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Examining Risk Management Failures:
The Case of the Boeing 737 MAX Program

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Abstract

The loss of two Boeing 737 MAX aircraft, their 346 passengers and crew in 2018 and 2019 stunned the aerospace community and the flying public. There is a natural inclination after an aviation mishap to ask, “What if…?” What if latent design flaws in the system had been found earlier? What if the aircrew had taken different steps in handling the non-normal events? What if the B-737 MAX certification by the Federal Aviation Administration (FAA) had been handled more rigorously? This paper will re-examine the antecedent events leading up to the mishaps through a counterfactual lens to envision how the two tragedies could have been avoided. Throughout the paper observations based on our combined 120+ years of aerospace, engineering and risk management experience will be offered to readers.

Keywords: risk management, 737 MAX, aerospace, mishap, MCAS

1. Introduction

Boeing is a behemoth in the aerospace industry with a century long, storied history. Their iconic aerospace product offerings range from commercial and military aircraft, to the space sector, to include the International Space Station, the CST-100 crewed spacecraft and the Space Launch System (SLS). But something happened to this engineering dynamo in the last twenty years.

In 1997 Boeing merged with the McDonnell-Douglas Corporation (MDC) 1997 in an all-stock deal valued at $16.3 billion. MDC’s Chief Executive Officer (CEO), Harry Stonecipher, became the Boeing Chief Operating Officer and later CEO in 2003. He was famously quoted as saying "When people say I changed the culture of Boeing, that was the intent, so that it's run like a business rather than a great engineering firm," and that "Boeing is a great engineering firm, but people invest in a company because they want to make money (Callahan, 2004)." And change the culture he did. In moving Boeing Corporate headquarters from its longtime Seattle home to Chicago, IL he not only signaled a separation of senior management from the design and manufacturing of commercial aircraft, but also that the intent to prioritize profits, return on investment, and install financial discipline into the company. Boeing's board of directors (BoD) approved go ahead for the MAX-8 in 2011. In the aftermath of the mishaps, the BoD charters and operations were highly scrutinized. The BoD prioritized aircraft production and corporate financial metrics and there was total absence of safety and enterprise risk management oversight (Volker, 2021). Post mishaps, the BoD added a permanent aerospace safety committee, and a new Product and Services Safety organization (Lipton, et. al, 2020).

In the 2014 timeframe, Boeing senior leadership began a series of stock buybacks to boost their share price. Between 2014 and 2019 Boeing repurchased $38Bn of its' shares from the market. While Boeing stock skyrocketed by a factor of 12 from the post 2008 economic meltdown through 2019, it suffered increasingly strained relations with its engineering and manufacturing workforce, who were downsized.

Observation 1: The actions and messaging, i.e., the "tone from the top," by the Boeing CEO and other senior Boeing managers clearly prioritized profits and emphasized cost and schedule compliance, all while downplaying safety and quality. This inevitably led to the accretion of technical risk in the 737 MAX program. In the absence of these biases, better engineering design and system safety decisions could have been made.

Observation 2: Boeing's BoD was not proactively involved in oversight of corporate enterprise risk management (ERM) or corporate safety culture. This led to a lack of checks and balances with regard to the company's risk appetite and risk tolerance. Had the board organization, governance structure, and perhaps membership, been different, their oversight, insight, and foresight may have averted potential reckless 737 MAX program decisions. In short, with regard to the BoD's ERM and safety functions, they appeared to be nonexistent prior to the mishaps.

In order to make the MAX-8 a desirable product, Boeing promoted the idea that flying the MAX-8 would be almost identical to flying the B-737 Next Generation (NG) – meaning that customers did not need to invest in expensive ground-based classroom or simulator training for their B-737-NG pilots to transition to the MAX-8. This business marketing imperative translated by Boeing management into an engineering imperative to show the FAA that the change from NG to MAX-8 was minor - only a "Level-B," not a "Level-A" change; the latter implying a major change requiring extensive certification and pilot training. This led to a wide-ranging pressure on those involved in the design, development and testing of the B-737 MAX aircraft to have the aircraft certified in 6-7 years versus the nominal 10-year timeframe.

2. The Threat from Airbus

Boeing and Airbus operated as a global duopoly in the large commercial aircraft sector. Airbus succeeded in surpassing Boeing sales in the 2007 timeframe and when they introduced the game changing A-320neo in 2010, Boeing was caught flatfooted without a competitive offering. The A320neo offered customers greater fuel savings than the existing B-737 Next Gen (NG) series and required no additional pilot training aircraft making the A320neo's introduction an existential threat to Boeing's market share. Within months of the A320neo's debut at the Paris Airshow and subsequent orders for 1000 aircraft, Boeing CEO W. James McNerney Jr. announced that Boeing would develop yet another updated B-737 series aircraft.

Boeing senior management believed that the development of a new "clean sheet," i.e., newly designed aircraft, would take as long as ten years, resulting in further market share erosion to Airbus. Boeing needed to truncate the design, development, test and evaluation (DDT&E) process and match two key selling features of the A320neo; 1) be at least as fuel efficient, and 2) not require additional pilot training.

Observation 3: Competition between Boeing and Airbus was a key driver in the decision to pursue a 4th generation B-737 versus a more innovative clean sheet design. A 6-7-year 737 upgrade effort was traded against a 10-year DDT&E and FAA certification timeline for a new single-aisle aircraft design. This trade was based on maintaining market share vis-à-vis the A320neo, but it induced unforeseen risks into the program. Had Boeing pursued a long-term strategy with an innovative clean sheet design, they may have produced a better, and probably safer, alternative to the MAX. Instead, Boeing senior management conflated financial and economic goals with a short-term strategy to beat Airbus.

3. B-737 MAX Design Challenges

To compete with the A-320neo on fuel efficiency required reengining the MAX. Boeing selected CFM International's LEAP-1B high-bypass turbofan engines. However, the larger engines had to be located higher and further forward on the wing to preserve ground clearance and the nose landing gear needed to be lengthened. With the centerline thrust of the engine higher and changes in the aircraft center of gravity and center of lift, the MAX now had a hazardous tendency to pitch nose up in a couple "corner of the envelope" flight regimes. Making matters worse, the engine nacelle itself created lift, which increased the pitch up tendency. Note that the nose up pitch increases of the aircraft angle of attack (AOA), which can lead to a stall. Boeing's solution was to code flight control logic to prevent these situations providing nose down trim which reportedly provided the MAX pilots the same control column feel inputs in these flight regimes as the B-737 NG as well as previous versions such as the Classic. This software fix was known as the Maneuvering Characteristics Augmentation System, or MCAS, and was designed to keep the MAX certification a Level-B change allowing pilots to fly multiple B-737 variants under a single type certificate rating as will be discussed below.

Observation 4: Aerospace companies, like Boeing, frequently look for opportunities to reuse heritage hardware as opposed to developing new equipment to take advantage of cost and schedule and extent knowledge embedded in the heritage design. However, if the heritage design is modified, there is a possibility that new technical performance risks will need to be identified, assessed, and mitigated to avoid accruing unknown, unknown risks as happened with the MAX.

4. Testing in the B-737 MAX Wind Tunnel and Simulator: An Early Warning

The use of flight simulators during the design, development, testing and evaluation (DDT&E) process is a common practice in the aerospace industry. During simulator flight testing in November 2012, a Boeing test pilot took more than 10 seconds to respond to un-commanded MCAS activation and found the condition to be “catastrophic.” In the extant literature reviewed for this paper we found is no reference to this pilot assigning a Handling Quality Rating (HQR) to this incident. A pilot rating of 10, or a *major deficiency*, means that control will be lost during some portion of required operation. In the test pilot evaluation vernacular, this means that improvement is mandatory (Cooper & Harper, 1969). See the handling qualities rating scale below in Figure 1.

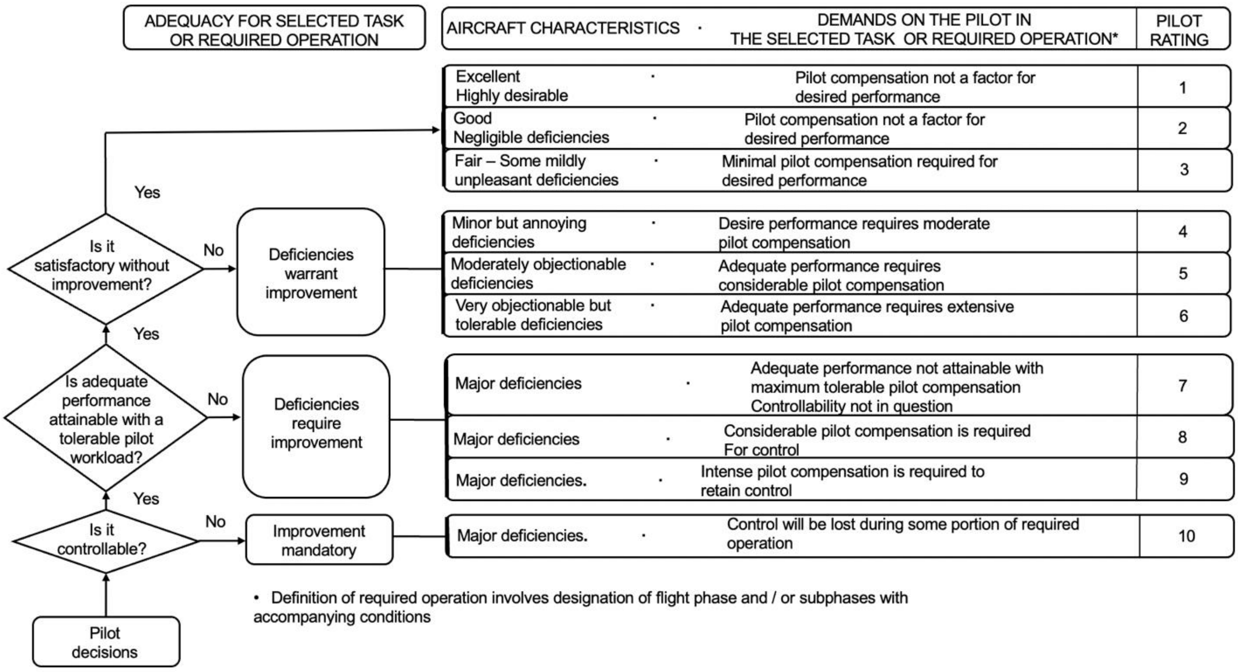

Figure 1. Handling Qualities Rating Scale

Under the best circumstances, MCAS activation would be a cue to the aircrew of an impending stall and allow them to safely fly out of the flight event. However, under the worst-case scenario, MCAS activation can result in a confusing cacophony of warnings in the cockpit and full nose down trim in 60 seconds if not diagnosed properly. There was no evidence that Boeing tested to see what would happen if the single AOA sensor failed off-scale high causing MCAS to initiate a nose down trim. Exacerbating this was that an MCAS initiation under these circumstances did not provide a clear annunciation to the pilots regarding the origin of the failure. A simple fault tree analysis may have captured this failure mode and worked its way into the MAX simulator test procedures for evaluation.

The expectation that an MCAS initiation event would simply be diagnosed as a runaway stabilator trim malfunction. Poor human factors design principles in the MCAS implementation and a lack of knowledge of the systems existence, resulted in low situational awareness, slow or incorrect aircrew actions (Endsley, 2019). While we have no visibility into the MAX-8 risk register, the MCAS would have been an integrated risk and had it been documented properly, would require mitigation activities from many disciplines including, but not limited to: engineering, avionics, flight dynamics, test and verification, human factors, software, system safety, systems engineering and integration, configuration management, flight test crew, aircrew training and others.

5. MCAS Explained

Boeing designed the MCAS system as an adjunct to the speed trim system and failed to mention~~ed~~ it in the operations manuals, aircrew checklists and went so far as to recommend to their customers that no additional training, beyond a 2-hour iPad-based “differences” lesson was required for a pilot to upgrade from the NG to the MAX. A sweetener in Boeing’s deal with Southwest airlines was rebate of $1 million per Max aircraft if expensive simulator was required (Shepardson and Rucinski, 2019). Given those boundary conditions from management, it’s no wonder that every level of management marched to that cadence. On March 28th, 2017, Boeing’s 737 Chief Technical Pilot sent the following email to his colleagues; “I want to stress the importance of holding firm that there will not be any type of simulator training required to transition from NG to MAX. Boeing will not allow that to happen. We’ll go face to face with any regulator who tries to make that a requirement (Horton, 2020).”

There were two versions of the MCAS made during the design process; first in 2013 for the high-speed windup turn situation and later in 2016 to handle slow speed handling issues. The third was made to recertify the MAX after the mishaps in 2018 and 2019. They are shown in the table below.

Table 1. MCAS Design Versions

MCAS Version	One	Two	Three (Post Mishap Redesign)
Timeframe	2012	2016	2020
Flight Regime	Manual flight (Autopilot not engaged), flaps up. High-speed windup turn	Manual flight (Autopilot not engaged), flaps up, slow speed	Manual flight (Autopilot not engaged), flaps up. Both hi-speed windup turn and slow speed
Sensors Used	2 AOA Sensors and G-Meter	One AOA sensor	2 AOA sensors and G-meter
Stabilator Deflection Down[1]	0.7°	2.5°	2.5°
Cockpit Alert(s)	Multiple if AOA fails	Multiple if AOA fails	AOA Disagree Light if AOA sensors differ
Expected Crew Response	Runaway trim Non-normal procedures	Runaway trim Non-normal procedures	Runaway trim Non-normal procedures
MCAS Activation	One activation per high AOA event	Multiple activations per high AOA event	One activation per AOA event. Can never command more stabilizer input than can be counteracted by the flight crew pulling back on the column

[1] MAX trim deflection is 4.7° nose down

Even though during testing Boeing pilots and human factors engineers noted that if the MCAS was activated it could result in controllability issues and would have to be correctly diagnosed within 3 seconds as a runaway trim condition requiring the speed trim switches to be turned off within ten seconds. In the windup turn scenario MCAS took readings from both angle of attack (AOA) sensors and the G-meter. In the second version of MCAS software design was changed during flaps up flight airspeeds approaching stall and; 1) took readings from only one AOA sensor, 2) increased the horizontal stabilizer deflection downward, and 3) allowed MCAS to repeat the nose down trim every 10 seconds if a stall condition was detected. The FAA response to the second version of MCAS was that the change to MCAS did not require an additional safety assessment because it did not affect the most critical phase of flight; i.e. higher cruise speeds. Ironically, that contradicts a recent Boeing-produced statistical study of commercial jet aircraft accidents, where it was estimated that 80 percent of all commercial accidents occur within the first three minutes after takeoff or the last eight minutes prior to landing, thus contradicting the FAA's assertion (Boeing, 2020).

Observation 5: The risks stemming from MCAS implementation required multiple, discrete mitigation steps that crossed organizational boundaries. Ownership of the MCAS risk, assuming a risk record was even generated, should have been the systems engineering and integration organization. If more rigor had been used to assess, mitigate, track, and control an integrated MCAS risk, the third version, as shown in the table above, along with proper documentation and training, would most likely have been selected and the mishaps avoided.

Observation 6: The acquittal of the former Boeing test pilot on 737 Max program in March of 2022 on charges of wire fraud due to communications about the training required for MCAS tried to place responsibilities on one individual. The summary of the case exhibits the lack of internal Boeing communication between test pilots and engineers on the MCAS program. Less than adequate communication has proven to be a risk factor in most failed programs, projects and mishaps.

Observation 7: Decision attributes for risk acceptance are generally cost, schedule, technical performance, safety and their associated likelihoods. In this case Boeing management appeared to overweight cost and schedule in their decisions to rigorously assess the impact of MCAS implementation. With schedule (or cost) as the dominant decision attribute, technical and safety issues may be downplayed or ignored. To guard against these issues organizations should define residual risk acceptance decision attributes and ensure these are communicated to all stakeholders. They must also ensure that that programmatic attributes (cost and schedule) do not overwhelm sound engineering and safety judgment.

6. The Mishaps

In an effort to be brief, Table 2 summarizes pertinent aspects of the mishaps. Links to the mishap reports are also provided in the table. Both reports point to cognitive overload and loss of situational awareness by both crews with multiple, and confusing caution and warning signals coupled with the MCAS upset events. A byproduct of the cockpit confusion was leaving the throttle at takeoff setting which exacerbated the emergency situations.

Table 2. B-737 Mishap Details

	Mishap 1	Mishap 2
Airline	Lion Air	Ethiopian Airlines
Flight	Flight 610	Flight 302
Pilot Flight Time	6,028 hours	8,122 hours
Co-Pilot Flight Time	5,174 hours	361 hours
Crew and Passengers	189	157
Date / Takeoff Time	29 Oct. 2018 / 0620	10 Mar. 2019 / 0838
Weather	*Clear*	*Clear*
Departure Airfield	*Soekarno–Hatta International*	*Addis Ababa Bole International*
Airfield Location	Jakarta, Indonesia	Addis Ababa, Ethiopia
Airborne Time	12 Minutes	6 Minutes
Autopilot	Off	Off
MCAS Activated	Yes. After flap retraction	Yes. After flap retraction
Proximate Cause	Mis-calibrated AOA sensor	Possible Bird Strike on AOA probe
MCAS Upsets	20+	5
Pilot Non-Normal Response	Did not execute runaway trim procedure	Executed runaway trim procedure too late; aircraft too fast for pilots to physically pull up yoke to save the aircraft
Throttles	Takeoff setting	Takeoff setting

FAA Response	Issued Emergency Airworthiness Directive, 2018-23-51 on 7 Nov. 2018. Advised pilots to use the runaway trim procedures in the event of an MCAS upset. Conducted Quantitative Risk Analysis ().	Grounded B-737 MAX Worldwide on 13 Mar. 2019
Link to Mishap Report	http://knkt.dephub.go.id/knkt/ntsc_aviation/baru/2018%20-%20035%20-%20PK-LQP%20Final%20Report.pdf	https://www.havkom.se/assets/reports/L-34_19-No-AI_01_18-ACCIDENT-FINAL-REPORT_compressed.pdf

6.1 Lion Air Flight 610

Prior to the final flight of this aircraft on October 26th, 2018 maintenance had been performed on the aircraft replacing the left angle of attack (AOA) sensor in Denpasar. On the day of the mishap flight, unusual readings were noted while still on the ground, less than 30 seconds before takeoff. The multiple alerts, repetitive 20+ MCAS activations pushing the nose down while airborne, and distractions related to numerous ATC communications contributed to the flight crew difficulties to control the aircraft (Baker, 2019).

Unfortunately for those who perished, more than two years prior to this crash of the Lion Air flight, Boeing engineers had predicted some of the key issues that led to this crash, including the potential adverse consequences of erroneous AOA sensor data on MCAS, and they questioned whether or not pilots would have trouble combating repetitive MCAS activation. These concerns, however, were either not adequately addressed or largely dismissed by their Boeing colleagues (Flight Crew Operations Manual Bulletin – Boeing, 2018). A dominating factor in Boeing's decision to proceed with limited iPad-based training was the contractual agreement with Southwest Airlines.

In the aftermath of the Lion Air mishap, the FAA performed what is known as a Transport Airplane Risk Analysis, or TARAM. The probabilistic model projected that without action, 15 more fatal crashes attributed to MCAS upset events could occur fleetwide during the 45-year lifespan of the MAX. The FAA accepted that residual risk owing to Boeing's promise to fix the software within ten months (Gates and Kamb, 2019). A true Faustian bargain. In a system of checks and balances between government and commercial organizations, what tends to keep actors honest, is knowing that someone is eventually going to check your work. In accordance with the Aircraft Certification, Safety and Accountability Act of 2020, the FAA contracted with the National Academies of Science, Engineering, and Medicine (the National Academies) to review, comment on and offer improvements to the TARAM process. While the FAA provided the MAX TARAM to the Academies, the FAA unfortunately declined to discuss this analysis with the Academies (NAS Report, 2022).

6.2 Ethiopian Airlines Flight 302

The preliminary accident report from Ethiopia on the 4th of April 2019 contains a flight history based on preliminary analysis of the airplane's digital flight data recorder (DFDR) and cockpit voice recorder and air traffic control (ATC) communications. In their initial findings, investigators found that shortly after takeoff, the value of the left angle of attack (AOA) sensor deviated from the right one, with the left AOA sensor reaching 74.5 degrees while the right sensor indicated 15.3 degrees. The AOA failure was theorized to have been from a bird strike. The stick shaker activated shortly thereafter. The flight crew twice reported flight control problems (Preliminary Report B737-800 MAX, (ET-AVJ), 2019).

According to the report the digital flight data recorder recorded an automatic aircraft nose down input and a commanded trim four times without pilot input. Also recorded was the attempt by the flight crew to utilize the electric manual trim to counter the automatic input. The crew also performed the runaway stabilizer checklist putting the stabilizer trim cutout switch to cutout position and confirmed the manual trim operation was not working (Preliminary Report B737-800 MAX, (ET-AVJ), 2019).

The final Ethiopian Air mishap report was issued in December of 2022. Several findings added to the preliminary report involve faults in electrical wiring and electronics as well as eliminating the issue of lack of pilot training playing a role. The U.S. National Transportation Safety Board issued a response disagreeing with these and several other lower-level issues.

Observation 8: Increased automation, particularly cockpit automation requires a rigorous human factors assessment to determine how humans can safely and proficiently be integrated with the technology. However, advanced automation, originally intended to relieve pilot workload has led to complacency and an over-reliance on automation. A more rigorous human factors-led design of MCAS may have resolved the Lion Air and Ethiopian Air cockpit confusion and led to a favorable outcome.

Observation 9: A systems engineering approach to training explicitly describes operator tasks and how each of those tasks will be trained. For critical safety functions performed by human operators, rigorous training, to include execution of emergency procedures, should be done in a realistic simulator environment. While the importance of pilot training cannot be underestimated, a lack of experience in “hand flying” the aircraft may have been a factor in the two mishap scenarios.

7. Certification: Assurance Control Processes

The FAA Certification process is an assurance control process. Organizations and enterprises implement controls. They check. Deming in the 1950’s established the Plan-Do-Check-Act paradigm that became the foundation for industrial process control, quality, and safety. Enterprise risk management ultimately seeks ways to avoid or control risks. Congressional committees conduct oversight hearings, Government agencies promulgate regulations and then conduct audits to confirm compliance. Private (as well as public) companies implement internal control and assurance processes. High risk activities are often embedded with layers of assurance controls. In one form or another, organizations have a due diligence responsibility to implement processes to verify compliance with requirements and the fidelity of products and activities.

It is also the case that implementation of controls comes at a measurable cost in terms of dollars and especially time. The cost of failure, in many cases, is more abstract and hypothetical and often difficult to weigh against the cost of assurance. Assurance functions may be considered to be redundant or limited in value. Accordingly, there is often “push back,” or resistance to Government Oversight - audits, reviews, inspections, and independent assessment activities – especially in organizations with weak safety cultures or environments driven by other agendas - such as financial performance.

Now consider the FAA, an organization faced with the daunting responsibility to check and verify that incredibly complex and sophisticated commercial aircraft are safe for the flying public with limited staffing, and often limited technical expertise in various niche areas. For years the FAA has implemented a process that delegates many of the assurance and control responsibilities to the industrial organization doing the work – while maintaining a depth of insight into work activities. This approach of delegation in which they employ (historically known) Designated Engineering Representatives (DERs), or in more recent legislation, Organizational Designated Authorizations (ODA’s) is central to their assurance strategy. The FAA ODA implementation is an example of a more general assurance concept called Insight/Oversight or I/O.

8. Insight/Oversight (I/O) Paradigm

The I/O approach is envisioned as a streamlined assurance approach that ideally requires fewer safety and mission assurance engineering and technical support personnel and at the same time imposes fewer delays for the design, development and manufacturing entity. For the I/O Paradigm to be a successful assurance control strategy there are a number of cardinal elements or truths that must be present. First and foremost is trust. The act of delegation is based on a belief that the delegated authority will be implemented with fidelity and independence. The second feature is a collaborative partnership mind-set which governs interactions between the delegating authority and the organization performing the work and at the same time implementing delegated authority. The third key element is transparency into relevant data that supports decision making. It is essential that the delegating authority will be afforded ongoing, full, transparent insight_and access to all relevant information - which, for example, may include design documents, risk management records, test results, simulation results, design analyses, quality audit information, and safety incident reports, as well as financial performance information. Insight is also enabled by electronic 24/7 data management infrastructure accessible by the delegating authority. Insight-based access includes the ability to view tests, integration activities, simulations, and other events.

The most critical feature in an I/O relationship is approval authority – who gets to decide. There are hundreds (if not thousands) of events and activities that historically have required Government approval. Greater delegation of approvals lessens potential impact to production schedules and costs. The vision of streamlining Government oversight is an I/O model in which the Government delegates most decisions while retaining insight into an organizations’ activities, and the basis and rationale for its decisions. At the same time the Government will reserve their (insight enabled) decision authority for inherently Government functions and potentially a small set of high risk/consequence issues or events. Other features of an effective I/O relationship might include establishing a dedicated ombudsman or facilitator to ensure the timely flow of information, and establishing an integration I/O working group of technical experts to discuss technical issues and risks. It is worth noting that NASA and its industry partners for the Commercial Crew Program have adapted an I/O approach very similar to that outlined above.

9. FAA I/O Processes and 737 MAX Certification

Unfortunately, the FAA I/O process implementation was ineffective. The FAA trust in Boeing was obviously misplaced as Boeing sought to hide test results from the FAA. The spirit of FAA/Boeing collaboration was instead replaced with Boeing's arrogant, contemptuous attitude toward FAA certification personnel. Information sharing and transparency was disabled by Boeing gatekeepers. In the end, Boeing made delegated decisions throughout the development of certification products in ways that afforded the FAA little (or "highly edited") insight. The FAA final decisions, as approval authority, concerning granting the Level-B change were ultimately made without the necessary insight – that is visibility, knowledge, and understanding of important performance and safety issues (MCAS).

It is also worth noting that the "2018 FAA Reauthorization Act, Subtitle B—Aircraft Certification Reform" addressed further expanding delegated authority without mentioning data transparency, Government insight, data sharing or visibility into processes fidelity. Following the accidents, in 2018 and 2019, Congress did a "180" - passing the 2020 Aircraft Certification Reform and Accountability Act, requiring the FAA to review manufacturers' ODA programs. In addition, the law directed FAA to hire more technical staff, more thoroughly address potential pilot performance issues, and require aircraft manufacturers to implement safety management systems. Subsequently – in February 2022 the Federal Aviation Administration issued additional guidance designed to protect aerospace employees doing certification work from what it calls "interference with those duties by employers."

Observation 10: Congressional meddling in safety critical functions of Federal Agencies is a *really* bad idea. Congress shares blame for weakening the I/O function by sending all the wrong signals to the FAA concerning ODA prior to the mishaps - and most tragically - throughout development of the 737 MAX. In addition, push-back (by the FAA) to the 2018 Congressional "reforms" (i.e., expand ODA – "back off FAA") was weak and ineffective.

Observation 11: All I/O implementation models are idealized concepts, intrinsically fragile and vulnerable to cost and schedule pressures. Also, as demonstrated by Boeing and the FAA they can be corrupted with relative ease. In addition, the assurance function (budget, staffing, experience, expertise), can erode over time as an organization or enterprise continues to experience successful outcomes. The diminished capability becomes exposed only after a disastrous event wherein investigators bemoan the ineffective assurance organization – as Admiral Hal Gehman observed during the Space Shuttle Columbia investigation - "There's no there there." How to avoid the Potemkin Village? Given all of the inherent difficulties in implementing and sustaining an effective I/O function what is the magic ingredient necessary to succeed? Put simply – leadership. The I/O process must be owned by stable, competent leadership that is uncompromised by conflicts of interest, and has the integrity and strength (within the enterprise) to maintain staffing, capabilities and expertise. The leader must also be willing to push back against external pressures (from political and industry interest groups) to compromise I/O effectiveness.

10. U.S Pilots' Perspective

This story wouldn't be complete without examining the unique perspective of the men and women who currently fly the MAX. Their knowledge of flight procedures, requisite aircrew training, cockpit automation, and airline industry trends provided us insight not only into the MAX mishaps but also to the potential safety of the flying public now and into the future. We interviewed several MAX pilots and synthesized their thoughts and observations here. A purposive sampling approach was used in selecting current MAX pilots with military experience that required detailed systems knowledge of their aircraft as well as airmanship skills.

The consistent theme presented throughout our interviews was accidents of the type discussed in this paper would not have happened with American trained pilots due to better systems knowledge and piloting skills. There seemed to be a dichotomy between systems managers in the cockpit versus pilots who understand the systems, the latter representing U.S. trained pilots. Systems managers do well as long as the plane functions correctly, but lack piloting and analytical skills when handling abnormal situations. This is a function of not having basic piloting skills in the initial stages of training with a foundation in aerodynamics. With piloting skills and aerodynamics as primary skills established, systems knowledge then becomes the next stage of the pilot's development. Lack of foundational training in piloting skills and aerodynamics develops what we might call "airline systems managers." To maintain piloting skills there is a necessity to hand fly the airplane on a routine basis. MAX aircrews in general stated that adherence to proficiency versus currency should form the framework for airline pilot training regimes.

As cockpits continue to become more automated and rely more heavily on technology, there is an assumption among the flying public that pilots across the globe have the same abilities and baseline training on piloting skills and aircraft systems. However, our interviewees claimed that the pilots in many foreign carriers do not have the same baseline training and capacity to adapt to the human-automation interface provided in the cockpit during normal operations and more importantly during abnormal and emergency operations. Compounding this issue is their reliance on automation and hesitancy to hand fly the aircraft in many situations.

Boeing's expectation that an MCAS activation would be treated the same as a runaway stabilizer trim condition, however flawed in terms of reaction time and non-normal procedures required, generated a lively discussion with each MAX pilot interviewed. One stated that; "You turn off two switches and you fly the jet. The problem is that you're dealing with people that can't turn the "magic" [autopilot, auto throttles, etc.] off and when they do you see what happens." Another aircrew commented that; "Our new runaway stabilizer checklist focuses on "flying the airplane." Our fourth step is "control column and thrust levers. Control aircraft pitch and airspeed.” That brings you back to what we have been talking about “flying the airplane.” That’s an addition. We never had that step until the Max was recertified and they came out with our new stabilator runaway checklist. They emphasize it.”

Our discussions inevitably led to the generation of ideas on how to fix the problem of weak hand flying skills. Our interviewees were somewhat skeptical that this could be handled through simulator training alone. One MAX aircrew, a former naval aviator with time in the C-9B Skytrain, a military version of the McDonnell Douglas DC-9-32 airliner, recalled that in his training they would shut an engine down to demonstrate single engine handling characteristics and/or purposely stall the aircraft and execute a stall recovery so that in the event that these situations present themselves the pilots are familiar how to deal with them. This same pilot stated that; “ 5-10 hours of this type of training [hand flying] is worth 10 years of gear up, flaps up, autopilot on, where we’re flying a five hour flight with only 15 minutes of stick and rudder stuff. The younger people don’t even realize their weaknesses or the threats in front of them. They don’t see it for what it is. They don’t appreciate the magnitude of their inexperience and how quickly things can go from a normal operation to a bad situation.” Unfortunately, cost conscious airline executives are not likely to adopt such a training strategy.

With the current global pilot airline shortage today, there is a rapid need to “fill the seat”. There are many articles that discuss lowering standards to get pilots through training and into the cockpit. An unnerving theme brought up through our interviews is that there are pilots filling seats that do not have the required time and training to be in that seat, and in essence become a liability on the flight deck. Akin to the Boeing management of 737 MAX for profit vice safety, expeditiously filling pilot or co-pilot seats with limited time or limited abilities, follows the same model of management that resulted in the accidents and human fatalities.

Observation 12: The continued automation and reliance on technology in cockpits assumes that pilots across the globe have the same abilities and baseline training on piloting skills and aircraft systems. Interviews with pilots in the US airline system indicate that this is simply not the case. While manufacturers such as Airbus and Boeing continue to modernize cockpits, there must be an emphasis on ensuring that new technology is properly understood by the aircrew communities, particularly its failure modes. Rigorous human factor assessments and training is also required from the manufacturers.

11. The Cost of Failure

The cost of failure is not a generally recognized business concept. It does not show up on a company’s annual Form 10-K filing to the SEC which provides a comprehensive overview of the business and financial condition of the company. We define it here to mean the direct and indirect costs to an organization in the event of program failure. Failure may come in several forms from program cancellation due to cost/schedule overruns or not meeting technical performance/safety standards, to legal liability for product failure leading to injury or loss of life, and so on.

First and foremost, the cost of failure to Boeing from the MAX program includes the 346 innocent crew and passenger lives lost on Lion Air flight 610 and Ethiopian Air flight 302. The U.S. Department of Justice DoJ) charged Boeing with fraud over the troubled certification of the Max and reached a deferred prosecution agreement for $2.5 billion; $500 million of which went to compensate the heirs, relatives, and/or legal beneficiaries of the crash victims (DoJ, 2021). Boeing also settled a subsequent investigation by the U.S. Securities and Exchange Commission (SEC) into allegations of fraud for deceiving investors after the mishaps stating basically that the MAX was “safe.” Boeing’s payment obligation was $200 million and former CEO Muilenburg’s was set at $1 million (Michaels, et al., 2022).

Various sources in the aerospace trade press put direct costs from the grounding of the Max at $20 billion. Indirect costs, such as discounts offered to airlines to jump start sales may exceed that amount and although we may never know, the final “cost of failure” may exceed the $68 billion costs British Petroleum (BP) had to absorb after the Deepwater Horizon explosion and subsequent oil spill in the Gulf of Mexico.

The deferred prosecution agreement, signed in January 2021, didn’t end there unfortunately for Boeing or the DoJ. Recently, “U.S. District Judge Reed O’Connor, rejected arguments by the DoJ and Boeing, and found that the 346 people killed in crashes in Indonesia in 2018 and Ethiopia in 2019 are crime victims under federal law (Laris, 2022).” This now opens the possibility of invalidating at least part of the deferred prosecution agreement.

Observation 13: Organizations involved in high-risk endeavors (e.g., aerospace, nuclear power, petrochemicals, medical devices) are subjected to existential risks. Generally, the likelihood of these risks occurring is small (e.g., 1 x 10-3 to 1x 10-5) but the impact is exceedingly high as shown by the MAX and BP cases. These risks are also characterized by having several interdependencies which makes scenario analysis a particularly efficient way of developing mitigation strategies. The consequences of these risks, particularly the cost attributes should be examined from the lens of the “cost of failure.”

12. Summary

No single root cause led to the loss of the 737-Max aircraft. Rather, a causal web of interlinked factors conspired to enable the events. The management branch of that web includes the Boeing Board members and senior management team. Boeing senior managers and program managers directed the “Level-B” mandate maintaining internal discipline and controlling information flow.

Another important branch of the causal web involves politics. Boeing lobbyist pressure on House and Senate committees worked to delegate more authority to Boeing and weaken FAA I/O capabilities during the 737-Max development period. Also, a key factor - Boeing risk managers and engineers (design, systems safety, flight dynamics, human factors, flight-test, verification), as well as those with delegated authority did not push back hard enough on the imperative to cave in and go along with the “Level-B” mandate. Finally, the FAA, with limited insight (both depth and breadth) into Boeing’s design, test results, and simulation data approved MCAS as a “Level-B” change. Innumerable counterfactual scenarios - “what ifs” –

as demonstrated above, can be constructed that illustrate how differently events might have unfolded.

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