BOEING 737' MAX: An analysis of the variables involved in aircraft failure.

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Abstract

This paper presents an analysis of the events involved with the fall of the Boeing 373 Max aircraft, trying to answer questions related to the reason for the aircraft malfunction.

Keywords

Case Study; Malfunction; Boeing; 373 Max.

1. Introduction

The Boeing 737 MAX plane crashed on march 10th of 2019, the disaster was preceded by another accident involving the same model as the American multinational company on October 29, 2018. These events raise questions about the safety and reliability of the model, where it was possible to observe several factors coinciding in both cases. Through exploratory research we try to analyze the facts involved in the tragedies and understand the chain of events that preceded the accidents.

In 2019 G1 news showed that in the first case, during a flight operated by the company Lion Air from Indonesia, in October, the autopilot system was questioned, pointed out by checking the aircraft's black box, showing that the automatic system the flight repeatedly put the aircraft in a diving position [with the tip down] due to a malfunction in the sensors.

Boeing chief executive Dennis Muilenburg said the company knows the chain of events that caused both disasters, in which a wrong activation of the anti-stall system (avoiding loss of aerodynamic lift) [MCAS] **is a common link between cases.** (G1, 2019)

2. The Boeing 737 and The Maneuvering Characteristics Enhancement System (MCAS)

According to analysis by Travis (2019), 737’ first appeared in 1967. It was very well accepted by airlines compamies for its simplicity, reliability and flexibility. Not to mention the fact that it could be flown by a crew of two. Over the years, the market and technological forces have pushed the 737’ to increasingly larger versions,

generating increased electronic and mechanical complexity. The most effective way to make an engine use less unit of energy produced is to make it bigger, which is why Boeing wanted to put the huge CFM International LEAP engine in its latest version of the 737' [the 737' MAX].

> Everything about Max's design and manufacturing was done to preserve the myth that it's just a 737'. Certifying it as a new plane would take years and millions of dollars. In fact, the pilot licensed to fly the 737 'in 1967 is still licensed to fly on all subsequent versions of the 737'. What's worse, these changes may be extensive enough to require not only that the FAA re-certify the 737', but that Boeing build an entirely new aircraft. Now we are talking about real money, both for the manufacturer and for the manufacturer's customers. (HEMMERDINGER, 2019)

However, the original 737 'had [by today's standards] relatively small engines, as the 737' MAX model grew and **was equipped with larger engines**, the **gap between the engines and the ground began to become dangerously limited**. (REBELLION RESEARCH, 2019)

The solution was to extend the engine up and right in front of the wing. However, this also meant that the thrust line of the engine changed. Now, when the pilots applied power to the engine, the aircraft would have **a significant propensity to lift** [lift its nose]. Slope and power changes are common in aircraft, however, there are limits to what safety regulators tolerate and what pilots can handle. (TRAVIS, 2019).

> Apparently, the 737' Max has risen a little too much for comfort in power application, as well as at already high angles of attack. It violated the oldest aviation canon and probably violated the US Federal Aviation Administration's certification criteria. But instead of going back to the drawing board and fixing the fuselage hardware [more on that below], Boeing relied on something called the Maneuvering Feature Enhancement System, or MCAS. (TRAVIS, 2019)

Boeing solved its hardware problem with a software application, the implementation of the MCAS system being much cheaper than extensively modifying the structure to accommodate the larger engines, thereby altering virtually the entire design, having to return to the aircraft concept and practically rebuild all engineering. (REBELLION RESEARCH, 2019)

> It all comes down to money, and in this case, MCAS was the way for Boeing and its customers to keep money flowing in the right direction. The need to insist that the 737 Max was no different in flight characteristics, not different in systems, from any other 737 was the key to the fungibility of the 737 Max fleet. This is probably also the reason why the documentation about the system MCAS was kept low. (TRAVIS, 2019)

3. Defective Software

Indonesian accident investigators found that the MCAS went into active mode when it shouldn't have, that a **failure of the angle of attack sensor** activated the anti-stall system, **causing the plane's nose to tilt to the ground**. (BBC, 2019).

The flight control software MCAS (Maneuvering Characteristics Increase System), whose objective is to improve the aircraft's behavior in non-normal operating conditions, since the positioning of the engines on the wings (higher and farther from the fuselage in relation to the old model), would have a **tendency to tilt upwards under certain conditions**, increasing the chances of aircraft stalling. (HEMMERDINGER, 2019)

Subsequent investigations revealed that the 737 MAX aircraft was able to **execute a bow** (alteration of the aircraft's nose angle) repeatedly for 10 seconds **under automatic control** due to the MCAS system error, which makes it difficult for the pilot to manually override the bow, using only the steering column. (REBELLION RESEARCH, 2019)

The MCAS is inside the 737 Speed Compensation System, which provides a speed adjustment to the stabilizer to generate an increasing force gradient as pilots retract the steering column, according to Boeing.

4. Training Deficit

The MCAS system is a unique system prepared exclusively to adapt the design changes of the aircraft in relation to the original 737' model, which makes its operability specific to the Boeing 737 MAX, thus making pilots' knowledge and training indispensable. to that environment.

However, at least five formal complaints about the Boeing 737 Max were recorded in the months leading up to the Ethiopian Airlines crash, several news portals have revealed. The complaints were sent anonymously to the Federal Aviation Administration database, in the documents, **problems with the Max 8 autopilot system** were highlighted (ZOGBI, 2019)

According to the Dallas Morning News, one of the pilots said the aircraft's flight manual, Boeing's latest model, was "inadequate and almost criminally insufficient". (ZOGBI, 2019) Zogbi (2019), still claims that other [pilots] said it was **inconceivable that they would continue to use these planes without proper training** or explanations about the difference between their system and those of previous versions of Boeing.

In the headline O Globo (2019), it shows that the planned solution was designed to detect the problem, and prevent it from recurring, also stated that Boeing officials, in response to union leaders, said **they did not believe that any additional training was needed** beyond to inform pilots how the software fix would work.

Pilot training is also the subject of discussion. To qualify to fly the plane, American Airlines pilots received **fifty-six minutes' training** on the iPad and about a dozen papers on the differences between Max and previous models of the plane, local unions reported. (O GLOBO, 2019)

5. Solution

Hemmerdinger (2019) MCAS updates announced by Boeing make the system rely on two AOA (angle of attack) sensors, and the computer monitors the sensor variation and disables it if the sensors differ by more than 5.5 °.

> The angle of attack is the angle between the wings and the air flow over the wings. Think about sticking your hand out of a car window on the road. If your hand is level, you have a low angle of attack; if your hand is released, you have a high angle of attack. When the angle of attack is large enough, the wing enters what is called an aerodynamic stall. You can feel the same thing with your hand through the window: as you rotate your hand, your arm wants to go higher and higher like a wing until you stop your hand, at which point your arm wants to fall on the car door. (TRAVIS, 2019)

The changes **prevent the MCAS from being activated repeatedly** and ensure that pilots can always override the MCAS stabilizer by pulling on the steering column, Boeing says.

Although Hemmerdinger (2019) points out that investigations are still ongoing, a text discloses that director of aerospace research and consultancy company Air [Michel Merluzeau], disclosed that the changes proposed by Boeing: "They will go a long way in preventing any problems with the system and its behavior, I'm generally satisfied with it [Boeing] presents."

Boeing has also **developed new training** to help pilots better understand MCAS. Pilots will need to complete the **thirty minut**e journey before returning to Max. (Boeing, 2019).

The company refuses to speculate when regulators can certify software and training updates, but observers suspect that grounding will increase as countries conduct independent reviews. Once certified, Boeing can distribute software updates for airlines in about a day, and update the aircraft takes an hour, according to the company.

In addition to the decisions made by the company to carry out appropriate training and to solve the MCAS system bug, Boeing could analyze the possibility of adapting the structure of the 737' to advanced technologies, producing a new model that efficiently manages the hardware and architecture changes of the aircraft. Technologies like IOT and the principles of Industry 4.0 can make it possible to effectively control the physical variables involved.

As mentioned, the 737' was initially produced in 1967 and despite undergoing changes it could not update itself so much that it had to produce new certifications, blocking the evolution of the model. Boeing would have to pay substantial upfront costs, but if well designed the new model could reduce the cost of launching modified versions of the aircraft if we expect the renewed model to have the same life time as the 737' (from 1967 to 2019), Boeing will have a reduction in its operating costs for about 40 years, in addition to guaranteeing the efficiency of its model, since after the disasters many airlines have suspended and are afraid to deal with Boeing 737 aircraft, way the company could regain its credibility.

6. Final Considerations

The causes of accidents with the Boeing 737 MAX are a combination of overconfidence in software-based decisions coupled with inadequate human training, so that pilots were not aware of the need to shut down the computer system if they failed on a single sensor. Pilots who assumed they could 100% trust the computer were doomed. It is an example of how software installations cannot be implemented without adequate training, both for the end user and those responsible for maintenance.

The company deliberately neglected the complexity of the changes in the original hardware structure of the model 737 ', adapting a software system to correct the variables involved in the physical environment, without providing adequate and extensive tests on the compensation of the aircraft's nose angle performed by the

application. This problem was mitigated by the lack of technical specifications and user training, which, as presented, it was limited to fifty-six minutes of flight simulation.

The facts presented demonstrate a lack of interest by the company in providing excellence in its products, due to the increased monetary and time costs involved in the production and training processes that the changes would accept it.

In news, G1 (2019) points out that Boeing engineers had identified a flaw in the alert software for pilots of the 737 MAX plane as early as 2017, several months before the Lion Air crash.

In 2017, in a review report, Boeing said: “The absence of a warning about AOA sensor discrepancies had no negative impact on the safety or operation of the aircraft, concluding that the existing functionality was acceptable until the relationship between the alert and the indicator could be undone in the next planned update of the system software. display”. Despite the claim to update the software, the changes were not made until the events involving the company's two aircrafts.

7. References

G1 (Brazil) (Org.). **Boeing stops production of the 737 MAX after model accidents:** Monthly production will be reduced from 52 planes to 42. The company's stock fell 4% on Friday. 2019. Available at: <https://g1.globo.com/economia/noticia/2019/04/05/boeing-corta-producao-do-737-max-apos-acidentes-com-modelo.ghtml> Accessed on: May 29th, 2019.

O GLOBO (Brasil) (Org.). The New York Times. **Boeing promised to update software for the 737 Max in 2018. Failure could be behind the accident:** A promise was made in a meeting with pilots after the first plane crash in October last year. 2019. Available at: <https://oglobo.globo.com/economia/boeing-prometeu-atualizarsoftware-do-737-max-em-2018-falha-pode-estar-por-tras-do- acidente-23524461> . Accessed on: May 29th, 2019.

BOEING (Usa). **737 MAX:** New 737 MAX Family from Boeing - Efficiency, Reliability, Attractive for Passengers. 2019. Available at: <https://www.boeing.com.br/produtos-e-servicos/avioes-comerciais/737-max.page>. Accessed on: May 29th, 2019.

ZOGBI, Paula (Brazil). **Pilots of the Boeing 737 Max 8 complained about the plane for months before the Ethiopian accident:** ç At least five formal complaints cited difficulties with the autopilot system. 2019. Available at: <https://www.infomoney.com.br/negocios/grandes-empresas/noticia/7979616/pilotosdo-boeing-737-max-8-reclamaram-do-aviao-por-meses-antes-do-acidente-daethiopian>. Accessed on: May 29th, 2019.

ISTOÉ (Brazil) (Org.). **Boeing reveals that 737 MAX suffered from a second problem in its software:** In new analyzes, Boeing identified a second problem in the control software of the 737 MAX, which has already been solved. 2019. Available at: <https://www.istoedinheiro.com.br/boeing-revela-que-737-max-sofreu-com-umsegundo-problemaem-seu-software/>. Accessed on: May 29th, 2019.

BBC (Brazil) (Org.). **Boeing 737 MAX 8: what is MCAS, the software at the heart of the Ethiopian Airlines tragedy:** In less than five months, two Boeing 737 MAX 8 planes had accidents that resulted in the death of everyone on board: a flight in October from Indonesia Lion Air and another from Ethiopian Airlines on Sunday .. 2019. Available at: j <https://www.bbc.com/portuguese/internacional-47564737>. Accessed on: May 29th, 2019.

TRAVIS, Gregory. **How the Boeing 737 Max Disaster Looks to a Software Developer:** Design shortcuts meant to make a new plane seem like an old, familiar one are to blame. 2019. Available at: <https://spectrum.ieee.org/aerospace/aviation/howthe-boeing-737-max-disaster-looks-to-a-software-developer>. Accessed on: May 29th, 2019.

REBELLION RESEARCH (Org.). **An Analysis Of The Boeing 737 MAX Accidents.** 2019. Available at: <https://www.rebellionresearch.com/blog/an-analysis-of-theboeing-737-max-accidents>. Accessed on: 29 May 2019.

HEMMERDINGER, jon (Boston). Boeing finally takes its 737 Max message public. 2019. Available at: <https://www.flightglobal.com/news/articles/analysis-boeingfinally-takes-its-737-max-message-p-456991/>. Accessed on: May 29th, 2019.

G1 (Brazil) (Org.). **Boeing knew of a 737 MAX failure a year before the tragedy:** The company did not inform airlines and authorities about a problem with the pilot alert system, detected by internal inspection as early as 2017, well before the disasters in Indonesia and Ethiopia. 2019. Available at: <https://g1.globo.com/mundo/noticia/2019/05/06/boeing-sabia-de-falha-no-737-maxum-ano-antes-de-tragedia.ghtml>. Accessed on: May 29th, 2019.

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