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The Adverse Effects of Implementation of the Novel Systems in the Aviation Industry in Pursuit of Maneuvering Characteristics Augmentation System (MCAS)

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ABSTRACT: In the aviation history, there are many remarkable accidents. But rare of them are close to each other with the same types of aircraft. Basically, incidents are categorized as the Controlled Flight into the Terrain (CFIT) accidents and Loss-of-Control (LOC) in-flight accidents. For preventing these accidents, the training system and certification methodology are designed meticulously. Recovering from emergencies is the most important part of the Air Transport Pilot License (ATPL) and during their tough training period, the cadets are trained primarily against adverse situations. However, there are some iconic fatal accidents that we have information regarding pilots' unawareness of the adverse situation. From crash investigation reports, it might be thought that these accidents are originated from Maneuvering Characteristics Augmentation System (MCAS). MCAS is a novel technology implementation for Boeing 737 Max Aircrafts. But MCAS is just a technical issue. The conventional approach for type certification carries potential risks for novel technologies. In this study, an investigation has been made through the near term fatal accidents which are originated by MCAS. It has been claimed by the author, who is a pilot, before assuming the technical implementations; the certification process should be put under the magnifier.

KEYWORDS: Aviation Industry, Aircraft Accidents, Airworthiness, Type Certification, Angle-of-Attack

I. INTRODUCTION

There are some organizations in the aviation industry that are responsible for regulating the aerial activities. Generally, these organizations are, ICAO (International Civil Aviation Organization) which is affiliated to the United Nations (UN) and it is also one of the largest and most successful organizations of the United Nations (UN) [1]. The other main organizations are, IATA (International Air Transport Association), and EASA (European Aviation Safety Agency) in the European Union, FAA (Federal Aviation Administration) in the USA, and Airports Council International (ACI).

These organizations release reports periodically for increasing flight safety and enlightening the people who work in the aviation industry. ICAO states that for the years between 2016-2030, the air traffic has doubled in every 15 years since 1977 and will continue to do so [2]. For supporting this forecasting, ACI states that 10.9 billion people will fly internationally and 11.3 billion will fly domestically between 2017-2040 [3]. IATA also provides very similar reports as it is shown in Table 1.

Table 1. Global Air Traffic 2006-2020 [4].

Year	Annual Growth of Passenger Demand (%)
2006	6,9
2007	7,9
2008	2,4
2009	-1,2
2010	8

2011	6,3
2012	5,3
2013	5,7
2014	6
2015	7,4
2016	7,4
2017	8,1
2018	7,4
2019	4,2
2020	4,1

In IATA's 2019 Annual Review report except for the 2008-2009 global recessions, the global air traffic is in the trend of increase. Although there's a second recession in the aviation industry because of Covid-19, in accordance with the IATA's Air Travel Expectation, at the end of the 2020 and through the Q3 and Q4 in 2021 the air traffic will increase [5]. It is noteworthy that ICAO's, ACI's and IATA's reports are compatible with each other.

In the aviaion industry, the passenger propels the airliners for more frequent flying. It is clear that this propelling is acceptable especially for low-cost flights. And the airliners propel the aircraft manufacturers for building more cost-effective. Conclusionally with providing more aircraft into the industry, passengers have more low-cost flying opportunities. As it is shown in Figure 1, it is a three-cornered close loop.

Figure 1. Three-Cornered Close Loop amongst Customer, Airliners and Aircraft Manufacturers

Conclusionally, it can be easily claimed that implementing the novel technologies in the manufacturing lines is a catalyzer for ramping up the production rate. Because the novel technologies generally decrease the price and increase the revenue. The European Commission's Digital Transformation Monitor, Industry 4.0 in Aeronautics: IoT Applications" report approves it. In accordance with this report, in the aviation industry, the expected impact of digitalization is a reduction of - 3.7% in costs and an increase of + 2.7% in revenue annually [6]. When the size of the budget is considered it is kind of a must for the companies adopting novel technologies. That's why the aviation industry was the earliest adopter of carbon fiber materials, and it was the first to integrate Computer-Aided Design (CAD) & Computer-Aided Manufacturing (CAM) into its design process [7].

Boeing and Airbus are known as the two major aircraft manufacturers as the key role players at worldwide. As it was mentioned previously, the technological development is the leverage for carrying out the recent and potential of air traffic. For example, Boeing declares that the company ramped up the production rate for B-737 from 52 to 57 with the new orders from airline companies in her 2018, Q2 report [8]. At worldwide, Boeing and Airbus are known as the two major aircraft manufacturers. Airbus also increases her product rate with the power of new technologies. These two major role-players have built highly successful commercial aircraft models, including the A320 and B-737 aircraft, which were often named as pair of the best-selling air vehicles at the global level [9]. Their annual orders are provided in Table 2. It is spotting that, for Boeing, becoming under scrutiny for falling short of safety standards many orders have been canceled. Boeing's sharp decline in 2019, after the B-737 Max issue

Table 2. Number of gross orders for Airbus and Boeing aircraft between 2006 and 2019 [10]

Year	Airbus Aircraft Orders	Boeing Aircraft Orders
2006	824	1050
2007	1458	1423
2008	900	669
2009	310	263
2010	644	625
2011	1608	901
2012	914	1339
2013	1619	1531
2014	1796	1550
2015	1190	878
2016	949	848
2017	1129	1053
2018	831	1090
2019	1131	246
2020	TBD	TBD

The number of manufacturing capacity is remarkable. As discussed previously this capacity is propelled by new technologies. On the other hand, ICAO warns in her global aviation safety plan 2020-2022 that the new technology and new concepts may impact flight safety negatively unless they are not matured enough [11]. It is a very important point that the technology which is used for preventing the accidents caused by human error can lead to a new, perhaps unpredictable, and covered and possibly even more deadly dangerous pattern of accidents oriented or intensified by the novel technology implementation [12]. For figuring out the killing-effect of a newly implemented system to an aircraft, checking only the technical issues cannot be enough. A deep consideration must be channeled to the certification process. For meeting the requirements of customers, engineers might have found some technical solutions and intended to implement it to the aircraft but the airworthiness body should use its influence against any activity if that solution has an adverse effect over flight safety.

As IATA states, there’s a natural relation between the flight hours and accident rates [13]. It should be noticed that the accidents are evaluated with the million flight hours. In the year of 2018, the all accident rate (Accidents per 1 million flights) was 1.35. In other words, one accident occurred for every 740,740 flights. For the previous 5 years, the all accident rate was 1,79 meaningly one accident for every 558,659 flights. Between 2014 and 2018 the most common accident category was runway/taxiway excursion, followed by gear-up landing/gear collapse, with hard landings the third most common category [14].

II. MATERIAL

How would a novel technology harm flight safety albeit it is designed for improving the safety precautions? For finding the answer of this question some near term accident will enlighten us: On October 29, 2018, a B-737 Max aircraft that operated by Indonesian Lion Air Airlines with call code PK-LQP, crashed into the Java Sea, at 23:31:53 UTC. All 189 people on board perished and the aircraft was destroyed. The flight was scheduled from Jakarta Soekarno/Hatta International Airport to Pangkal Pinang Depati Amir airport with IATA flight number 610 and it lasted only about 13 minutes [15]. Less than five months later, on March 10, 2019, again a B-737 Max operated by Ethiopian Airlines with a call code ET-AVJ, crashed into the near the town of Bishoftu at 05:44 UTC. In this second accident, all 157 people on board perished and the aircraft was destroyed. The flight was scheduled from Addis Ababa Bole International Airport to Kenya Nairobi Jomo Kenyatta Airport with IATA flight number 302. The flight lasted just about 6 minutes [16]. Both accidents caused a total loss of 346 lives.

As it was mentioned earlier ratio of accidents over flight hours has been decreasing with the help of technological development. It can be easily stated that encountering these two crashes within five months was fairly unusual. So far for PK-LQP final and ET-AVJ interim investigation reports were released. The similarities between the two above mentioned accidents are spotting. It has been understood from Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR) that in both accidents, the cockpit crew informed the Air Traffic Controller (ATC) that they had flight control, altitude and airspeed emergencies. At that point this question should be asked; what would be the reason that the pilots were declaring emergencies with these almost brand-new aircraft? For answering this question, the novel systems of these aircraft should be inspected.

2.1. The Relation Between MCAS and Angle of Attack (AoA) Sensors

The CVR and FDR data directly indicate that the MCAS might have been the core-reason of the incidents. The brand new B-737 Max aircraft were flying with the new type of engines in the name of fuel consumption efficiency. Boeing's competitor company Airbus had already jumped up to more fuel-efficient and powerful engines with the type of A320 Neo [17]. Boeing had to make a similar improvement for being not to be fallen behind its competitor. So Boeing's engineers made a similar study for the installation of more fuel-efficient and powerful engines. The new type engines were larger hence this geometry forced the Boeing's engineers to move the engines further forward and higher up on the wing compared to the engines' position to its predecessor B-737 NG [18]. The relocation of the engine brought the risk of the unintended vertical vector changing in the positive direction, which means nose-up especially during the climb after takeoff, therefore the aircraft could stall.

As it is shown in Figure 3, the AoA is the angle between the wing's chord line and the relative and since all aerodynamic forces are functions of AoA, it is one of the critical parameters in a fixed-wing aircraft [19].

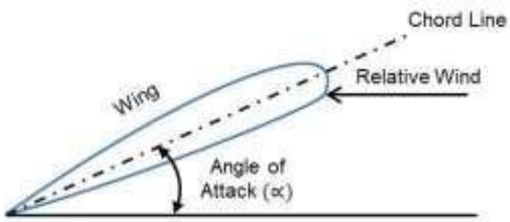

Figure 3. Graphical Description of AoA [19]

As a result, as the Center of Gravity (cg) of the B-737 Max was moved forward as a conclusion the nose-down moment increased. MCAS was implemented to B-737 Max for preventing the vertical instability in particular flight conditions induced by the aircraft's larger engines [20].

Eventually, a stall can be defined as is an unwanted phenomenon that occurs when the lift is lost and angle of attack (AoA) can be defined as the angle between the oncoming air or relative wind and a reference line on the wing. The speed of stall is not a fixed value for all flight maneuvers but a particular aircraft always stalls at the same AoA independent from airspeed, weight or density altitude [21]. In accordance with FAA-H-8083-3B Airplane Flying Handbook, the stalls occur when the AoA reaches to the value between 16° and 20° depending on the aircraft's design [22]. As it is depicted in Figure 4, to prevent an unintended stall, pushing the nose down is essential for regaining the speed [23].

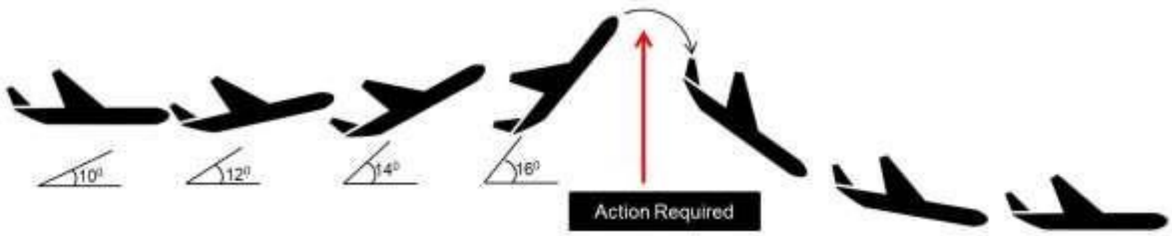

Figure 4. For Stall Recovery Nose-Down Action [22, 23].

If a technology is not designed from a human-centered philosophy it doesn't decrease the level of human errors nor minimize the impacts. Humans may make mistakes. From this perspective, while building up a novel technology machine-centered errs should be considered as much as human-centered errors. The training is a method for decreasing the human-centered errors. The pilots should have been more suited to trainings [24]. But, the MCAS is designed with a machine-centered philosophy hence when it is activated the pilots are ineffective. The B-737 Max pilots had no idea what they were up against. Designing a system that a pilot has no control or know of is cannot be acceptable since a skillful pilot is more reliable than Artificial Intelligence (AI) oriented MCAS [25].

On a modern commercial aircraft, there are many computers that communicate with each other but the pilot doesn't need to know about this interaction unless any failure occurrences.

There are two AoA sensors on the B-737 Max's left and right sides at the nose zone. When the AoA senses the aircraft's nose increases in the vertical vector and approached to the limit value, then activates the MCAS. The MCAS swivels the horizontal stabilizer for moving the nose down automatically. But as Porter Donald J., et al 2020 states, being fed from a single AoA can be accepted as lack of flight safety [26]. For AoA, MCAS triggering architecture, corrected and verified signals from both sensors should have been used. This is also underlined by FAA Airworthiness Directive (AD) which was released after B-373 Max accidents [27].

In accordance with the crash investigation reports and the other PK-LQP and ET-AVJ accidents-documents, it is clear that MCAS incapacitated the cockpit crew's abilities to recover the aircraft's nose-down orders. For figuring out whether pilots had followed the correct recovery procedure, the accidents were discussed online with more experienced airliner pilots since the author of this manuscript has lesser flight hours comparing with commercial pilots. A similar scenario was the topic of the discussion for reaching an accurate judgment. The pilots who are flying the A320, A321, B-777 have common judgments that, when the aircraft assumes the control of the flight, a human can't regain it. Undoubtedly, a human's muscle cannot beat the force of a commercial aircraft.

III. DISCUSSION

From aircraft crash investigation reports it is being understood that in PK-LQP and ET-AVJ accidents pilots were unaware of the root cause of the nose-down action of auto-pilot. As it is shown in Figure 5, the MCAS was pushing the nose-down for gaining speed and stall recovery while pilots were trying to nose-up for avoiding from dangerously approaching the ground.

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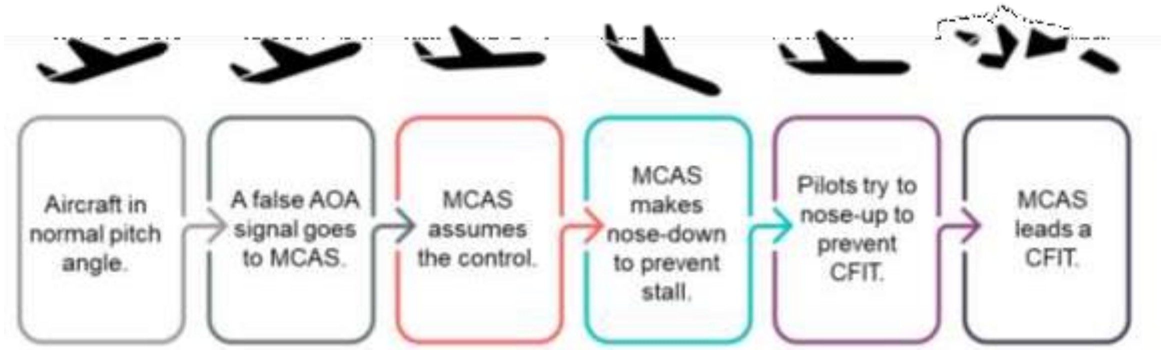

Figure 5. The Steps of the MCAS-CFIT [18].

When PK-LQP and ET-AVJ aircrafts had crashed, both sides; human-pilot and auto-pilot were doing their designated jobs for recovering the aircraft. In fact a false AOA signal confused the MCAS and led the aircraft into a CFIT.

It has been found out that the pilots were unaware the MCAS was still active even the pilots were thinking that they were controlling the aircraft. The pilots were trained during their initial training which was detailly organized by the U.S. Department of Transportation and dictated by Stall and Spin Awareness Training advisory circular [28].

It was a promising issue that for an upgrading pilot, no face to face retraining was needed neither the simulator training for a conversion pilot [29]. In other words, B-737 Max was an easy aircraft, which pilots could fly with a small “fill-in-the-gap" training. Eventually, one hour of tablet-based training was given to pilots in the fleets. However, two fatal accidents showed that; MCAS should have been considered as a vital difference from B-737 NG to B-737 Max during a strong certification process the pilots should have been trained more densely. In some studies, researchers are offering systematic simulator training models for preparing the pilots for the MCAS switch-off session [30].

As Giordano Bruno said, "If the first button of one's coat is wrongly buttoned, all the rest will be crooked". In the aviation industry, the first button is buttoned by the Country Airworthiness Authority (CAA) for type certification. So this question should be answered; “Was there any defect of safety precautions during the initial airworthiness approval period?". There's a clue for the answer to this question in the study of Kun Y., & Cunxi L. et al 2011. In this study, it has been stated that FAA delivers some privileges to individuals as the designated representatives including DER (Designated Engineering Representative), DMIR (Designated Manufacturing Inspection Representative), and DAR (Designated Airworthiness Representative). These representative people are hired by the manufacturer company and reporting the aircraft certification issues to FAA. It is noteworthy that this kind of designation is more risky compared with the authorization of a design organization [31].

So it is worth emphasizing that, focusing on the accident from an engineering point of view may not be enough unless airworthiness issues are not involved in the investigations. Because of the fierce competition in the aviation industry, the technical teams will try more frequently to implement the novel technologies to their new discoveries on behalf of their companies.

The aviation industry has developed the automatic systems far too much to reconstruct now. For example, additive manufacturing technologies used in the aviation industry have been expanding rapidly albeit there are questions related to the qualification of the additively manufactured airborne parts [32].

It is obvious that such as MCAS and additively manufactured components in the future many new technologies will be implemented to aircraft.

It took two crashes before it was diagnosed that there was a fatal mistake with the MCAS of B-737 Max aircraft. From the technical side, MCAS issue can be taken as an engineering defect, but when a deep-dive is done, then it will be seen these accidents are the result of not taking safety precautions properly. Unless prescribed safety precautions are taken into serious consideration an event unavoidable [33].

IV. CONCLUSIONS

It is seen that the aviation industry will continue to expand. This trend will attract many new technologies to aircraft manufacturers, airlines, maintenance organizations, aviation training organizations as well. For sure, the industry is developing rapidly. Can certification systems keep up the developments of the aviation industry? It is observed that the gap is increasing between the regulations and the industry. As ICAO warns with every novel technological application there's a risk, hence implementations of the matured technologies assume lesser risks than the new technologies [11]. It is a dilemma. From one side new technologies integration is essential for aviation companies, from the other side regulatory bodies are still using the legacy methods for certification of the new technologies. It is a well-known reality that the airworthiness audits have been applied with the regulatory-based traditionally [32].

Airworthiness certification is the most important stage of the whole lifespan of the aircraft. There is a stiff connection between airworthiness and flight safety. The person, environment, and machine are the chain buckles of the safety [35]. So for diminishing the risks of a new type of aircraft validation;

4.1. Training Issues

It's one of the most important "lessons-learned" issues from the accidents that, while integrating the new technologies the personnel especially the pilots should be trained in action (i.e. either flying on a real air-vehicle or in a flight simulator at least). Koglbauer I., and Braunstingl R., et al 2018 states that the simulator training method is a very effective method for ab initio student pilots' situational awareness and performance [36]. The training has to be repeated until it is learned as a memory-item. Especially after flight-critical system integrations, tablet-based training is not enough. This study highlights the negative impact of the new technologies unless they are not taught as an autonomous response of pilots and implemented to Flight Crew Training Manual (FCTM) and Flight Crew Operational Manual (FCOM). It can be taught that such training methodology is both time-consuming and expensive, but everything is cheap when compared with human loss.

4.2. Implementation of the Novel Technologies

The novel technologies such as AI, additive manufacturing, augmented virtual reality, etc. are implementing the aviation industry rapidly. These technologies should be observed under industries such as automotive, white-goods, naval systems, etc. As they are satisfactorily used in the sectors other than aviation then a gradual implementation may be executed. For example, still there are challenges over the qualification of the additively manufactured flight-ready parts validation. [32, 37].

4.3. Certification Issues

The certification approach should be switched from regulatory-based to risk-based. Because it is obvious that, a risk-based certification model will focus on the new integrations more than a regulatory-based one. Not only for an avionic system such as MCAS, but should the additively manufactured parts also be considered for the subject of risk-based certifications. In the beginning, there might have been some delays but especially for the flight-critical parts fatigue analysis, stress, corrosion tests must be applied to simulate the real flight conditions. Irrelevant from the brand of the aircraft manufacturer company, certification activities should be executed considering the flight critical issues.

V. CONFLICT OF INTEREST

The author states no conflict of interest

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