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A Study on the Crash of Boeing 737 MAX

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Abstract: ***Air travel is one of the safest (0.18 fatal accidents per million flights) and fastest mode of transportation out of all the other modes of transportation. The aviation industry has generated over 838 billion USD in revenue globally (2019, Statistica). Despite its huge contribution to the global economy, the aviation industry is majorly dominated by two key aircraft manufacturers, Boeing (American) with its 7-series of jets and Airbus (European) with its A-series of jets. To compete in the market, Boeing launched 737 MAX series in 2011, which promises to be more fuel-efficient compared to its previous model (737 NG) and competitors (A320). However, within a few years of its operation, two 737 MAX fatal crashes occurred in October, 2018 and March, 2019, respectively, killing all passengers and crew onboard (Total = 346). This raised a serious question as to how safe is 737 MAX for further operation. This research paper aims to review the facts, analyze critical decisions, study their impact on the results and to discuss the best practices on the subject under review.***

Keywords: Project Management Failure, Aviation, Boeing 737 MAX groundings, Air crash, Aircraft manufacturers

1. Introduction

The Boeing Company was founded in Seattle, Washington on 15th July, 1916 by William E Boeing. The company designs, manufactures and sells airplanes, rotorcrafts, rockets, satellites, telecommunication equipment and missiles worldwide (Boeing, 2018). Boeing generated about 76.6 million USD in revenue in 2019 compared to 101 million USD in 2018. Every industry strives for improved performances, cost reduction, higher profit margins and to have an edge over their competitors. Aviation industry is no different. In fact, aviation industry is one of the most volatile industries in the world, as it functions on various parameters such as oil prices, demand and supply of crew and pilots (huge shortage, huge demand), taxes, government policies many more parameters. To stay ahead of its competitors i.e., Airbus A320 series (A320 NEO), Boeing introduced 737 MAX series in 2011. The inaugural flight occurred on January 29, 2016 (Aviation Safety Database) and 737 MAX was certified by the Federal Aviation Administration (FAA) in March, 2017 (Boeing, 2017). 737 MAX was actually one of the fastest selling planes in the company's history, reaching more than 5000 orders from 100 customers worldwide (Boeing, 2020, Orders and Deliveries). 737 MAX 8, the most popular version of 737 MAX series, made its first flight on May 22, 2017 with Malaysia's Malindo Air (CNET.com). 737 MAX experienced catastrophic crashes in 2018 (Lion Air Flight 610) (Al Jazeera. 29 October 2018) and 2019 (Ethiopian Air Flight 302) (BBC News, 10 March 2019). Similarities were observed between two crashes by aviation experts. After two fatal crashes of 737 MAX, FAA officially ordered to ground all 737 MAX in United States airspace (Reuters, 2019), which is considered to be a huge downfall for Boeing as well as aviation industry as a whole.

2. Research Methodology and Limitations

The current research is a qualitative, descriptive based single case study, with Boeing 737 MAX being used as a unit of analysis. Secondary data has been acquired through literature review and archival research. This research is limited to Boeing 737 MAX only and other aircraft manufacturers and aircrafts are not taken into consideration for research purposes. As aforementioned, the purpose of this research paper is to investigate the fatal crashes of Boeing 737 MAX.

3. Flight Analysis

3.1 Lion Air Flight 610

On 29 October, 2018, Lion Air Flight 610 was preparing for its departure from Soekarno-Hatta International Airport in Jakarta heading to Depati Amir Airport in Pangkal, Pinang. It was noticed by the pilots during "before take-off checklist" that the ADI (Automatic Direction Finder) of the plane was not working properly. It is clear from the recorder that the captain was the Pilot-In-Command and Co-Pilot was the one monitoring the flight. At 11:15 UTC, pilots attempted to set the pitch trim of the plane, which is a standard operating procedure before take-off. Pitch trim helps the pilots from exerting a constant pressure on the control column. For example, pilot may trim the plane to nose up before take-off, so when airborne, the pilots won't have to exert a constant pressure on the control column. After the flight received a green signal from the tower for take-off, one of the pilots engaged TOGA (Take-off/Go Around) and the engines were on their maximum power. A few seconds after take-off, the left stick shaker got activated, which is a warning to the pilots that their plane is about to stall. After few seconds in the air, "Take-off Configuration" warning was given to the pilots by the system, which indicate that the plane was not properly configured for take-off. At 11:22 UTC, co-pilot noticed that the primary flight display (PFD) displayed different airspeeds to co-pilot and captain. The PFD displayed 173 knots to co-pilot and 164 knots to the captain. Both the pilots in cockpit were in speed disagreement. After some time, another problem popped up. Both of them were now in altitude disagreement by 230 feet. The tower asked the pilots to climb to 27000 feet, which was the scheduled cruising altitude for the flight. As the pilots were trying to figure out a solution, they asked the tower to hold on to 5000 feet. At 5000 feet, the pilots retracted the flaps and at this point, the MCAS (Maneuvering Characteristics Augmentation System) system came out alive. MCAS is a

flight control software that adjusts the horizontal stabilizer trim to push the nose downwards, when the aircraft is operating in manual flight, with flaps up (Boeing Statement on Lion Air Flight 610 Preliminary Report, Nov, 2018). MCAS takes input from one of the two angle of attack (AOA) sensors, making it susceptible to single point of failure. The MCAS got automatically activated for 10 seconds ON and 5 seconds OFF, which made it difficult for pilots to figure out as to why the plane's nose was pitching downwards automatically. The plane was losing 600 feet of altitude within seconds. The captain asked the ATC (Air Traffic Controller) to return back to the airport as they could not figure out a solution to problem and was struggling to maintain a stable cruising altitude. While returning to the airport, the pilot asked for 3000 feet altitude to be locked, as they lost control of the actual altitude and wanted to refrain from causing a trouble to other aircrafts in the airspace. While returning, pilots mentioned that most of the systems and equipment were not working properly. MCAS got activated every 10 seconds and switched OFF for 5 seconds which resulted in loss of altitude with nose pitched downwards for 10 seconds and pilots tried to regain the altitude in the remaining 5 seconds. This cycle kept on repeating itself and as it was happening rapidly, without prior information to pilots about MCAS, pilots were not able to understand the reason behind sudden loss of altitude of the plane. The plane was experiencing a steep descent for 10 seconds (when MCAS is ON). A sudden shift in altitude and airspeed can be observed from the graph given below. Pilots had to adjust the pitch trim every few seconds. It was a nightmare in the cockpit as the pilots did not even had sufficient time to consult the Boeing checklist. At 11:32 UTC, the Lion Air Flight 610 crashed in the Jawa Ocean with 40-degree steep nose downwards with system repeatedly announcing "PULL UP TERRAIN PULL UP TERRAIN" killing all 189 crew and passengers onboard. (Indonesian National Transport Safety Committee)

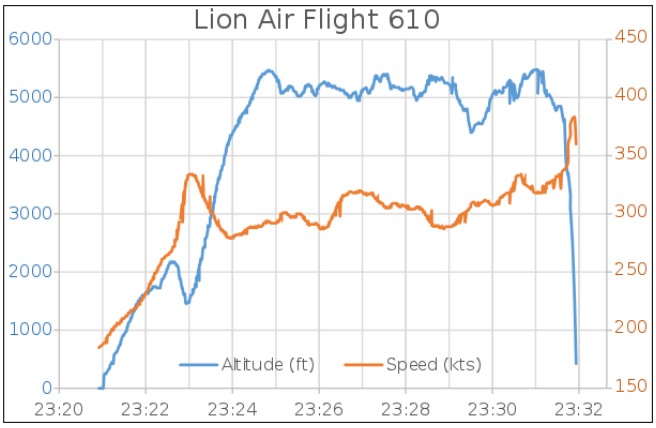

Figure 1: Altitude and speed of Lion Air Flight 610
Source: Flightradar24

3.2 Ethiopian Airlines Flight 302

On 10 March, 2019, Ethiopian Airlines Flight 302 was all set to depart from Addis Ababa, Bole International Airport in Ethiopia to Jomo Kenyatta International Airport in Nairobi, Kenya. The Pilot-In-Command for the flight was the captain with 8,122 hours of flying experience on 737 series along with first officer with 361 hours of flying experience on 737 series. The plane took-off at 8:38 without any difficulties. Shortly after the lift-off, the first officer noticed that the captain's angle of attack (AOA) sensor was displaying erroneous readings. Within few seconds of the plane being airborne, the left stick shaker got activated and the values shown by PFD (Primary flight display) of captain was different from that of the first officer. The airspeed, altitude and flight director pitch bar values were different on both the sides. The captain attempts to engage the auto-pilot twice, but this resulted in two auto-pilot warnings. At about 1000 feet, the left auto-pilot was engaged, pitch trim position was reduced to 4.6 units. At 8:39:45, the flaps were completely retracted by the first officer. At 8:39:57, the captain asked the first officer to inform ATC that they were facing flight control issues. As the captain was not able to have a control over the systems of the aircraft, hence to gain control over situation, the captain disengaged the auto-pilot. Shortly after the auto-pilot disengagement, the pitch trim moved from 4.6 to 2.1 units and an automatic Aircraft Nose Down (AND) got activated for 9 seconds, which caused the plane to tilt downwards. To counteract the tilt, the flight crew moved the control column manually, to re-establish a positive climb. Approximately 5 seconds after the end of the stabilizer motion, a second instance of automatic AND stabilizer trim occurred, pushing the trim down further to 0.4 units. The ground proximity sensors warned out the pilots as the altitude of the plane dropped suddenly. Both pilots used trim button on their controls to counteract the automatic change. The pilots decided to disable the "Stab Trim". This means that the stabilizer can no longer automatically lower the pitch and the crew will no longer be able to adjust stabilizer manually. The only option left is to rotate the trim wheel to adjust the pitch trim. At 8:40:41, a third instance of AND automatic trim command occurred without any corresponding motion of the stabilizer. As the pilots were busy understanding the altitude issue, the pilots forgot to retract the throttle. The engines were running on maximum power. The airspeed of the plane was more than 340 knots, which indicated an overspeed warning. In an attempt to stabilize the plane's altitude, the first officer tried to adjust the pitch by rotating the trim wheel manually. The captain asked the first officer to request the vectors to return back to the airport, as they were completely losing control over the plane. With sudden ups and downs in the altitude of the plane, even landing the aircraft safely to the airport would have been a challenge. At 8:43:20, a fourth instance of AND automatic trim command occurred, which pulled the plane's nose further down. With plane's nose down, engines running on full power, the plane crashed with a speed of more than 700 miles per hour, killing all 157 crew and passengers onboard. The aircraft disappeared from the radar screens at 8:44, 6 minutes after the take-off.

3.3 Similarities between Ethiopian Airlines and Lion Air Crashes

- Both the planes crashed shortly after take-off (Within 15 minutes of take-off).
- Both the planes experienced a sudden loss of altitude, with the nose of the plane pitching downwards automatically.
- The readings shown by Primary Flight Displays were different in both the cases. Both, the captain and first

officer had a disagreement on the values of airspeed and altitude.

- The MCAS got automatically activated after the retraction of flaps, in both the cases.
- Both the planes had to experience a bumpy ride, as the altitude of the plane was changing very frequently (in time intervals of 10 seconds).
- Pilots in both the planes struggled to understand the MCAS software.
- In both the cases, the left stick shaker got activated, which implies a stall position of the aircraft.

4. Background

Aviation industry has always struggled to maintain steady profit margins due to change in oil price. Cost reduction is one of the lucrative options for airlines, in an attempt to maintain steady profit margins. Airlines operate on something called "seat cost mile", which is a terminology used in the industry to describe the cost of one seat from point A to point B. One of the ways to get an optimum value on seat cost mile is to have engines with better fuel efficiency. As oil price is a factor that influences the airlines directly, having engines that could use lesser amount of fuel and at the same time cover equal or even larger distances, will be advantageous for airlines. The modern aircrafts used by the competitor of Boeing is Airbus A320 NEO. Airbus A320 NEO is efficient as compared to the older models of 737 series i.e., 737 NG. In order to compete in the market, Boeing released 737 MAX. 737 MAX turned out to be 14% more efficient than its older version, 737 NG. A comparison between Boeing 737 MAX and Airbus A320 Neo is shown in the table below.

Table 1: Comparison between 737 MAX 8 and A320 NEO

	Boeing 737 MAX 8	*Airbus A320 NEO*
Cost	USD 121.6 Million	USD 110.6 Million
Range	3550 Nautical Miles	3500 Nautical Miles
Maximum Capacity	210	195
Thrust Per Engines	125 kN	121 kN
Maximum Take-off Weight	82,191 kgs	78,000 kgs
Cruise Speed	M0.79	M0.82

According to Carnot efficiency and Laws of Thermodynamics, larger the size of engines, better will be the efficiency. To deal with larger size of engines and to have better ground clearance, Boeing tried to change the mounting point of the engines, placing them forward and much higher on the wings. The engine's position on the wings forced the nose of the plane to go up, creating a stall possibility (if the angle of attack is too high). To prevent the plane from going into stall position, Boeing installed MCAS software, which automatically turns ON (for 10 seconds) and OFF (for 5 seconds). The purpose of MCAS is to bring the nose of the plane downwards as a counteract to the automatic lift in the nose of the plane in upward direction (due to placement of the engines) so as to nullify the whole effect and to prevent the plane from going into stall position.

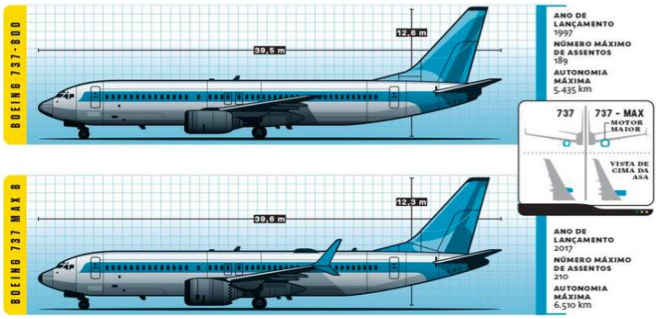

Figure 2: Altitude and speed of Lion Air Flight 610
Source: Boeing, 2020

5. Results

- Crash of two 737 MAX had a severe impact on Boeing's reputation as well as business side of it.
- Boeing had to deal with aviation authorities (FAA) to bring the planes back to the market.
- The company had to face lawsuit against the 346 passengers that died in the crash.
- The sale of aircrafts other than 737 MAX was impacted, as the company had taken a huge hit in terms of their reputation.
- USD 4.9 Billion order from Indonesian airlines, to deliver 50 737 MAX was canceled.
- 5000 737 MAX aircrafts worldwide in jeopardy.
- Boeing reported a loss of USD 636 million due to grounding all 737 MAX planes. (Bilotkach, V.,2019)
- An upgradation to MCAS software, training to pilots and redesign of the 737 MAX body is expected.

6. Discussion and Further Research

The two biggest aircraft manufacturers in the world are Airbus and Boeing and they have a fierce rivalry. If one of the manufacturers comes up with a better option for their customers in the market, the other will definitely suffer. It all started back in 2010, when Airbus announced that they'll be releasing a new version of A320 i.e., A320 NEO (New Engine Option) with a new geared turbo-fan engine which was expected to provide better fuel economy (roughly by 15%) and had much larger engine than A320. This was a problem for Boeing. Their obvious move was to upgrade the engine of their single isle plane, i.e., 737. But there was another problem for Boeing. The ground clearance of Boeing 737 is lesser as compared to A320, hence in order to place a larger engine, Boeing had to mount their engines up and further closer to the wings. Boeing made these changes on their previous designs of 737 and did not felt a need to change the design of the aircraft. Placing the engines on a different position but with older design of 737, raised the angle of attack (AOA) of the plane. To deal with higher angle of attack and to prevent the plane from moving into a stall position, Boeing installed MCAS software, that automatically lowers down the nose of the plane depending upon the input from the sensors. When 737 MAX was under development, regulators determined that pilots could fly the planes without re-training because they were essentially the same as previous generations. This saved airlines a lot of money by neglecting the extra training. Pilots at United

Airlines put together a 13-page guide to 737 MAX, which did not mention MCAS. According to investigators, the approval process for Boeing 737 MAX was rushed and possibly compromised. It was also found that FAA managers pushed the agency's engineers to delegate safety assessments to Boeing in order to speedily approve the resulting analysis. "There wasn't a complete and proper review of document. Reviews was rushed to reach certain certification dates" former FAA engineer said (The Associated Press,2020). The fact that MCAS was turned OFF and the plane was not brought under control does raise questions about the emergency procedures provided by Boeing. Before the first crash of 737 MAX, there were several complaints reported from the pilots regarding the instability of the aircraft. "The aircraft was used on a flight from Ngurah Rai International Airport, Bali, to Soekarno-Hatta International Airport, Jakarta the night before the crash. Detailed reports from that flight revealed that the aircraft had suffered a serious incident, which left many passengers traumatized. Passengers in the cabin reported heavy shaking and a smell of burnt rubber inside the cabin. At one point, the aircraft had dropped more than 61 m (200 ft) in a few seconds" (MSN. Retrieved 7 November 2018). "The seat belt sign was never turned off from take-off to landing. A recording of air traffic control communications indicated that the pilot had called a "pan-pan" (Pan-Pan: International standard urgency signal) (Kami, Indah Mutiara, 2018). Chesley Sullenberger, who successfully ditched US Airways 1549 in the Hudson River, did flight simulator replication of flight 302 and commented "Even knowing what was going to happen, I could see how crews would have run out of time and altitude before they could have solved the problems (Bloomberg- "Fight for survival..", July, 2019). Boeing 737 MAX is a sure shot result of project management failure, which resulted in loss of 346 innocent lives, a huge loss to Boeing and other airlines associated with Boeing. Had Boeing not rushed for the project completion, tested the planes several times, instructed the pilots for a few hours of simulator training instead of learning about MCAS on iPad, 346 lives could have been saved. One can outsource the services, but not the trust. Any further research is appreciated.

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