ENGG 404 TEAM PROJECT FINAL TECHNICAL REPORT:

Submitted by Team #: 204

Case Study: Boeing 737 Max:
Boeing, Plane Crash, Ethiopia Airlines Flight 302 and Lion Air Flight 610, October 28, 2018 and March 10, 2019 respectively.

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EXECUTIVE SUMMARY

Incident Description and Losses:

The Boeing 737 Max was introduced to the market in 2017 as a response to Airbus' newly redesigned A380 [14]. The 737 Max was a dramatic redesign of a 50-year-old aircraft that utilized new engine technology and aerodynamics for improved overall efficiency [14].

On October 29th, 2018 Indonesian Flight 610 crashed into the Java Sea. This resulted in the loss of life of all 189 passengers and crew members as well of the equipment loss of a 737 Max [4]. This was the deadliest incident involving a 737 in Boeing's history [4].

On March 10th, 2019, Ethiopian Airlines Flight 302 crashed near Bishoftu, Ethiopia. This resulted in the loss of all 157 passengers and crew as well as the loss of a 737 Max [5].

On March 13th, the Federal Aviation Administration (F.A.A.) ordered an official grounding due to the evidence linking the two incidents [14]. Due to competitive business practices and Boeing prioritizing their profit over the safety of passengers, the 737 Max disasters resulted in the loss of life of 346 people, two aircraft lost, and assets estimated to be lost in the billions due to the grounding of the 737 Max fleets [14], [18].

Context and Purpose:

The Boeing Company is an American multinational corporation specializing in the aerospace industry [15]. Boeing's contribution to the commercial aerospace industry included the development of one of its most popular single row airliners, the Boeing 737 [16]. Backed by American Airlines among many other potential supporters, Boeing set out to redesign its most popular aircraft to flood the market. With this generation, known as the 737 Max, being an iteration of the nearly 50-year-old aircraft style [14]. The 737 Max improved on the aerodynamics and overall efficiency, by employing larger diameter motors and advanced winglet architecture [17]. The redesign would offer airlines to improve profit margins by reducing fuel costs and increasing the overall flight distance between layovers [17]. The 737 Max was seen to many as the solution for the increasing costs associated with airline travel. Furthermore, this revolutionary redesign was ideal for the many pilots transitioning from the previous generation due to the similarities between the 737 to the 737 Max. Due to the circumstances surrounding the two isolated incidents, an investigation has been requested and root cause analysis be provided by our firm. With the stringent safety regulations that airline manufacturers are prohibited to, our firm believes that there would be many beneficial lessons from this analysis that will impact the airline design and manufacturing processes, in order to ensure there are dramatic safety improvements to industry. Through working for ABC Conglomerate, we are interested in exploring the latent causes of these incidents in order to improve the overall safety of airline travel and adjust the standard for design and manufacturing processes.

Root Cause Analysis:

The root cause analysis for this investigation is centered around the two crashes involving Lion Air (Oct. 29th, 2018) and Ethiopian Airlines (March 10th, 2019). In both instances, the aircraft fell into a dive after a struggle between the aircraft pilots and the system controls [4], [5]. With the cause each instance was pointed to the aircrafts MCAS (Maneuvering Characteristics Augmentation System) responding to erroneous data from the flight sensors [14]. These incidents pointed to the latent cause of **weakness in Management Leadership,**

Commitment, and Accountability due to management overlooking crucial design elements in order to bring the 737 Max to market as quickly as possible [19]. The 737 Max was doomed from the day development began, as Boeing prioritized profit margins over the safety of their craft [18]. Boeing dramatically redesigned a nearly half century old aircraft with state-of-the-art engines [14]. As Boeing wanted to increase profit margins on their new craft, they opted to redesign an existing model rather than re-engineer an entirely new plane [14]. As the Boeing 737 was never initially designed to house such large diameter engines, this forced the weight balance further to the nose as the engines were forced further up front [20]. Due to this, the MCAS was developed, in order to retain similar flight characteristics to that of its previous generation 737 [20]. Ultimately, it was fault in this MCAS that brought down the two individual flights [14]. Further developing the causation which linked both events draws to the **Risk Assessment and Management of Risks**. As Boeing managed the development of the project with profit in mind, there were crucial safety aspects that were overlooked or mismanaged in the development of the 737 Max. Boeing prioritized assets in order to ensure a quick development time such that the craft could be brought to market as quickly as possible.

Latent Causes:

The development, manufacturing, and production of the 737 Max was riddled with errors that ensured imminent failure as witnessed through the two aircraft disasters. Although, the latent causes of these incidents are expansive, there are two key latent causes which ultimately caused the 737 Max to fail. Firstly, Boeing prioritized the profit of their airliner over their safety assessment of the craft [14]. This was primarily due to the face that Boeing had a very short development period. Boeing prioritized this quick development, due to the recent announcement of a high efficiency and long-range variant from its competitor Airbus [9]. Boeing faced pressure internally from investors and management, as well as from the market with airline companies who wanted Boeing to bring a similar variant to market. Boeing ultimately chose to appeal to the demands of their corporate backers and rush a revised version of their 737 Max to market [9]. This decision would jeopardize the overall safety of their craft and in the eventual fallout point the blame on misguided corporate values. Secondly, Boeing engineers wanted to limit the changes between the 737 and the 737 Max [1]. This was one of the crucial design choices that Boeing decided on instead of the development of an entirely new craft. This design choice dramatically overhauled the flight characteristics of the nearly half century old craft. From this, engineering decisions required the use of MCAS in order to retain similar flight handling dynamics to the previous generations of the craft [3]. Furthermore, the new integration of this system went unknown to the pilots and crew operating the aircraft [2]. This extensive overhaul of an aging platform required the use of many engineering systems that increased complexity and increased the overall risk of failure dramatically. Therefore, the second key latent cause was the decision to limit changes between models and retain the aging platform of the 737 instead of developing a new craft built specifically for the criteria laid out by Boeing [1]. Boeing neglected the safety of the Boeing 737 Max due to its priority of increasing the profit margins of is craft, as well as limiting the changes between the previous generation 737 and the 737 Max [1]. Overall, these choices would cause for the PEAP loss of two aircraft, 346 persons, and the market valuation of Boeing [14].

List of Latent Causes:

Element	Latent Cause
Management Leadership, Commitment and Accountability	○ Rushed to speed up getting approval from the F.A.A. ○ Boeing valued profit over safety. ○ Industry prioritized profit. ○ Boeing valued profit over the safety of the development. ○ The plane would be cheaper for airlines to buy if they don't have to provide additional training.
Risk Assessment and Management of Risks	○ Boeing did not properly assess the risks associated with MCAS. ○ F.A.A. inadequately assessed the risk of an updated MCAS. ○ Boeing engineers did not do a risk assessment because the sensors were industry standard. ○ Engineers made inadequate risk assessments. ○ Boeing incorrectly assessed the limitations of the MCAS. ○ Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.
Management of Change	○ Another arm of the agency knew about changes but did not do a safety analysis on these changes. ○ Boeing overlooked the significance of making the MCAS more aggressive. ○ Boeing did not plan and communicate the change of removing the G-force threshold effectively within the design team.
Program Evaluation and Continuous Improvement	○ F.A.A. rules allow for no second look if changes didn't affect plane operation in extreme situations. ○ Boeing engineers did not re-evaluate program application adequately. ○ Boeing assumed the MCAS would solve the issues with retrofitting the engines.

Design, Construction, and Startup	○ Boeing shortened the design process to speed production. ○ Boeing only tested situations of MCAS working ideally. ○ Boeing wanted to quickly introduce an aircraft to market. ○ Failed sensors were cost effective to replace due to simple design. ○ Retrofit of old design changed handling characteristics. ○ Boeing wanted to limit changes between 737 models.
Employee Competency and Training	○ Boeing employees were not properly trained on how to conduct a safety assessment. ○ F.A.A. employees were not properly trained how to store and communicate information. ○ F.A.A. employees were not adequately trained to assess iterations of safety systems.
Operations and Facilities Information and Documentation	○ F.A.A. officials in charge of training didn't know about the changes to the MCAS.

Key Recommendations and Alignment to Elements:

Based off key latent causes derived from analysis of the Boeing 737 Max incidents, it was determined that there was a lack of emphasis on safety within all levels of management of the Boeing corporation. Therefore, it was determined that in order to ensure that safety is prioritized within all aspects of ABC Conglomerate, it was determined that redevelopment of corporate values was required.

Furthermore, Boeing lacked an adequate risk assessment program that would have addressed technological implementations that were out of line of safety. Therefore, it was determined that in order to ensure an incident similar to that of Boeings does not recur, a proper risk assessment program must be in place that assesses the risk of crucial design choices and changes.

Recommendation Ranking:

Rank	Recommendation	Gain Index	Effort Index	Total Score	Nature of Fix	Latent Cause Addressed	Applicable RME
1	Redevelop corporate values	4	19	76	Solution is not technology.	• Boeing valued profit over safety • Industry prioritized profit • Rushed to speed up getting approval from the F.A.A. • Boeing valued profit over the safety of the development • The plane would be cheaper for airlines to buy if they don't have to provide additional training • Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.	RME #1 RME #2
2	Redevelop Risk Assessment Program	4	19	76	Solution is not technology	• Boeing did not properly assess the risk associated with MCAS. • Boeing incorrectly assessed the limitations of MCAS. • Engineers made inadequate risk assessment. • Boeing engineers did not do a risk assessment because the sensor was industry standard. • Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.	RME #2
3	Develop a Communication and Documentation System	4	17	68	The solution requires pre-existing technology and development of program for company.	• Another arm of the agency knew about changes but did not do a safety analysis on these changes. • Boeing did not plan and communicate the change of removing the G-force threshold effectively within the design team. • F.A.A. rules allow for no second look if changes didn't affect plane operation in extreme situations. • F.A.A. officials in charge of training didn't know about the changes to the MCAS.	RME #4 RME #6 RME #11
4	Asses the limitations regarding iterative design.	4	12	48	Apply complex technology.	• Boeing want to quickly introduce an aircraft to market. • Retrofit of old design changed handling characteristics. • Boeing valued profit over safety. • Boeing shortened the design process to speed production.	RME #1 RME #7

Whereas, the ranking of these four recommendations was based off complex effort gain matrices that weighed in crucial components of these recommendations. Such components include cost benefit analysis, difficulty with implementation, and latent causes addressed. Therefore, from this analysis, it was determined that redeveloping corporate values was deemed the most effective recommendation due to the ease of implementation and amount of latent causes addressed.

Business Case Analysis:

Through the business case analysis, the total cost of the incident and the cost of the top two recommendations were investigated. The outcome was that by implementing the top two recommendations ABC Conglomerate could save 395 million dollars from the potential risks and incidents. In addition, these numbers were generated without considering some factors as they are either unknown quantities or can not be monetized. The fact that ABC Conglomerate could save 395 million dollars just by implementing the top two recommendations makes it very worthwhile for ABC Conglomerate to act on these recommendations.

	Top Two Recommendations
Cost Avoidance of a Loss Incident	$4,900,000,000 ($4.9bn) + $9,200,000,000 ($9.2bn) + $5,000,000,000 ($5bn) = $19.1 bn
Initial Costs of Improvements	$9,000,000 ($9m) + $4,000,000 ($4m) = $13,000,000 ($13m)
On-going Costs of Improvements per Year	$7,000,000 ($7m)
Life of Project	30 Years
Total Cost of Improvements	$223,000,000 ($223m)
Annual Risk Exposure without Improvements	$637,000,000 ($637m)
Annual Risk Exposure with Improvements	$19,100,000 ($19.1m)
Gross Benefit	$618,000,000 ($618m)
Net Benefit	$395,000,000 ($395m)

Issues with Implementation and Next Steps:

The issues for implementing the recommended training program can be boiled down to issues of scalability and meeting the learning demands of a large and diverse workforce. The problems with scalability are the amount of time required to do the training, making sure that the time is broad and rigorous enough without consuming too much time of the employees but still ensure the efficiency of the training implementation. The training will have to be ongoing to make sure that all employees are up to date, the cost of this will have to scale up with the size of ABC Conglomerate. The problem with learning demands of a large and diverse workforce is that the training program must be applicable for employees come from various backgrounds and education levels. Therefore, the program should be free of jargon or other technical terms that some may find confusing. Furthermore, the training program should be designed with a variety

of aids such as visuals, hands on learning or text to provide a suitable learning experience for every employee.

The hurdles to implementing the recommendation of ensuring adherence to corporate values is mostly to do with ensuring the program is being followed on all corporate levels. This will require regular auditing of employees, and management. This will require a considerably complex program considering the number of employees and management personnel that work at ABC Conglomerate. Other hurdles would be the need for regular continuous training and meeting the learning needs of a very large and diverse workforce.

We urge ABC Conglomerate to implement these recommendations in order to ensure a similar incident to that of the Boeing 737 Max 8 not occur in the foreseeable future. With newly developed corporate values, safety would be held as a high standard through all levels of the corporation and management. As well, with a newly developed risk assessment program, this would ensure that all critical systems, such as Boeings MCAS, would receive additional attention to ensure that no harm comes to the clients of the craft. With these implemented recommendations, a higher standard of safety will be placed on all levels of the corporation ensuring that safety is the utmost priority for ABC Conglomerate.

CHAPTERS:

Chapter 1: Incident Description and Losses:

Incident Description:

The incident begins with Airbus's announcement of their new high efficient revision of their A320 in December of 2010. In February 2011 American Airlines, a long-time backer of Boeing, stated in a news release that they would purchase 100 re-engine Boeing 737s with CFM Leap turbines bending conformation from Boeing. This led to Boeing announcing in September 2011, that they would be releasing a new competitive Boeing 737 model.

Due to the competitive nature of the aerospace culture, a newly designed aircraft would result in minimal profit gains in comparison to an aircraft redesign. The profit margins for designing a new plane from the ground up are a lot lower than that of redesigning an existing model [9]. Due to the high-pressure Boeing faced from its consumers, Boeing valued the quick profit turnover from retrofitting an existing aircraft. Furthermore, Boeing understood that designing a new aircraft from the ground up would create doubt from its backers [11]. As a new aircraft would require airlines to retrain pilots and crew. Therefore, the motion was brought forward to redesign the 50-year-old 737 plane for its 4th generation [3].

During the development of the Boeing 737 Max, engineers became increasingly aware of the tendency for the planes to stall during pitch. This was since the new engines were moved forward as they were larger to increase fuel efficiency. This shift upset the overall balance and dynamics of the aircraft. This increased the tendency for the nose to pitch was undesirable from Boeing's perspective [3]. Therefore, a system was introduced called MCAS (Maneuvering Characteristics Augmentation System). In order to retain the same flight characteristics of the previous generation 737, Boeing implemented MCAS to augment the 737-flying behaviour. The hopes of this was to allow pilots to easily transition from flying the previous generation 737 to the 737 Max with minimal additional training [3].

Six years after the announcement of the Max in 2017, the first Boeing 737 Maxes were released to market. This was an extremely quick turnover from development cycle to production of an airplane [9]. The Boeing 737 Maxs were put into operation and pilots certified on the Boeing 737 completed the required two and a half hours of computer training to get them familiar with the new features of the 737 Max [3]. Although, there was one system left out of the mandatory training and pilot manuals which was the MCAS. This was decided in order to increase the purchasability of the 737 Max, as the MCAS system would require additional training from pilots [3].

On October 29th, 2018 a 737 Max flown by Lion Air crashed into the Java Sea, resulting in loss of all life onboard. Following the crash, the Indonesian Transportation Ministry ordered all airlines within the country to investigate their 737 Max fleet. A Boeing technician and a team from the US National Transportation Safety Board (NTSB) aided in the investigation of the incident. The investigation showed a dramatic change in altitude during the course of the 737 Maxs flight pattern. Ten minutes into the flight, there was a drop of more than 3000 feet. The investigation noted a previous incident on a previous flight where the aircraft dropped 200 feet in a matter of seconds [4].

Nearly five months later on March 10th, 2019 a 737 Max flown by Ethiopian Airlines crashed near Bishoftu, Ethiopia again resulting in a total loss of life of all onboard [5].

Following both incidents, the F.A.A. ordered the grounding of all 737 Max fleets across the globe. This resulted in losses estimated to be in the billions of airline companies and from Boeing itself [4], [5], [3].

Investigation of both incidents linked the MCAS automated flight system to the causation of the crashes. During the incidents, false readings from angle of attack sensors caused for overcorrection from the module. This then caused for planes to nosedive towards the ground even after the input from pilots [2].

Due to poor business practices and a rush to provide a competitive model to market, Boeing claimed the lives of 346 lives, two aircraft, and high equipment downtime over the span of a few months [14]. Boeing suspended the production of the 737 Max July 2019 [18].

Losses:

People: 346 people killed in the 2 plane crashes [4], [5]. from this there is a possibility of a

Environment: At the sites where the planes crashed, there was shrapnel from the planes [4], [5].

Assets: Two Boeing 737 Maxs were lost valued at 121.6 million USD, Boeing stocks fluctuated with estimated losses of $4.9 billion and a drop of 35% in revenues by July 24th, 2019 [20]. Airline companies were estimated to be affected in the order of billions in costs due to the grounding of the 737 Maxs [3].

Production: Boeing had suspended production of the 737 Max [18].

Chapter 2: Context and Purpose:

Context:

As part of ABC conglomerate, our team operates within the same commercial aviation industry as the Boeing Company. We are conducting a research analysis on the Boeing Company (Boeing) regarding their catastrophic events to learn from and prevent the repetition of similar incidents from occurring at ABC conglomerate. The loss incidents' we are focusing on are the Indonesian flight 610 and Ethiopian Flight 310 crashes.

Boeing is a multinational corporation that designs, manufactures, and sells airplanes, rotorcraft, rockets, satellites, telecommunications equipment, and missiles worldwide. [1] Specific to the alluded incidents are Boeing's design, manufacturing and selling of airplanes. The industry Boeing takes place in is the aviation industry, providing a worldwide network for passengers and cargo, facilitating international travel, trade and tourism. [13] Like all industry, the Boeing and all airline industry face several inherent risks. The inherent risks relevant to the airline industry are climate change, pilot shortage, aging technology, and in particular to the case study, system failure. [12] Such consequences of these risks range from the economical, increased costs due to carbon taxation, to flight delays due to pilot shortages, to PEAP losses due to malfunctioning technology.

Purpose:

Senior Management at ABC conglomerate has heard of the Indonesian flight 610 and Ethiopian Flight 310 incidents' and asked our team to investigate the root causes. This is due to Boeing and ABC Conglomerate sharing similar design, manufacturing and business structure and operating in the airline industry. Furthermore, this report will state recommendations based on the root causes of these incidents. This report is written with the purpose to investigate the causes of two Boeing 737 Max incidents in Indonesia and Ethiopia. Although technical issues play a major role in both incidents, this report will focus on the management failures. Therefore, this report will be centered around the development and manufacturing of the 737 Max which covers the time period of 2011-2019 inclusively. Due to the recentness of this event, this report will only utilize information available prior to the submission of this report. From these findings, the proper adjustments and regulations will be considered for Boeing's management system to prevent similar air crashes from happening again. This report is interested in exploring the business practices and further events that lead to these incidents. With these learnings, we hope to prevent further airline incidents resulting from failed business practice from occurring in the future.

Chapter 3: Root Cause Analysis – Discussion:

Scope and Boundaries:

The scope of this root cause analysis (RCA), will primarily be concerned with the decisions and actions made by the Boeing company concerning the design and construction of the Boeing 737 Max. Also within the purview of this RCA is the actions of the F.A.A. in relation to the Boeing 737 Max. Outside the scope of this RCA are decisions and actions of the airline companies that operated the two Boeing 737 Maxs that crashed, these being Lion Air, and Ethiopian Airlines, as well as any extenuating immediate circumstances that may have contributed to the incidents that are unrelated to the design and construction of the Boeing 737 Max.

Key Latent Cause #1: Boeing employees were not properly trained on how to do a proper safety assessment.

The immediate cause of the Lion Air Flight 610, and Ethiopian Airlines Flight 302 crashes, was both airplanes driving their noses into the ocean and ground respectively. The cause for this was the activation of MCAS which pushed the noses of both aircraft downward to compensate for the perceived high pitch. The reason for the activation of MCAS was that the AOA (angle of attack) was detected as being too high. This resulted from the input of erroneous data from the AOA sensor. This incorrect data was received from a single faulty AOA sensor rather than the usual two sensors that MCAS normally used in most applications. The reason why an MCAS system with only one sensor was being used on the two 737 Maxs that crashed was that the F.A.A. had approved the new version of the MCAS that uses only one sensor without an updated safety assessment from Boeing. The errant behavior of the iteration of MCAS that was used was unknown to the F.A.A. as the safety assessment from Boeing was compromised. The reason for this compromise was the Boeing had submitted an incomplete safety assessment that didn't fully account for the behavior of the new MCAS. Why an incomplete safety assessment was submitted to the F.A.A. from Boeing was that Boeing employees were not properly trained on how to do a proper safety assessment.

Key Latent Cause #2: Boeing valued safety over profit.

The immediate cause of the Lion Air Flight 610, and Ethiopian Airlines Flight 302 crashes, was both airplanes driving their noses into the ocean and ground respectively. The reason for this was that the pilots of both aircraft did not react within four seconds to correct the downward pitch of the aircrafts. The reason for this was that pilots were not trained to deal with errant behavior from MCAS. Why the pilots lacked this training was the airlines that were operating the two aircraft were not aware of the new version of MCAS that displayed this anomalous behavior. Why the airlines where uninformed about the new MCAS was that MCAS was deleted from the manual of the 737 Max. Why the manual lacked this information was that Boeing had assumed that pilots operating the aircraft didn't have to know the procedure for dealing with failure of the MCAS. Why Boeing made this assumption was that they believed that the MCAS failure was similar to the failure of the aircraft's rear stabilizer, which pilots generally know how to handle. The reason for this was that MCAS uses the rear stabilizer of the aircraft. Why MCAS was given control over the aircraft's rear stabilizer was that it can be used to reduce the pitch of the aircraft and avoid stalls. This was necessitated by the fact that Boeing had designed an aircraft that was prone to stalling. The cause for the stalling was the installation of

larger engines that improved the fuel efficiency of the old 737 design. Why Boeing made this design decision was to respond to the market demand for more fuel-efficient jetliners. Boeing sought to capitalize on this demand and increase the sales of their new aircraft. The ultimate latent cause for this was that Boeing valued profit over safety.

Chapter 4: Application of the Cause and Effect Model – Discussion:

Immediate Causes:

Substandard Conditions:

- Defective Equipment
  - The plane drove its nose into the ground.
    - MCAS changed the pitch of the nose towards the ground against the pilot's input, this happened because the AOA sensor failed.
  - AOA sensor failed.
- Inadequate guards/protective devices
  - MCAS Activated.
    - The safety instrument system, MCAS, activated due to a broken sensor providing false data because it only relied on one sensor.
  - MCAS Received Erroneous Data.
    - The MCAS had inadequate guards against faulty data being used
  - MCAS detected AOA as too high.
    - MCAS had no way to distinguish if it had the correct angles
- Inadequate warning systems
  - No warning Light for disagreement in the AOA sensors.

Substandard Work Practices:

- Improper decision making or lack of judgment
  - Pilot's did not react correctly within 4 seconds

Basic Causes:

Engineering Design Factors:

- Inadequate technical design:
  - MCAS wasn't fully developed.
  - Boeing only used data from one sensor instead of two for the MCAS.
  - Boeing removed the G - force sensor.
  - Alarm would require new system.
- Inadequate evaluation and/or documentation of change:
  - MCAS was deleted from the manual for 737 Max.
  - F.A.A. approved new version of MCAS without an updated safety assessment.
  - Airlines didn't know about the new MCAS.
  - F.A.A. had already approved the previous version of MCAS.
  - Boeing assumed that MCAS system would be rarely used.
  - Boeing believed that the MCAS failure procedure was similar to stabilizer failure, which was a common occurrence.
  - Boeing believed MCAS would protect against stalling.
  - F.A.A. overlooked the new development of the MCAS.
  - Boeing engineers assumed that the sensors would be reliable to use.
  - Boeing did not evaluate the implications of retrofitting engines.
  - Boeing did not anticipate the results of removing the G-force sensor.

    - Boeing assumed pilots didn't need to know the procedure for failure of the MCAS.
- Inadequate inherently safe design:
    - Boeing didn't believe removal of the AOA sensor disagreement light would compromise safety.
    - Resources were used on other functions deemed more critical to safety.
    - Boeing used cost effect sensors.
    - Stabilizer was used to reduce the pitch to avoid stall.
    - MCAS utilized the rear stabilizer.
    - Boeing designed an aircraft prone to stalling.
    - Boeing installed larger motors for efficiency.
    - Retrofitted of old 737 engine design made it unstable at low speed.
    - Boeing sold the disagreement light as part of an optional safety package.
    - Conflicting data would trigger the alarm.
    - Boeing made the MCAS more aggressive.
- Inadequate standards, specifications and/or design criteria
    - Boeing designed MCAS based off previous military applications.
    - Boeing wanted to ensure there was no conflicting data between the 2 sensors.
    - Military applications shared similar flight characteristics.
    - Boeing enhances previous MCAS design.
    - Boeing wanted to limit change to new aircraft.
- Inadequate assessment of operational readiness
    - Boeing did not assess the risks of an aircraft prone to stall.
    - Safety assessment was compromised.
    - MCAS was originally only activated at high speeds.
    - Boeing 737 was stalling at slow speeds in test flights.
    - Stabilizer failure was a common/known occurrence.
    - Boeing's testing was inherently flawed.
    - The original safety assessment of the 737 Max from Boeing was compromised.

<u>Job Factors:</u>

- Inadequate training:
    - F.A.A. didn't require Boeing to create any training programs.
    - Boeing didn't want to spend millions of dollars for additional training.
    - Pilot's were not trained how to deal with errant MCAS behavior.
    - Boeing wanted to mitigate additional training.
    - Pilots would need to be trained on how to react to alarms from conflicting data.
    - Boeing promised to pay for any additional training that was required.
- Inadequate job procedures:
    - Documents weren't reviewed properly by F.A.A.
    - Boeing submitted an incomplete safety assessment.
    - Boeing submitted an inadequate safety assessment.
    - Boeing had short deadlines.
- Organizational factors:
    - Boeing was facing competitive pressure from Airbus.
    - Boeing was facing pressure from clients.
    - Retrofit of old design was rushed
    - Boeing had strict budgets on the development of the 737 Max.

  - Boeing maximized profitability.
  - Boeing created a training program that would take 2.5 hours for pilot to complete.
  - Boeing wanted to increase ease of transition from previous generation 737 to 737 Max.
  - Airline companies wanted a cost-effective aircraft.
  - Boeing knew consumers valued highly efficient aircraft.
  - Boeing wanted to increase sales of new aircraft.
  - The Airlines didn't purchase the warning lights.
  - Boeing wanted to maximize profit margins.
  - Quick development turnover would deliver sales sooner.
  - Limited market shifted corporate values.
  - Pilot training is a costly expense for airline companies.
  - Pilots were adequately trained to deal with stabilizer failure.
- Inadequate communication
  - Limited industry created a competitive culture.
  - Demand to fill from new budget airline companies.
  - There are only two key airplane manufacturers within the market.

<u>Personal Factors:</u>

- Lack of knowledge/ Lack of skill
  - Test pilots were having trouble handling controls.

Latent Causes (weaknesses in Management System Elements):

- RME #1: Management Leadership, Commitment and Accountability
  - Rushed to speed up getting approval from the F.A.A.
    - Boeing and the F.A.A. were trying to rush through the approval process to get the 737 Max out to market. This led to the hasty approval processes and the failure to reassess the MCAS.
  - Boeing valued profit over safety
    - Boeing valued their profit over the safety of the design of the 737 max. This is shown is some of the decisions made such as Boeing's decision to rush the development of the 737 Max.
  - Industry prioritized profit
    - Airline companies opted for cost effective models in their fleet in order to ensure higher profit margins. Commercial airlines would back the most economically suitable variant of craft in order to sustain profit.
  - Boeing valued profit over the safety of the development
    - Boeing continuously pressed hard deadlines and shifted engineering and development teams to other areas of the project in order to ensure quotas were met. Bringing the aircraft to market and turning a profit was prioritized over the safety of the aircraft.
  - The plane would be cheaper for airlines to buy if they don't have to provide additional training
    - This swayed Boeing to decide to retrofit the old 737 model and guided some of their design decisions to allow the airlines to not have to provide lots of additional training for the new plane.
- RME #2: Risk Assessment and Management of Risks

- Boeing did not properly assess the risks associated with MCAS
  - Boeing did not fully assess what could happen if the MCAS behaved inappropriately and what that could mean to the pilots.
- F.A.A. inadequately assessed the risk of an updated MCAS
  - In the rush to get everything approved the F.A.A. did not have time to review everything properly. The F.A.A. ended up approving the more aggressive MCAS without fully realizing the new risks associated with the new design.
- Boeing engineers did not do a risk assessment because the sensors were industry standard
  - The engineers maybe never thought about what could happen if the sensor failed and therefore did not fully assess the risk associated with using the AOA sensor.
- Engineers made inadequate risk assessments
  - Engineers did not assess the risks that modifying the MCAS would have on the overall flight dynamics of the aircraft.
- Boeing incorrectly assessed the limitations of the MCAS
  - Boeing engineers incorrectly assessed how much control and how big a part of flying operations the MCAS would prove to be.
- Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.
  - Boeing did not do an appropriate safety assessment for removing the AOA sensor disagreement light and how that could leave the pilot's without vital information to diagnose what was going wrong

- RME #4: Management of Change
  - Another arm of the agency knew about changes, but did not do a safety analysis on these changes
    - This was a failure to communicate the changes to the MCAS to the F.A.A., which led to the new MCAS getting approved without being fully reviewed.
  - Boeing overlooked the significance of making the MCAS more aggressive.
    - Boeing did not investigate what the implications were to the alterations made on the MCAS system.
  - Boeing did not plan and communicate the change of removing the G-force threshold effectively within the design team
    - Boeing did not investigate what affects removing the G-force threshold would have on the MCAS system and overall vehicle dynamics.

- RME #6: Program Evaluation and Continuous Improvement
  - F.A.A. rules allow for no second look if changes didn't affect plane operation in extreme situation
    - Based off F.A.A. regulations, the update of the MCAS did not require a second look as it was considered not critical to the development of the 737 Max.
  - Boeing engineers did not re-evaluate program application adequately
    - Boeing failed to give the updated MCAS a second look as the belief was that this did not alter the characteristics of the system significantly.
  - Boeing assumed the MCAS would solve the issues with retrofitting the engines

        - Boeing relied heavily on the MCAS to solve the issues with retrofitting the engines and did not fully evaluate how much control they were giving the MCAS.

- RME #7: Design, Construction, and Startup
    - Boeing shortened the design process to speed production
        - Boeing prioritized the quick turnover of the development of their craft. Therefore, there were stringent deadlines set by Boeing in order to reduce the development time.
    - Boeing only tested situations of MCAS working ideally
        - Boeing only conducted tests of the MCAS system in single use cases. There was no test performed in the case of a continuous call for MCAS engagement.
    - Boeing wanted to quickly introduce an aircraft to market
        - Boeing was faced with tight deadlines due to a competitor's aircraft that would overtake the market. Facing pressure from potential airline buyers, Boeing opted for a short development time to quickly introduce the craft to market.
    - Failed sensors were cost effective to replace due to simple design
        - AOA sensors were a relatively simple design that was financially cheap to replace. Boeing overlooked the need for such sensors to be reliable and therefore opted for a cost-effective solution.
    - Retrofit of old design changed handling characteristics
        - The idea to retrofit the old design with new engines changed the handling characteristics and made the plane more prone to stalling.
    - Boeing wanted to limit changes between 737 models
        - When designing the plane Boeing had to limit changes from the previous model to get it certified and to avoid having lots of additional required training.

- RME #9: Employee Competency and Training
    - Boeing employees were not properly trained how to conduct a safety assessment
        - The Boeing safety assessment of the 737 was riddled with errors. These errors could have been mitigated if proper training was provided with adequate safety assessment training.
    - F.A.A. employees were not properly trained on how to store and communicate information
        - This is a possible reason that the documents submitted by Boeing to the F.A.A. were not reviewed properly. Which led to the MCAS getting approved without the changes being fully reviewed.
    - F.A.A. employees were not adequately trained to assess iterations of safety systems
        - The F.A.A. employees did not have adequate training for assessing changes to systems after the initial approval was completed.

- RME #11: Operations and Facilities Information and Documentation
    - F.A.A. officials in charge of training didn't know about the changes to the MCAS
        - The F.A.A. was not made aware of the critical changes to the MCAS system by Boeing after alterations were made.

Chapter 5: Key Recommendations:

Gain Index	Gain Index Criteria
4	● Addresses latent causes. ● Eliminates hazards or has the greatest reduction in risk levels. ● Eliminates initiating events.
3	● Addresses basic causes. ● Reduces risk levels to a lesser extent than “4”. ● Prevent incidents by eliminating subsequent condition splits. ● Eliminates impact in overall PEAP despite having an event.
2	● Addresses immediate causes. ● Reduces risk levels to a lesser extent than “3”. ● Minimizes impact significantly in overall PEAP i.e. mitigates the consequence of an incident.
1	● Minimizes impact slightly in overall PEAP i.e. mitigates the consequence of an incident. ● Does not address any cause. ● Reduces risk levels to a lesser extent than “2”, or not at all.

Effort Index Criteria				
	1 (High Effort)	**2**	**3**	**4 (Low Effort)**
Practicability	difficult/ challenging/ develop new technology	apply complex technology	apply simple technology	the solution is not technology
Initial Cost	>$200M	$200M - $100M	$100M - $10M	< $10M
On-going Costs	>1$00M	$100M - $10M	<$10M	no additional on-going cost
Timeline	Can be implemented more than 1 year	Can be implemented within 1 year	Can be implemented within 3 months	Can be implemented immediately
Duration	Requires more than 3 months	Requires less than 3 months	Requires less than one month	Requires less than one week
Frequency	Once per month or more often	once per quarter	once per year	one-time

M = Million in dollars (cad)

The complex effort model was modified by increasing the dollar amounts in the initial costs and ongoing costs to better serve our analysis.

1) **Redevelop Corporate Values**
   - Description: Review existing corporate values and ensure that safety is a top priority at all levels of the corporation. Develop a training program to ensure that employees understand the corporate values and can apply these within their line of work.
   - Deliverables:
     - Deliverable 1: Reaffirm that safety is a top value for the company and incorporate it into all aspects of the corporation and begin all meetings with a discussion about safety.
     - Deliverable 2: Create a training program to educate employees on the corporate values of the company. This program would require a refresher course annually in order to affirm the company values of safety as a key priority.
     - Deliverable 3: Create a training program for the board of directors of the company to instill ideal safety standards at the highest level of management.
   - Gain index = 4
     - This recommendation addresses lots of latent causes related to the rush of the design. It also helps with the motivation to limit changes to avoid additional training, as if safety is a value then the company wouldn't mind additional training if it helps with operating the plane more safely.

    - This recommendation also would eliminate the initiating events of rushing the design and not paying adequate attention to safety.
- Effort index = 19
    - Practicality = 4
        - The solution is training employees and management about the company's values and ensuring safety is a top value, thus it is not a technology.
    - Initial cost = 4
        - The development of the training program and initial training should cost less than 10 million dollars as it is not hard to create a training program, and the initial training could be around 1 hour in duration, based on a company of Boeing's size.
    - On-going Costs = 3
        - This would be relatively minimal as it could be just a 1-hour refresher course, so the only cost would be the employee's time for an hour. Therefore, depending on company size, this on-going cost would vary, based on a company of Boeing's size the cost would be less than 10 million.
    - Timeline = 3
        - It would probably take around 3 months to develop a training program and next to no time for management to reaffirm that safety is a top value and next to no time for management to begin meetings with discussions about safety.
    - Duration = 2
        - The training would start to address the latent causes as soon as the employees complete it, but it could take around three months for everyone to complete the training.
    - Frequency = 3
        - The training would need to be repeated every year, so the employees are reminded that safety is a top value of the company and that they act with that in mind.
- Total score = 4 * 19 = 76, "Low Hanging Fruit" recommendation.
- Nature of fix: The solution is a training program.
    - Permanent in terms of the once a year routine training for the duration of company operation.
- Latent causes addressed:
    - Boeing valued profit over safety
    - Industry prioritized profit
    - Rushed to speed up getting approval from the F.A.A.
    - Boeing valued profit over the safety of the development
    - The plane would be cheaper for airlines to buy if they don't have to provide additional training
    - Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.

- Alignment to RME'S:
    - RME #1: Management Leadership, Commitment and Accountability
        - This recommendation is aligned directly with this element as it is all about renewing management's commitment to safety and making sure it is at the forefront of all activities
    - RME #2: Risk Assessment and Management of Risks
        - The recommendation is aligned with risk assessment because if the main value of the company and its workers is safety then employee's will take risk assessment and management of risks very seriously.

2) Redevelop Risk Assessment Program

- Description: Create a stronger risk assessment program, that overlooks design and development procedures. Develop a training program to ensure that engineers understand how to assess the risk properly and from then come up with the best solution to eliminate or reduce the risk.
- Deliverables:
    - Deliverable 1: Develop a document on procedures for risk assessment for the design and development phase.
    - Deliverable 2: Create a comprehensive training program to educate engineers on risk assessment and training regarding procedures.
    - Deliverable 3: Set a higher level of standard relative to that of the aerospace manufacturing industry.
- Gain index = 4
    - This recommendation directly addresses the latent causes of not assessing the risk properly during the design phase. With a stronger risk assessment program, the company would never rush the design process until all safety requirements have been met.
    - This recommendation would also be able to prevent tragic airplane incidents such as Boeing's since with the training program, the engineers would understand and know how to assess the risks associated with the design phase properly. then, they would be able to come up with the best solution to eliminate or reduce the risks.
- Effort index = 19
    - Practicability = 4: No technological solutions are needed to develop a document on procedures for risk assessment nor the training program for engineers.
    - Initial cost = 4: Cost of developing a risk assessment document and a training program would be less than 10 million dollars since this does not require any technologies and it can easily be done by the company itself or a third-party company.
    - On - going cost = 3: Less than 10 million dollars would be required to organize a risk assessment training section for engineers every year.
    - Timeline = 3: It would take less than 3 months to improve the document on procedure as well as to develop a training program for engineers.

    - Duration = 2: It would take less than 3 months for engineers to fully understand and apply the updated procedure for safety assessment document into their works.
    - Frequency = 3: The risk assessment document needs to be updated once every year. The training program also needs to be organized annually to ensure that all engineers understand and apply the latest document update on risk assessment.
- Total score = 19 * 4 = 76, “Low Hanging Fruit” recommendation.
- Nature of fix: The solution is not technology.
    - Permanent annual document update and organizing training event for engineers.
- Latent causes addressed:
    - Boeing did not properly assess the risk associated with MCAS.
    - Boeing incorrectly assessed the limitations of MCAS.
    - Engineers made inadequate risk assessments.
    - Boeing engineers did not do a risk assessment because the sensor was industry standard.
    - Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.
- Alignment to RME’S:
    - RME #2: Risk Assessment and Management of Risks
        - This recommendation specifically relates back to RME number #2: Risk assessment and Management of Risks as it ensures the company will improve its document on procedure for Risk Assessment as well as all engineers will understand and know how to assess risks properly through a training program.

3) Develop a Communication and Documentation System

- Description: Develop a comprehensive communication system, that allows for stronger communication flow within the internal network of the company. This system should include progress tracking, such that separate departments can stay up to date on updates. As well, this tracker should flag all significant changes so that they are communicated between all design staff. This communication system should incorporate a regular in person meeting, for staff to address concerns, answer questions, and stay up to date on the progress of the project. Furthermore, this communication system should incorporate an anonymous feedback program between employees and management that ensures that management remains accountable and issues are addressed from the lowest levels of project development.
- Deliverables:
    - Deliverable 1: Develop an internal communication system.
        - Develop an online documentation system that tracks any changes and highlights important changes to the project.
        - Train staff on effective execution of program. Clear, efficient and comprehensive use of program to be easily used and understood.

        - Develop oversight of program.
        - use intra-team meetings which highlights project changes and addresses any questions or concerns. This should be done on a weekly basis. All meetings should begin with a precedence on safety.
        - Communication program should include the use of anonymous reporting that ensures management remains accountable.
    - Deliverable 2: Develop a communication system with third party groups.
        - Program will emphasize crucial design to regulators, clients and operators.
        - Develop a program oversight in line with corporate safety culture.
        - Develop training programs for clients on significant changes affecting their use of the product.
- Gain index = 4
    - This recommendation addresses the latent causes of the incident as well as targets the initiating factors that influenced the incident. This recommendation directly addresses the issues that Boeing had with internal communication and communicating the changes that affected inter department designs within Boeing. Furthermore, this recommendation would directly affect the communication with third party organizations, such as the F.A.A. This recommendation would ensure all third-party organizations are kept up to date with crucial changes that impact review from governing bodies such as the F.A.A. Therefore, since multiple latent causes are targeted from this recommendation, there is a strong gain from a recommendation of bettering communication flow.
- Effort Index = 17
    - Practicability = 3: This solution requires simple technology, such as shareable spreadsheets, progress tracking, and track changes.
    - Initial Cost = 4: It is estimated that the combined costs of training for use of inter department track change forms and the use of spreadsheets are less than $10M initially. Since technology of the program is limited, and requires no new technologies, this will in turn keep these costs lower.
    - On-going costs = 2: Due to the requirement to set aside time per week for inter department meeting, the ongoing costs will be higher (est. within $100M to $10M per year). Furthermore, ongoing training for these programs would be assessed with this ongoing cost.
    - Timeline = 3: The primary factor affecting the initial implementation would be the time to train staff on how to use the program and the requirements for the interdepartmental meetings.
    - Duration = 4: As soon as these changes are made, and staff are trained the effects and benefits will be noticed by the company immediately.
    - Frequency = 1: Due to the time required to provide an interdepartmental team meeting, the frequency is extremely high.
- Total score = 4*17 = 68, “Low Hanging Fruit” recommendation.
- Nature of fix: The solution requires pre-existing technology and development of program for company.

- Latent Causes Addressed:
    - Another arm of the agency knew about changes but did not do a safety analysis on these changes.
    - Boeing did not plan and communicate the change of removing the G-force threshold effectively within the design team.
    - F.A.A. rules allow for no second look if changes didn't affect plane operation in extreme situations.
    - F.A.A. officials in charge of training didn't know about the changes to the MCAS.
- Alignment to RME'S:
    - RME #4: Management of Change
        - The recommendation specifically relates back to RME # 4: Management of Change, as it ensures that changes are not overlooked by staff and ensures that company values are not altered through employee decisions. As well, the anonymous reporting program would ensure that all levels of the organization are adhering to company policy and safety standards, ensuring that management remains accountable.
    - RME #6: Program Evaluation and Continuous Improvement
        - The documentation program would ensure that critical iterative design changes are highlighted and made apparent to governing bodies and regulators. This ensures that crucial changes are not overlooked by these third-party members.
    - RME #11: Operations and Facilities Information and Documentation
        - This documentation program would ensure crucial information within the organization is shared internally to departments requiring this information as well as to appropriate external governing bodies.

4) Assess the limitations regarding iterative design.

- Description: Assess the viability of older platforms in a market that is increasingly geared to towards greater speed and fuel efficiency. This can be accomplished by conducting a thorough analysis of the capacity of older platforms to be modified without disrupting fundamental flight characteristics and score the findings according to a rubric that will assess whether the safety of the aircraft is compromised. This analysis can be carried out internally and can be verified by an impartial 3rd party. If these findings indicate a failure of the modified design in terms of safety, then it will have to be accepted that a brand-new design that meets the criteria of market demands will be required.
- Deliverables:
    - Deliverable 1: Evaluate the capacity of older platforms to meet future market demands.
    - Deliverable 2: Accept the cost of designing a new platform from scratch to meet those market demands.
    - Deliverable 3: Have a third party assess the safety of a retrofitted design.
    - Deliverable 4: Develop an internal program that assesses the risks associated with a retrofitted design.
- Gain index = 4

    - This recommendation addresses the root cause of design construction and start up, as it was the retrofitting of the old Boeing 737 and its disruption of the flight characteristics that necessitated the incorporation of MCAS into the flight controls. This recommendation will have management and employees make a more honest assessment of the risks involved in taking an old platform to its limits, and should rule out simple technical fixes that could have unintended consequences.
- Effort index = 12
    - Practicality = 2: This assessment will most likely require highly sophisticated modelling software and the construction of models to be wind tested, all of which is rather complex technology.
    - Initial cost = 2: The design and development of software sophisticated enough to emulate the flight characteristics of a modified airframe with enough precision will be costly.
    - On going cost = 2: The testing of the modifiability of older platforms won't be something that will happen very often but will most likely incur a substantial cost when it does. Another ongoing cost will be the contracting of an independent third party to verify the safety of a retrofitted design, along with the operational cost involved with the internal safety auditing program.
    - Time line = 2: Designing the modelling software will mostly likely take more than 3 months but less than 1 year, and establishing the internal audit program along with contacting and establishing a relationship with an external third party will also most likely take more than 3 months but less than a year.
    - Duration = 1: The testing of the modifiability of older platforms along with the internal and external safety auditing will take over 3 months, and the designing of whole new aircraft may take years.
    - Frequency = 3: At most this measure will be implemented once a year, but over an extended period with the testing of modified designs and having those test results audited by the internal audit program, and the external third party.
- Total score = 4*12 = 48, "Nice to do" recommendation.
- Nature of fix: Apply complex technology, and permanent.
- Latent causes addressed:
    - Boeing wanted to quickly introduce an aircraft to market.
    - Retrofit of old design changed handling characteristics.
    - Boeing valued profit over safety.
    - Boeing shortened the design process to speed production.
    - Boeing wanted to limit changes between 737 model.
- Alignment to RMEs:
    - RME # 1: Management Leadership, Commitment, and Accountability.
      The recommendation to assess the viability of older platforms and coming to terms with the possibility that an iterative design approach isn't the best practice in terms of reasonable safety levels, will require management to commit themselves to safety leadership and accountability.

- RME # 7: Design Construction and Startup:
  Rigorously assessing the risks involved with modifying older designs which might lead to the ruling out of an iterative design approach will have significant implications of the design process for airline manufacturers.

Recommendation Ranking:

Rank	Recommendation	Gain Index	Effort Index	Total Score	Nature of Fix	Latent Cause Addressed	Applicable RME
1	Redevelop corporate values	4	19	76	Solution is not technology.	● Boeing valued profit over safety ● Industry prioritized profit ● Rushed to speed up getting approval from the F.A.A. ● Boeing valued profit over the safety of the development ● The plane would be cheaper for airlines to buy if they don't have to provide additional training ● Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.	RME #1 RME #2
2	Redevelop Risk Assessment Program	4	19	76	Solution is not technology	● Boeing did not properly assess the risk associated with MCAS. ● Boeing incorrectly assessed the limitations of MCAS.	RME #2

						• Engineers made inadequate risk assessment. • Boeing engineers did not do a risk assessment because the sensor was industry standard. • Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature.	
3	Develop a Communication and Documentation System	4	17	68	The solution requires pre-existing technology and developme nt of program for company.	• Another arm of the agency knew about changes but did not do a safety analysis on these changes. • Boeing did not plan and communicate the change of removing the G-force threshold effectively within the design team. • F.A.A. rules allow for no second look if changes didn't affect plane operation in extreme situations. • F.A.A. officials in charge of training didn't know about the changes to the MCAS.	RME #4 RME #6 RME #11
4	Asses the limitations regarding iterative design.	4	12	48	Apply complex technology.	• Boeing wanted to quickly introduce an aircraft to market. • Retrofit of old design changed handling characteristics.	RME #1 RME #7

						• Boeing valued profit over safety. • Boeing shortened the design process to speed production. • Boeing wanted to limit changes between 737 models.	

In conjunction with ABC Conglomerate, the recommendations were ranked with a standard effort and gain matrix. Due to the ranking system producing a tied complex gain index, the top two recommendations were further analysed in order to select the most effective recommendation. For the key two recommendations, it was decided that re-evaluating corporate values would be a more effective recommendation for the following reasons:

- Redeveloping and training staff on corporate values would address latent causes at all levels of the corporation. Ensuring that the highest levels of management understand and abide by these values, therefore propagating through the company.
- Redeveloping corporate values would target a majority of our latent causes which specifically align to RME #1.
- The estimated costs of redeveloping corporate values are estimated to be significantly lower than that of developing a risk assessment program. These costs were assessed as start up costs and on-going costs which were both estimated to be significantly lower in both instances.
- Redeveloping corporate values, can be effectively implemented within ABC Conglomerate and effectively prevent and reduce the likelihood of loss incidents as seen in the Boeing 737 Max cases.

Therefore, it is with great confidence that redeveloping corporate values is our highest recommendation to ABC Conglomerate, who operates a similar company to that of Boeing.

Chapter 6: Business Case Analysis:

In conjunction with ABC conglomerate, the following cost benefit analysis was calculated using our top two recommendations of the incident. Due to the complexity of the incident, the overall cost of a loss incident has been speculated based off available reports, news articles, and publicly available company documentation from Boeing.

	Top Two Recommendations
Cost Avoidance of a Loss Incident	$4,900,000,000 ($4.9bn) + $9,200,000,000 ($9.2bn) + $5,000,000,000 ($5bn) = $19.1 bn
Initial Costs of Improvements	$9,000,000 ($9m) + $4,000,000 ($4m) = $13,000,000 ($13m)
On-going Costs of Improvements per Year	$7,000,000 ($7m)
Life of Project	30 Years
Total Cost of Improvements	$223,000,000 ($223m)
Annual Risk Exposure without Improvements	$637,000,000 ($637m)
Annual Risk Exposure with Improvements	$19,100,000 ($19.1m)
Gross Benefit	$618,000,000 ($618m)
Net Benefit	$395,000,000 ($395m)

Quadrant: Low hanging fruit

With an evaluated life of the project stated at 30 years, the net benefit deduced places the gain as low hanging fruit due to the extreme net benefit figure produced. This value of benefit was placed at $395m, which is a substantial avoidance for a company the size of ABC Conglomerate and Boeing. Furthermore, this evaluation was given due to the relative ease of implementing a new set of company values and risk assessment program in respect to the potential outcomes as seen by Boeing in the 737 max cases. Furthermore, with conjunction to ABC Conglomerate, it is foreseen that these programs could be implemented in a matter of months with the assistance of an external risk management association. Therefore, for a company of a similar size and scope of the Boeing company, the derived solutions are the most effective with the least effort.

Conclusion:

From the Business Case Analysis, ABC Conglomerate will save 395 million dollars with only two simple training programs that do not require any technological solutions. Therefore, these two recommendations are evaluated as “Low Hanging Fruit” and we determine that they are worth implementing since they would reduce ABC Conglomerate's risk levels significantly.

Other Factors Not Considered:

One of the other factors that has not been considered in this analysis is that the public has lost faith in Boeing due to this incident. Loss of faith is huge as it could affect their business for a long time to come. Although, this was represented in their initial stock losses, there are further issues that need to be discussed. Another cost that could not truly be quantified is how many airlines will decide to order planes from other companies. Airlines might not want to risk using Boeing planes fearing they get grounded again, which lead to consequences for the airlines such as having to cancel flights, costing them clients. One last thing that was not considered in this analysis is the cost of current and future lawsuits against Boeing. Due to the recent nature of these incidents most of these suites are yet to be filed and awarded compensation. Also, this is still an ongoing incident, so the true cost of the incident is still unknown, and the total effect of this incident won't be fully understood for years.

Chapter 7: Issues with Implementation

In conjunction with ABC Conglomerate, a company of a similar size and scope of Boeing Company, there are multiple projected issues with implementation of the recommendations given.

Based off Recommendation 1: Redeveloping corporate values, the following issues were derived from the recommendation. It is to note that these issues were deliberated and placed in the most logical order. Therefore, further issues may be found later through implementation of the recommendation:

1. **Scalability**: Due to the large scale of ABC Conglomerate, it is foreseen that upscaling a training program may result in multiple issues. Therefore, the company should keep scaling in mind when developing training programs for the entire corporation. This should include:
    - Ensuring that a training program incorporates the learning needs of all employees with a variety of backgrounds and education. With a large-scale corporation, this factor is increased exponentially and therefore should be prioritized in program development.
    - Developing a well-rounded program that effectively utilizes time. Consider the large size of the company, the program must ensure corporate time is used efficiently in order to ensure the efficiency of their implementation.
    - The program should also ensure that all employees are trained and kept aware of all updates. Therefore, a tracking document should be implemented to ensure that all employees are trained on the corporate values and updated on an annual basis

2. **Incorporating learning demands of a diverse workforce**: Due to the scope of implementation, being all employees at ABC Conglomerate. Therefore, a diverse workforce, with a variety of backgrounds are expected to partake in this training program, resulting in multiple issues. This should include:
    - The training program should be applicable to a diverse background, education level, and not restricted to ability. Therefore, the program should be free of jargon or other terms which some may find incomprehensible.
    - The training program should implement a variety of teaching aids such as visuals, hands on learning, and text in order to provide a beneficial learning experience to all employees of the company.

3. **Ensure adherence to company values**: Due to the large scale of the company, it becomes difficult to ensure all employees work according to the values set by the company. This should include:
    - Auditing and documentation should be set in place to ensure that employees at lower levels of the company are implementing company values in their specific lines of work.
    - Board of directors should be required to keep close tabs on the higher levels of management such as elected directors and officials. Therefore, this would ensure that company policy and values are abided by at the highest level of management.

- Regular training would ensure that safety is an utmost priority for ABC Conglomerate. This would keep the idea and the topic fresh on all employees' minds to further ensure this is incorporated into daily work life.

Chapter 8: Next Steps

On behalf of all employees within our firm, group 204, we would like to thank ABC Conglomerate for the opportunity to work alongside them to develop a rigorous analysis of the Boeing 737 Max incidents. Through comprehensive root cause analysis and development of latent causes, a deeper understanding of the issues that lead up to the incident was developed. We would like for management to implement these developed recommendations in order to strengthen company safety standards and prevent further loss of life incidents. Regardless of fault, we hope that the lessons learned through this report prevent further unnecessary losses of life and develop a safe work culture within ABC Conglomerate and other similar firms in the airline industry.

For our top recommendation, the next step requires the management team to assess the current corporate values and reconfigure them such that safety is prioritized above all other values. This will require a high level of commitment to establishing a rigorous training program along with compulsory annual training to make sure that all stakeholders, namely employees will be on board with a renewed commitment to safety.

Redeveloping the corporate values with safety as the value and highest priority will have the major benefit for ABC Conglomerate of making all employees focused on safety in all aspects of their work environment. Whereas, it would be ensured that these values are enacted at the highest levels of management in order to ensure that they are engrained deep within the organization. This will help reduce the number of incidents and will help ABC Conglomerate develop designs which implement safety as a main driving force behind them. Implementing safety as top value would prevent an incident similar to Boeing's incident with the 737 Max because the employees and the company would have given the design a more thorough safety inspection before allowing the plane to go to market. Another way safety being a top value would have avoided this incident is that the MCAS would not have been left out of the training manual for the pilots, as that does not align with ensuring the safety of the pilots and passengers.

The consequence of not implementing these measures would be to repeat the errors made by Boeing's management team, all of which resulted directly from their low valuation of safety. This is evident in them implementing and then modifying MCAS which had critical implications for the operators of their aircraft, and the passengers onboard these aircraft all of which resulted in significant loss of life and assets. Throughout the RCA carried out for this report, many of the decisions made by Boeing were directly related to Boeing valuing profit over safety, which this recommendation directly addresses.

This recommendation will require from the management team a continuous commitment to the value of safety. This commitment will have to be evident on all corporate levels and in all activities, and thus will require leadership from management to set the standard to be followed by the employees. Therefore, it is required that these corporate values are instilled within all aspects of the work culture. To do this, regular training is required to ensure employees remain up to date and have safety developed as a consistent thought.

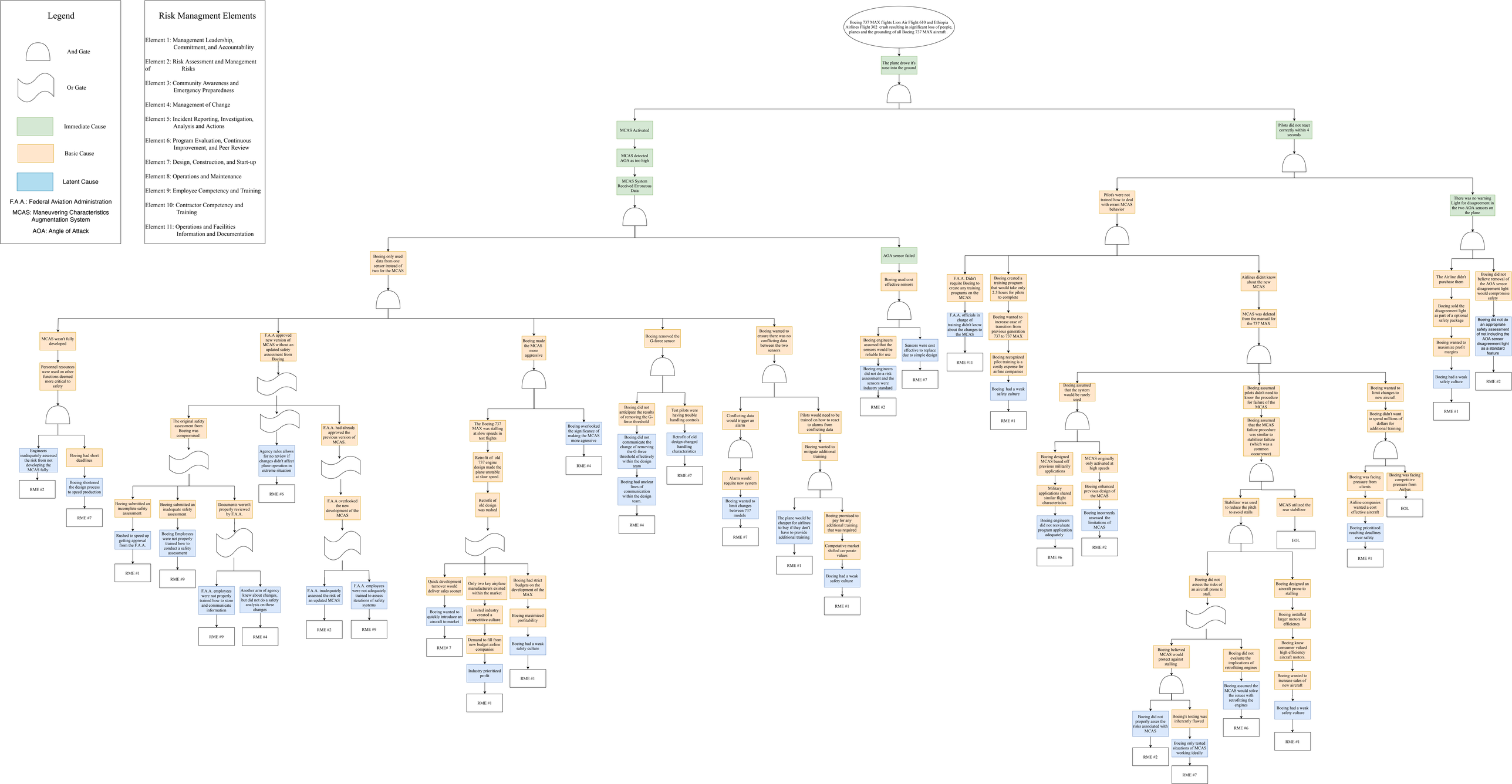
For our second recommendation, the immediate next step will be defining a clear set of procedures to be followed by employees for assessing the risk in the design and development phase of new aircraft. Adherence to these procedures will require the employees working on the design and development teams to be trained in these procedures, so establishing a training program to do exactly this will be of immediate priority for the management team. These first two steps will do much to advance the ultimate goal of setting a safety standard that is higher relative to the standards held by the industry at large.

Devising a clear set of guidelines for assessing the risk in new designs and training the design staff in implementing them will have the immediate and obvious benefit of removing the latent risk in those designs. Risk assessment is an essential skill for any design team in all fields of engineering and design, but it is especially relevant to the designing of new airplanes, considering the risks to people and assets involved. The cost to benefit ratio of implementing more stringent, and standardized risk assessment guidelines speaks for itself. Implementing these new risk assessment procedures would prevent a similar event to the 737 Max from happening to ABC Conglomerate. This is because if Boeing had better ways of assessing the risk of a design, they would have found the problems with the MCAS and the incidents could have been avoided.

The cost of not devising and implementing a standard set of risk assessment guidelines can easily be gauged by merely looking at the lack of commitment to risk assessment displayed by Boeing in designing the 737 Max. The fallout from their lack of integrity in this regard has so far cost them $19.1 billion in losses. These losses could have easily been avoided if Boeing had committed to a strong standardized set of risk assessment guidelines in the design stage of the 737 Max.

Furthermore, this risk assessment program would be implemented into departments specifically responsible for the design and development of the project. Therefore, it would be an utmost priority to ensure that documentation is in place to keep management in the know of projects development. This documentation as well as specified risk assessment procedures would ensure that all aspects of the design and startup remain with a strong emphasis on safety. Finally, this documentation and program would allow for management to follow up on any issues flagged in the initial stages of the project that are out of scope of allowable risk.

Therefore, through proper implementation of these recommendations would ensure that incidents such as the Boeing 737 Max 8 never take place again. With the rigorous workplace safety culture and risk assessment, we would ensure that safety is prioritized throughout the to be acted on in the design and development of commercial aircraft. We sincerely hope that these recommendations are implemented and prioritized by ABC Conglomerate in order to develop a safe work culture and as such, safe commercial aircrafts. Whereas, if safety takes a backseat, we run the catastrophic risk of another airline disaster which has plagued Boeing in the incidents analyzed by our firm. Therefore, we urge ABC Conglomerate to implement these recommendations in order to ensure the avoidance of a loss incident like that of Boeing. Whereas, the proper time and cost should be spent on these recommendations to ensure they are implemented properly.


Legend
And Gate
Or Gate
Immediate Cause
Basic Cause
Latent Cause
F.A.A.: Federal Aviation Administration
MCAS: Maneuvering Characteristics Augmentation System
AOA: Angle of Attack
Risk Managment Elements
Element 1: Management Leadership, Commitment, and Accountability
Element 2: Risk Assessment and Management of Risks
Element 3: Community Awareness and Emergency Preparedness
Element 4: Management of Change
Element 5: Incident Reporting, Investigation, Analysis and Actions
Element 6: Program Evaluation, Continuous Improvement, and Peer Review
Element 7: Design, Construction, and Start-up
Element 8: Operations and Maintenance
Element 9: Employee Competency and Training
Element 10: Contractor Competency and Training
Element 11: Operations and Facilities Information and Documentation
Boeing 737 MAX flights Lion Air Flight 610 and Ethiopia Airlines Flight 302 crash resulting in significant loss of people, planes and the grounding of all Boeing 737 MAX aircraft
The plane drove it's nose into the ground
MCAS Activated
MCAS detected AOA as too high
MCAS System Received Erroneous Data
Boeing only used data from one sensor instead of two for the MCAS
MCAS wasn't fully developed
Personnel resources were used on other functions deemed more critical to safety
Engineers inadequately assessed the risk from not developing the MCAS fully
RME #2
Boeing had short deadlines
Boeing shortened the design process to speed production
RME #7
F.A.A approved new version of MCAS without an updated safety assessment from Boeing
The original safety assessment from Boeing was compromised
Boeing submitted an incomplete safety assessment
Rushed to speed up getting approval from the F.A.A.
RME #1
Boeing submitted an inadequate safety assessment
Boeing Employees were not properly trained how to conduct a safety assessment
RME #9
Documents weren't properly reviewed by F.A.A.
F.A.A. employees were not properly trained how to store and communicate information
RME #9
Another arm of agency knew about changes, but did not do a safety analysis on these changes
RME #4
Agency rules allows for no review if changes didn't affect plane operation in extreme situation
RME #6
F.A.A. had already approved the previous version of MCAS
F.A.A overlooked the new development of the MCAS
F.A.A. inadequately assessed the risk of an updated MCAS
RME #2
F.A.A. employees were not adequately trained to assess iterations of safety systems
RME #9
Boeing made the MCAS more aggressive
The Boeing 737 MAX was stalling at slow speeds in test flights
Retrofit of old 737 engine design made the plane unstable at slow speed.
Retrofit of old design was rushed
Quick development turnover would deliver sales sooner
Boeing wanted to quickly introduce an aircraft to market
RME# 7
Only two key airplane manufacturers existed within the market
Limited industry created a competitive culture
Demand to fill from new budget airline companies
Industry prioritized profit
RME #1
Boeing had strict budgets on the development of the MAX
Boeing maximized profitability
Boeing had a weak safety culture
RME #1
Boeing overlooked the significance of making the MCAS more agressive
RME #4
Boeing removed the G-force sensor
Boeing did not anticipate the results of removing the G-force threshold
Boeing did not communicate the change of removing the G-force threshold effectively within the design team
Boeing had unclear lines of communication within the design team.
RME #4
Test pilots were having trouble handling controls
Retrofit of old design changed handling characteristics
RME #7
Boeing wanted to ensure there was no conflicting data between the two sensors
Conflicting data would trigger an alarm
Alarm would require new system
Boeing wanted to limit changes between 737 models
RME#7
Pilots would need to be trained on how to react to alarms from conflicting data
Boeing wanted to mitigate additional training
The plane would be cheaper for airlines to buy if they don't have to provide additional training
RME #1
Boeing promised to pay for any additional training that was required
Competative market shifted corporate values
Boeing had a weak safety culture
RME #1
AOA sensor failed
Boeing used cost effective sensors
Boeing engineers assumed that the sensors would be reliable for use
Boeing engineers did not do a risk assessment and the sensors were industry standard
RME #2
Sensors were cost effective to replace due to simple design
RME #7
Pilots did not react correctly within 4 seconds
Pilot's were not trained how to deal with errant MCAS behavior
F.A.A. Didn't require Boeing to create any training programs on the MCAS
F.A.A. officials in charge of training didn't know about the changes to the MCAS
RME #11
Boeing created a training program that would take only 2.5 hours for pilots to complete
Boeing wanted to increase ease of transition from previous generation 737 to 737 MAX
Boeing recognized pilot training is a costly expense for airline companies
Boeing had a weak safety culture
RME #1
Airlines didn't know about the new MCAS
MCAS was deleted from the manual for the 737 MAX
Boeing assumed that the system would be rarely used
Boeing designed MCAS based off previous militarily applications
Military applications shared similar flight characteristics
Boeing engineers did not reevaluate program application adequately
RME #6
MCAS originally only activated at high speeds
Boeing enhanced previous design of the MCAS
Boeing incorrectly assessed the limitations of MCAS
RME #2
Boeing assumed pilots didn't need to know the procedure for failure of the MCAS
Boeing assumed that the MCAS failure procedure was similar to stabilizer failure (which was a common occurrence)
Stabilizer was used to reduce the pitch to avoid stalls
Boeing did not assess the risks of an aircraft prone to stall.
Boeing believed MCAS would protect against stalling
Boeing did not properly asses the risks associated with MCAS
RME #2
Boeing's testing was inherently flawed
Boeing only tested situations of MCAS working ideally
RME #7
Boeing did not evaluate the implications of retrofitting engines
Boeing assumed the MCAS would solve the issues with retrofitting the engines
RME #6
MCAS utilized the rear stabilizer
EOL
Boeing designed an aircraft prone to stalling
Boeing installed larger motors for efficiency
Boeing knew consumer valued high efficiency aircraft motors.
Boeing wanted to increase sales of new aircraft
Boeing had a weak safety culture
RME #1
Boeing wanted to limit changes to new aircraft
Boeing didn't want to spend millions of dollars for additional training
Boeing was facing pressure from clients
Airline companies wanted a cost effective aircraft
Boeing prioritized reaching deadlines over safety
RME #1
Boeing was facing competitive pressure from Airbus.
EOL
There was no warning Light for disagreement in the two AOA sensors on the plane
The Airline didn't purchase them
Boeing sold the disagreement light as part of a optional safety package
Boeing wanted to maximize profit margins
Boeing had a weak safety culture
RME #1
Boeing did not believe removal of the AOA sensor disagreement light would compromise safety
Boeing did not do an appropriate safety assessment of not including the AOA sensor disagreement light as a standard feature
RME #2

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