, the NTSB's critique highlighted that the "operational context" often involved a cascade of simultaneous, sometimes contradictory, alerts like stick shaker, airspeed, and altitude disagree warnings, all stemming from the same underlying sensor failure that erroneously activated MCAS. These were not just distractions but could act as 'anti-information,' actively misdirecting diagnostic efforts. Compounding this, the profound element of surprise from an entirely undisclosed system making powerful, uncommanded inputs would dramatically degrade even well-practiced crew responses, a critical human factor that the simplistic 'few seconds' reaction premise failed to adequately translate into Boeing's safety case.

The crash of Lion Air Flight 610 starkly revealed the consequences of deliberately excluding key actors from the network's discourse. With its existence entirely undisclosed to the pilots of the 737 MAX, the MCAS's assertion of its agency left the pilots blindsided. They correctly responded to the anomalous behavior with manual trim and control column input, but because their mental model contained no reference to MCAS or its inner workings, they were unable to correctly diagnose the underlying cause or understand why their corrections were only temporary as the MCAS re-engaged. The FCOM and QRH, the only readily available actors to communicate with in an emergency and already aligned with Boeing's company interests, were of no use to the pilots, as all three suffered from the same lack of discussion with the other relevant actors in this network. The pilots were not merely lacking a piece of information; they were attempting to negotiate with and control an actor whose existence, purpose, and behavior had been rendered imperceptible to them by the very network that designed and certified the aircraft.

Boeing's Cost-Driven Culture

Boeing's transformation from a "great engineering firm" into a finance-driven enterprise began well before the MAX program. After the 1997 merger with McDonnell Douglas and the 2001 headquarters move to Chicago, senior leadership recast technical excellence as a means to a financial end. Former McDonnell Douglas chief Harry Stonecipher made the shift unmistakable: "When people say I changed the culture of Boeing, that was the intent so that it is run like a business rather than a great engineering firm" (U.S. House Committee on Transportation & Infrastructure [T&I], 2020, p. 210). In ANT terms, that declaration acted as a translation, enrolling executives, managers, and designs into a network where quarterly cash flow and stock performance, as opposed to engineering standards, became the shared reference point.

Financial metrics soon functioned as powerful non-human actors. Between 2014 and 2018, Boeing repurchased more than $40 billion of its own shares, and executive bonuses were pegged to earnings-per-share and on-time deliveries (T&I, 2020, p. 212). These targets trickled down to all facets of the company's operation, constraining test schedules and framing safety debates as threats to fiscal gain. When a flight-control engineer proposed dual-sensor redundancy for MCAS, a manager replied that the change would "jeopardize the business case" and risk triggering costly simulator requirements discussed before (T&I, 2020, p. 215). Market pressure only further sealed Boeing's trajectory. Airbus's A320neo announcement forced Boeing to choose between an expensive clean-sheet jet and a rapid derivative. Company leaders opted for the latter, arguing it would enter service three years sooner and at roughly one-tenth the development cost (T&I, 2020, p. 213). That early commercial translation locked engineers into managing 1960s landing-gear geometry with 21st-century engines, creating the pitch-up tendency that MCAS later masked. Cost and schedule became irreversible inscriptions that constrained every subsequent technical decision.

The pervasive cost-driven culture within Boeing actively suppressed internal dissent, particularly when it threatened financial targets. E-mails released by Congress capture the disgruntled attitude of Boeing engineers concerning this trend, with one engineer even going as far as to describe the 737 MAX as "designed by clowns [and] supervised by monkeys" after a change review was passed through (T&I, 2020, p. 219). Further, in a disturbing exchange between two Boeing employees, one asked, "Would you put your family on a MAX simulator-trained aircraft? I wouldn't," only to be met with the cynical reply, "No, but that's what these regulators get paid for" (T&I, 2020, p. 219). Such messages reveal the prevalent norm that while it was possible to voice safety concerns, they were often disregarded if they threatened delivery milestones or training promises. Performance dashboards and career incentives effectively neutralized technical objections, ensuring that compromises stayed within budget envelopes. Cost logic also left tangible fingerprints on the technology Boeing produced, seen through MCAS itself as a low-cost software patch, flight manuals being scrubbed of MCAS references to protect their promises to airlines, and certification slide decks downplaying system novelty to avoid reopening failure-hazard analyses. Each document and line of code carried the imprint of financial expediency, turning complex trade-offs and necessary compromises into a black box that regulators and airline customers accepted at face value. Viewed through ANT, Boeing's cost-driven culture was not background context but an active participant that translated aerodynamic instabilities into software patches, reframed regulators as schedule partners, and cast pilots as low-cost caretakers. By aligning every actor to financial imperatives, the network grew tight and brittle until a simple sensor failure escaped the spreadsheets and shattered the alignment for all to see.

Even after the fatal crash of Lion Air 610 and a subsequent one only a year later, the culture proved resilient. In 2022, CEO Dave Calhoun told investors the company aimed to generate $10 billion in free cash flow within a few years (T&I, 2020, p. 224). Acting FAA administrator Billy Nolen cautioned that Boeing needed a "cultural shift to put safety above profits" (T&I, 2020, p. 225). Whether recent changes can recalibrate a decades-old operational custom remains uncertain.

Conclusion

A lone software routine, a single unaware cockpit, or a lapse in oversight cannot completely explain the crash of Lion Air Flight 610. Actor-network theory shows that each of those visible failures was merely a symptom of deeper misalignments among four tightly coupled forces. First, MCAS transformed a structural pitch-up problem into software, but once stripped of redundancy and hidden from manuals, it became a black box whose behavior no longer intersected with the knowledge or authority of pilots and regulators. Second, the FAA's increased opting in favor of delegation and shrinking engineering faculty shifted the agency from an independent scrutinizer to a scheduling partner, allowing for critical design changes to be passed through the paperwork loop unchallenged. Third, Level B "differences" training met Boeing's promise of continuity but deprived flight crews of the wherewithal needed to diagnose automation they had never heard of, let alone rehearsed in a simulator. Fourth, an earnings-driven corporate culture translated every technical trade-off into a cost or timeline variable, ensuring that dissent, redundancy, and simulator bills lost out to speed and margin.

ANT also clarifies why these forces amplified one another. Delegated oversight allowed cost targets to dominate hazard labels, which in turn demanded thin training and hidden software. Weak training magnified the risk of a single-sensor architecture, and the sensor logic, once black-boxed, reinforced the FAA's belief that nothing novel required deeper review. The result was a brittle network that shattered the first time an AoA vane defect met an unbriefed crew.

Important lessons follow in the wake of this tragedy. First, transparency must be treated as a design requirement, not an optional undertaking. Systems that change flight controls should never be pedagogically invisible; instead, they should use the same pathways to convey information as checklists and simulators. Second, regulators must retain a technical depth comparable to the complexity of what they have delegated. ODA can work only if the FAA has enough in-house expertise to challenge those labels that should flag minor changes when their scope or the authority of those doing the work drifts. Third, financial metrics need counterweights. Boards and investors should reward the implementation of redundancy, simulator procurement, and whistle-blower engagement with as much enthusiasm as they show for commercial targets.

Only when software logic, cockpit training, regulatory vigilance, and balance-sheet incentives are synchronized and held mutually accountable can aviation reconcile the unspoken agreement with passengers that every unseen bolt, line of code, and managerial chart is transparently aligned to protect human life above all.

References

Airbus. (2016, May). *A320neo with CFM LEAP-1A engines receives joint EASA and FAA certification* [Press release]. https://www.airbus.com/en/newsroom/press-releases/2016-05-a320neo-with-cfm-leap-1a-engines-receives-joint-easa-and-faa

Curran, N. T., Kennings, T. W., & Shin, K. G. (2024). Analysis and prevention of MCAS-induced crashes. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems, 43*(11). https://doi.org/10.1109/TCAD.2024.3438105

Federal Aviation Administration. (2019, October 11). *Boeing 737 MAX flight control system: Observations, findings, and recommendations (Joint Authorities Technical Review)*. https://www.faa.gov/sites/faa.gov/files/2022-08/Final_JATR_Submittal_to_FAA_Oct_2019.pdf

Gates, D., & Baker, M. (2019, June 22). The inside story of MCAS: How Boeing's 737 MAX system gained power and lost safeguards. *The Seattle Times.* https://www.seattletimes.com/seattle-news/times-watchdog/the-inside-story-of-mcas-how-boeings-737-max-system-gained-power-and-lost-safeguards/

Komite Nasional Keselamatan Transportasi [KNKT]. (2019). *Final report: Aircraft accident investigation of Lion Air Flight JT 610 Boeing 737–8 MAX PK-LQP in Karawang, Java Sea, West Java, Indonesia, 29 October 2018*. Retrieved from https://www.aaiu.ie/sites/default/files/FRA/2018%20-%20035%20-%20PK-LQP%20Final%20Report.pdf

Latour, B. (1999). *Pandora's hope: Essays on the reality of science studies.* Harvard University Press. https://cristobal.space/library/Bruno%20Latour/Pandora%27s%20Hope%20-%20Bruno%20Latour.pdf

Law, J. (1992). Notes on the theory of the actor-network: Ordering, strategy, and heterogeneity. *Systems Practice, 5*, 379–393. https://doi.org/10.1007/BF01059830

Leeham News and Analysis. (2011, September 1). Boeing claims 737MAX better than each NEO. https://leehamnews.com/2011/09/01/boeing-claims-737max-better-than-each-neo/

National Transportation Safety Board. (2019, September 19). *Safety recommendation report: Assumptions used in the safety assessment process and the effects of multiple alerts and indications on pilot performance* (Accident Report ASR1901). https://www.ntsb.gov/investigations/AccidentReports/Reports/ASR1901.pdf

U.S. House Committee on Transportation and Infrastructure, Democratic Staff. (2020, September 15). *Final 737 MAX report for public release*. https://democrats-transportation.house.gov/imo/media/doc/2020.09.15%20FINAL%20737%20MAX%20Report%20for%20Public%20Release.pdf