CHALLENGES OF RISK MANAGEMENT IN INDUSTRY: THE BOEING CASE

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This talk is dedicated to

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THE FUNDAMENTAL IMPORTANCE OF RISK MANAGEMENT

In the past, Management Science was focused on efficiency and optimization.

A good manager was one who gets a lot from a limited set of resources. Maximizing profits, minimizing costs were the main objective .

THE DOMINATION OF FINANCE

- **In recent years, the overwhelming role of the market value of shares on the market on a short-term basis has exacerbated the race for profits and for cost reduction.**
- **At the same time, the importance of providing value to shareholders and the manner incentives for CEOs are designed contribute to this race. This change of goal from excellence in Engineering to Financial success had affected BOEING.**
- **However, numerous examples, along all kinds of industrial sectors and services, show overwhelmingly that the main evidence of good management lies first in the management of risks.**

WHY IS MANAGING RISKS SO IMPORTANT ?

- **The first reason is that overlooking risks can be destructive or very harmful, even for well managed organizations**
- **The second reason is that most of the risks are not visible. More precisely, they could be perfectly visible to outsiders, but not to the victims. In fact, there is generally blindness of decision makers with respect to the risks which can impact their action. In Risk Management, it is called <u>Overoptimism.</u>**
- **To be obsessed by one objective, intensifies this blindness. It is like acting as a gambler, without being conscious of the addiction.**
- **The third reason is that major mistakes are of human nature, even in highly technical domains.**

WHY IS MANAGING RISKS SO IMPORTANT ?

- **The fourth reason is that one commonly persists in the wrong behavior, while willing to recover. Failures and hard consequences will accumulate.**
- **The roots of wrong decisions are hubris and incompetence.**
- **However, we emphasize in this talk that the main origin is the lack of culture about Risk Management.**
- **What can happen is incredible, beyond belief.**

LIVING WITH RISKS

- **Corporations must take risks to avoid regression and benefit from opportunities**
- **Innovation, Globalization are key to growth and competitiveness**
- **They are sources of risk, which must be considered and mitigated.**
- **This commonsense statement turns out to be very hard to implement.**

BASIC CHALLENGES

- **Risks are numerous and diverse. One must be exhaustive, without hampering decision.**
- **There are quantitative aspects, since decision relies on a cost-benefit analysis.**
- **There are organizational aspects. Since major failures are of human nature, stringent sustained measures are indispensable.**
- **There are psychological aspects, since the perception of risks is very subjective. This concerns all stakeholders and the public.**

WHY DO WE NEED TO STUDY THE BOEING CASE?

- **The issue of safety: We know reliability of equipment, quality control of products and production processes. What about complex systems, and complex systems with embedded software? What about autonomous systems?**

  What about connected systems? What about degradation and maintenance? What about humans in systems?
- **The issue of strategic risks: What about survivability? Can we accept to lose leadership?**
- **The issue of trust : The more complexity, the more we need trust. How do we build and maintain trust?**

WHY DO WE NEED TO STUDY THE BOEING CASE?

- **The issue of design and development : Do we accept to pay the price?**
- **The issue of communication: To what extent shall we tell the truth?**
- **The issue of training and competence : Operators must understand the complexity of systems they are using.**
- **The issue of regulation: How can we insure independence and expertise of regulators?**
- **Without a culture of Risk Management, at all stages of the life cycle, disastrous decisions will occur.**

THE BOEING CASE

THE BOEING CASE

- **CRASH LION AIR 610 , 10-29-2018, JAKARTA-PANGKAL PINANG, 12 m. AFTER TAKE OFF, 189 DEAD.**

  AIRCRAFT , BOEING 737 MAX 8
- **CRASH ETHIOPIAN AIRLINES 302, 03-10-2019, ADDIS-ABABA NAIROBI, 6m. AFTER TAKE OFF, 157 DEAD.**

  AIRCRAFT , BOEING 737 MAX 8

By all means these were not UNPREDICTABLE ACCIDENTS. They could and they should have been prevented. We advocate that adequate risk management practices would have avoided this tragedy.

THE PLANE WAS GROUNDED BY CHINA ON MARCH 11, BY EUROPE ON MARCH 12, BY THE US (FAA) ON MARCH 13.

One can wonder why the US was the last one?

CONSEQUENCES

- **LOSS OF LIFE: 346 innocent people. Trains can be stopped, not airplanes. Death is certain in airplane accidents.**
- **ECONOMIC CONSEQUENCES FOR BOEING:**
  - **MARKET: BOEING has produced 10,478 737 planes , since its introduction in 1967, on a total of 15,534.**
  - **The 737 MAX is the flagship plane. Introduced in March 2017. The order book in 2019 was 5,012 , with 4,661 unfilled. The total number of BOEING unfilled planes 5,948 (78%)**
  - **737 MAX was supposed to represent 33% of BOEING revenue in the next 5 years.**

ECONOMIC CONSEQUENCES

- **Reducing the production rate and stopping it has considerably impacted the production cost.**
- **Most payments come only after delivery and BOEING must park the planes till delivery.**
- **The accidents and grounding cost Boeing an estimated $20 billion in fines, compensation and legal fees, with indirect losses of more than $60 billion from 1,200 cancelled orders.**
- **Nevertheless, scrapping the plane is not an option ($ 400 Billions).**

THE STORY

- **Boeing's 737 and Airbus' A320 are the two main players in the massive — and massively profitable — market for narrow-body passenger jets. Together, both airplanes comprise nearly half of the world's 28,000 commercial airliners.**
- **Both manufacturers are locked in a race to make their airplanes cheaper for airlines to operate, especially when it comes to fuel.**
- **In 2018, for instance, Southwest Airlines' fleet of 751 Boeing 737s burned through 2.1 billion gallons of fuel for a total of $4.6 billion. A 1 percent increase in fuel efficiency would save $46 million.**

THE STORY

- **On December 1st, 2010, Airbus stunned the aviation community. In "secret", it had developed a more efficient version of the A320 called the A320neo (which stands for "new engine option"). It would burn about 6 percent less fuel than the 737NG (Predecessor of 737 MAX) .**
- **Airlines loved it. The following summer at the 2011 Paris Air Show, the aerospace industry's equivalent of Black Friday, Airbus sold a record-setting 667 A320neos in the span of a week. That was more orders than the 737s had received in the entirety of 2010.**

TIMETABLE


Timeline
12/1/2010 A320neo publicly announced
6/23/2011 Paris Air Show 2011
8/30/2011 Boeing 737 publicly announced
7/23/2013 MAX completes firm configuration
8/13/2015 First fuselage complete
12/8/2015 First completed airplane leaves factory
1/29/2016 Prototype first flight
3/8/2017 FAA Certifies MAX
3/27/2017 EASA certifies MAX
5/6/2017 First customer delivery
10/29/2018 Lion Air 610 crash - first fatal accident
3/10/2019 Ethiopian crash
3/11/2019 China suspends MAX flights
3/12/2019 EASA, India, South Korea suspend MAX flights
3/13/2019 Canada, US suspend MAX flights
3/14/2019 Boeing suspends deliveries
3/19/2019 USDOT requests audit of certification process

THE ROOT CAUSE OF RISKY DECISIONS

- **BOEING and AIRBUS are the only two players for long and middle range commercial aviation market, with a longstanding domination of BOEING. Its hubris cannot stand that AIRBUS takes the leadership.**
- **Both companies were of course preparing the future, in the direction of reducing energy consumption. They have the same supplier for engines, the team General Electric-Safran.**
- **The engines are not identical, but the technology is the same. The only secret is in the decision to start the development.**
- **The first mistake of BOEING is not to have anticipated the decision of its competitor.**

HASTY DECISIONS AND OBSESSION OF MINIMIZING COSTS

- **Basic knowledge of Risk Management tells that there is no free lunch. Reducing time and reducing cost necessarily increase risks and can be a recipe for disaster.**
- **Boeing's execs made up their minds in a matter of weeks. The company would launch a fourth-generation 737, and it would do it in record time.**
- **Boeing could save billions of dollars in engineering costs by basing the Max off the 737 platform.**

WHAT IS THE CATCH?

- **It would take a considerable amount of work to update a 46-year-old design with all of the technology it needed to be just as efficient as the competition.**
- **This destroys the advantage of choosing the 737 platform, namely that the new plane is not a big evolution of the previous one, and thus the certification process should be very fast. It was imperative to convey the narrative that the new plane is efficient, but not very much different from the previous model.**
- **Not only the certification should be fast, but also a very light training of pilots would be necessary. This annihilated any other consideration.**

THE “MYTH OF 737”

- **According to Gregory Travis**

“ Everything about the design and manufacture the Max was done to preserve the myth that is just a 737. Recertifying it as a new aircraft would have taken years and millions of dollars.”

IMMEDIATE MISTAKES IN PR POLICY: COMMIT SOMETHING WHICH IS NOT GUARANTEED.

- **Two years into development, Boeing promised the Max would be 8 percent more fuel-efficient than the A320neo. Five and a half years in, the FAA granted the Max its Amended Type Certification. Just months later, the program's chief pilot, Ed Wilson, boasted that pilots rated on previous versions of the 737 could switch to the Max with just "2 ½ hours of computer-based training."**
- **Boeing sold a record-breaking $200 billion worth of Maxes before the first prototype took to the skies.**

CHALLENGES IN SYSTEM ENGINEERING

- The Max was designed around a new set of engines called LEAP-1Bs. These are much more efficient than the engines on the 737NG, but they are also much heavier and larger.
- This created a design problem. The engines on the NG sit only 18 inches off the ground and mounting the LEAP-1Bs in the same spot gave them too little clearance during takeoff. So, Boeing placed them further forward and slightly higher on the wing of the Max.
- That solution created an aerodynamics problem. Due to their size and position, the engines on the Max create lift when the airplane enters a steep climb (or, in aviation parlance, at high angles of attack). This extra lift causes the Max to behave differently than previous versions of the 737, supposedly only when it's climbing steeply.

THE ISSUE OF STABILITY

- **The risk of high angle of attack is stalling, which leads to difficulties in controlling the plane.**
- **Less stability may be necessary to increase maneuverability. This happens for fighter jets. It is not acceptable for commercial airplanes, although well training pilots can cope with it.**
- **So, the main dilemma for BOEING was not that the new plane was unstable and thus dangerous. It was that the new plane would look significantly different from the 737 NG.**

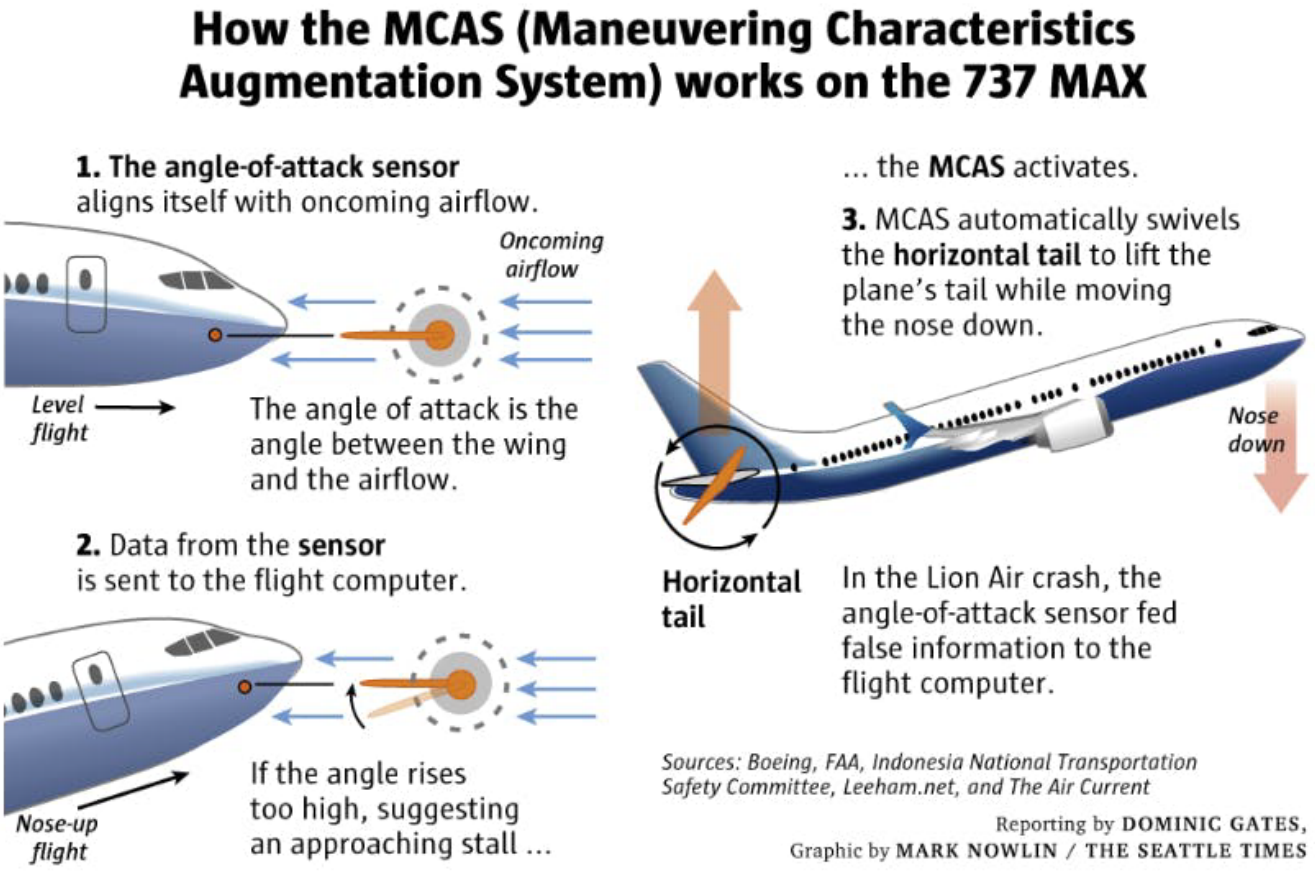
THE ISSUE OF STABILITY

- **Consequently, a full certification process will be necessary, as well as an intensive training of pilots.**
- **This will destroy the objective of commonality with the 737 family, which was the obsession of BOEING in order to reduce costs.**
- **They decided to solve a hardware difficulty by software.**
- **This is not uncommon, or necessarily a bad decision, although in this case, the problem arises simply from a bad initial analysis, focused on cost reduction without considering risks.**

INTRODUCTION OF MCAS

- **MCAS (Maneuvering Characteristics Augmentation System) was designed to compensate.**
- **It would use an angle of attack (AoA) sensor to detect when the airplane entered a steep climb.**
- **It would activate the airplane's pitch trim system, to stabilize the airplane until it detected that the airplane had returned to a normal AoA and ended its steep climb.**
- **It looks quite reasonable, but using software introduces a new category of risks: The risks of embedded software. They need a special attention.**
- **Not only BOEING did not use specialists of embedded software (they had suppliers), but they did not even pay attention to what is common sense, to an extent which is beyond belief.**

HOW DOES MCAS WORK?



UNBELIEVABLE DESIGN OF THE SOFTWARE

- **The Data of MCAS come from only one sensor, and the software believes that it is always correct.**
- **This is absolutely forbidden in life-critical system engineering practice, and by international standards.**
- **Boeing considered that the need for MCAS would be rare, thanks to a g-force threshold. They did not mention MCAS in the pilot's manual. So, pilots could not have the opportunity to feel it is a different plane.**

UNBELIEVABLE DESIGN OF THE SOFTWARE

- **No synergy between the pilot and the software was specified in the design.**
- **On the contrary, MCAS overrides the actions of the pilot even when it has been triggered erroneously.**
- **MCAS is activated repeatedly, even after action from the pilot to counteract. The pilot cannot win.**
- **These aspects can only be addressed at system-level design and are not a matter of software development.**

UNBELIEVABLE DESIGN OF THE SOFTWARE

- **When triggered, it nudges the plane's nose down ready to take a dive.**
- **The "gain" in the control loop, consisting of the pilot and MCAS interacting with the aircraft wings was much higher than expected in the design. This results in oscillations.**

UNDERSTANDING EMBEDDED SOFTWARE

- **In 2016, a test pilot reported that the Max wasn't handling well when nearing stalls at low speeds.**
- **The decision was taken to expand the use of MCAS to lower-speed situations required removing the g-force threshold.**
- **Using MCAS at lower speeds also required increasing the power of the system.**

UNDERSTANDING EMBEDDED SOFTWARE

- So MCAS was used in different conditions. No study was made to analyze the risks of this change.
- Basic rules of risk assessment of embedded software have not been considered.
- Embedded software must be compliant with specifications considering the conditions of use.
- For MCAS specifications were incomplete, thus error-prone.
- The FAA should have applied basic lifecycle verifications for checking the embedded software. That has not been the case.

BLATANT DISREGARD FOR SENSOR FAILURE

- **Although MCAS uses only one AOA sensor, the aircraft has two.**
- **It has also an AOA Disagree alert, intended to notify the crew if the aircraft's two AOA sensor readings disagree, which occurs if one sensor is malfunctioning or providing faulty AOA data. This alert was certified as a standard aircraft feature.**
- **It was inoperable on most of the 737 MAX fleet.**

NO CONSIDERATION FOR WARNINGS IN TESTS

- **In 2012, BOEING got an important test data**
- **It took a Boeing test pilot more than 10 seconds to diagnose and respond to uncommanded MCAS activation in a flight simulator, a condition the pilot found to be "catastrophic".**
- **Federal guidelines assume pilots will respond to this condition within four seconds.**
- **BOEING did not report this information, which is inconceivable.**

THE DAY BEFORE

- **The day before the Lion Air crash, pilots got the problem after take-off, and initiating climbing. The plane was diving instead.**
- **The pilot could not control the plane diving. The captain could not find anything in the pilot's manual.**
- **Fortunately, an off-duty pilot was on the plane and suggested to check the horizontal stabilizer manual, with instructions to cut it off, thereby removing electrical power from the flight control that MCAS was erroneously activating.**
- **Although it was not clear it was the reason of the diving, the captain cut it off, and things came back to normal.**

THE DAY BEFORE

- **It was signaled to maintenance, which did not find anything abnormal (they cannot check the software) and let the plane go the next day, resulting in the crash.**
- **Unfortunately, the captain did not report the stabilizer cut off to address the unexpected horizontal stabilizer movement.**
- **Nevertheless, it is a gross incompetence in risk management. The warning was not considered, resulting in death of people.**

CRASH OF THE LION AIR

- **The pilots got the same diving problem as the day before.**
- **Unfortunately, because the previous flight crew did not document its use of the stabilizer cut off to address the same condition, the new flight crew did not have an important piece of information that could have helped them to identify and respond to the problem.**
- **This occurred more than 20 times as the pilots fought MCAS (without knowing its existence) while struggling to maintain control of the aircraft.**
- **Amid a cacophony of confusing warnings on the flight deck, the horizontal stabilizer ultimately forced the airplane into a nose-down attitude from which the pilots were unable to recover.**

BEHAVIOR AFTER THE FIRST CRASH

- **The attitude of BOEING, and unfortunately also FAA, was first to blame the pilots.**
- **They were thoroughly convinced that MCAS was an easy fix.**
- **One of the Boeing officials attempted to explain away MCAS to the American Airlines pilots: MCAS is a control law, in the flight control system. So, it's just a little bit of software in the flight control system that is designed to change the handling characteristics of the airplane at high angles of attack.**

BEHAVIOR AFTER THE FIRST CRASH

- **On November 6, 2018, eight days after the Lion Air crash, Boeing issued an Operations Manual Bulletin (OMB) that directed airline operators and flight crews to various flight crew procedures to address erroneous angle-of-attack (AOA) sensor data.**
- **The OMB issued by Boeing had the subject line, "Uncommanded Nose Down Stabilizer Trim Due to Erroneous Angle of Attack (AOA) During Manual Flight Only"**
- **No mention to MCAS**

BEHAVIOR AFTER THE FIRST CRASH

- **A bulletin appeared on MyBoeingFleet, the company's online portal for pilots and airlines. It read:**
- **"Boeing would like to call attention to an [Angle of Attack] failure condition that can occur during manual flight only."**
- **They described what happened and the horizontal stabilizer cut off instruction, without mentioning MCAS.**
- **BOEING promised a software patch that would make its anti-stall feature safer. However, by the time of the Ethiopian Airlines crash, the update had not been issued.**

SERIOUS CONCERNS ABOUT FAA

- **According to The Seattle Times, managers at the Federal Aviation Administration pushed its safety engineers into delegating the work of carrying out safety assessment of the then new Boeing 737 MAX to the aircraft manufacturer. The basis for this? The FAA didn't have the resources to perform its functions by itself!**
- **BOEING personal acting on behalf of FAA are called AR , authorized representatives.**
- **It is true that BOEING has no interest in certifying an unsafe aircraft, but it is nevertheless an obvious conflict of interest, since situations may not be clear cut.**

SERIOUS CONCERNS ABOUT FAA

- **Additionally, the managers also pushed for a speedy approval process.**
- **As a result of the lack of independent safety evaluation, the results of the safety analysis were flawed. Essential information was missing, and erroneous numbers were given.**
- **A Boeing AR raised concerns internally in 2016 about repetitive MCAS activation and the impact of faulty AOA data on MCAS. There were not relayed to FAA.**
- **In 2013, an AR concurred on a decision not to emphasize MCAS as a "new function" because of Boeing's fears that doing so would increase "costs" and lead to "a greater certification and training impact" on the 737 MAX.**

SERIOUS CONCERNS ABOUT FAA

- **When the use of MCAS was extended to lower speeds, it required increasing the power of the system. It was not mentioned to FAA.**
- **The FAA had already approved the previous version of MCAS. And the agency's rules didn't require it to take a second look because the changes didn't affect how the plane operated in extreme situations.**

WHAT FAA DID AFTER THE FIRST CRASH: EMERGENCY AD (AIRWORTHINESS DIRECTIVE)

- **"This emergency AD was prompted by analysis performed by the manufacturer showing that if an erroneously high single angle of attack (AOA) sensor input is received by the flight control system, there is a potential for repeated nose-down trim commands of the horizontal stabilizer".**
- **"This condition, if not addressed, could cause the flight crew to have difficulty controlling the airplane, and lead to excessive nose-down attitude, significant altitude loss, and possible impact with terrain."**

FAA RISK MANAGEMENT STUDY: TARAM

- **On December 3, 2018, the FAA prepared a quantitative risk assessment, based on a Transport Airplane Risk Assessment Methodology (TARAM). The study predicted the risk of another potential accident.**
- **The study predicted there would be one fatal 737 MAX accident every two years for the next 30 years. The FAA assumed that these potential future crashes would result in the loss of life for everyone on board the planes and some bystanders on the ground as well. However, they also estimated that Boeing would have a fix for MCAS by July 2019.**

FAA RISK MANAGEMENT STUDY: TARAM

- **Despite the TARAM analysis, the FAA permitted the 737 MAX aircraft to continue flying.**
- **In addition, Boeing continued to expand the MAX fleet in between the time of the Lion Air crash in October 2018 and the Ethiopian Airlines crash in March 2019. In those five months, Boeing delivered nearly 150 more aircraft to its customers, increasing the global 737 MAX fleet to 387aircraft.**
- **They considered that issuance of the Boeing OMB and the FAA's Emergency AD would be sufficient and relied on pilots to act in case of problems.**

DISASTROUS COMMUNICATION

- **More than 400 737 Max pilots are suing Boeing over an 'unprecedented cover-up' of flaws in the plane's design.**
- **BOEING CEO Dennis Muilenburg reportedly called President Trump to assure him that the 737 Max was safe to fly.**
- **BOEING defended the delegation process from FAA to the manufacturer.**
- **The image of BOEING, one of the stars of American industry, became dramatically damaged.**
- **The trust of users was also largely lost. It can take a lot of time to restore it.**

RALPH NADER

- **Consumer advocate Ralph Nader lost relative on Ethiopian 737 Max jet crash in March.**
- **He said the larger engines mounted to the Boeing 737 Max represented a design flaw and called for the plane to be permanently grounded.**
- **The 737 Max "must never fly again," Nader said. "It's not a matter of software. It's a matter of structural design defect: the plane's engines are too much for the traditional fuselage."**
- **He lambasted Boeing Co. for designing the 737 Max as yet another revision to an airframe that was first built in the 1960's, rather than designing a new plane from scratch.**

CONGRESS COMMITTEE REPORT

Peter A. DeFazio, Rick Larsen
September 2020

- **The report has been very professionally done.**

- **The Committee has held five hearings on issues related to the 737 MAX program; received an estimated 600,000 pages of records from Boeing, the FAA, airlines, and others; and conducted two dozen official interviews with current Boeing and FAA employees and others.**

CONGRESS COMMITTEE REPORT

Peter A. DeFazio, Rick Larsen
September 2020

- **The report is very critical on BOEING and FAA. It identifies**
  - **Production pressures**
  - **Faulty design**
  - **Faulty performance assumptions**
  - **Culture of concealment**
  - **Conflicted representation**
  - **Influence over the FAA's Oversight structure.**
- **The Committee insists on the need to restore Boeing's safety focus.**

CONGRESS COMMITTEE REPORT

Peter A. DeFazio, Rick Larsen
September 2020

- **However, the Committee's investigation raises questions regarding Boeing's commitment to doing that or even to simply acknowledging that it made mistakes in the design, development, and certification of the 737 MAX aircraft.**
- **Answering the question about Lessons learnt, BOEING indicates several organizational changes to enhance its focus on safety.**

CONGRESS COMMITTEE REPORT

Peter A. DeFazio, Rick Larsen
September 2020

- **The Committee stresses the need of a cultural change and states "Both Boeing and the FAA share responsibility for the development and ultimate certification of an aircraft that was unsafe. Both must learn critical lessons from these tragic accidents to improve the certification process, and the FAA must dramatically amplify and improve its oversight of Boeing. While the changes that the FAA and Boeing have proposed will be the start of a long process, changing the fundamental cultural issues that led to an environment that permitted Boeing to build, and FAA to certify, a technologically faulty aircraft will take much longer"**

THE CURRENT SITUATION

- **In November 2020, the FAA announced that it had cleared the 737 MAX**
- **In January 2021, after two years of grounding, Canada and EASA both cleared the MAX subject to additional requirements.**
- **180 countries out of 195 have lifted the grounding by December 2021 .**
- **Decision of China occurred in January 2022.**

THE CURRENT SITUATION

- **BOEING had produced over 450 MAX awaiting delivery. It estimates most of them should be delivered by the end of 2023. Up to February 2022, 706 planes have been built.**
- **BOEING claims it has corrected all the issues with MCAS.**
- **A more convincing statement should come after a validation process run by the FAA**?

RISK MANAGEMENT

- **It is striking to see that Risk Management does not appear anywhere.**
- **Safety, security, compliance are mentioned in Boeing organizational chart, but not Risk Management**
- **It has not appeared in the Congress investigation and not in the list of actions that Boeing committed to perform, as consequence of lessons learnt.**
- **Transforming a company into a risk intelligent organization requires a huge transformation.**

RISK MANAGEMENT

- **The study that FAA has performed is simply a quantitative risk assessment comparable to the computation of the reliability of an equipment.**
- **This is far from what is needed.**
- **What is at stake is the reliability of a complex system equipment (hardware, software), completed by an exhaustive risk assessment and management study.**

PRELIMINARY REMARKS

- **BOEING is a space company. Space agencies like NASA or ESA proceed differently when a serious failure or accident occurs.**
- **An independent investigation team is tasked to study thoroughly the accident, to identify the causes and to recommend actions.**
- **After Lion Air accident, such a team should have been created, in addition to any internal action. FAA should have requested it. Very likely the Ethiopian Airlines accident would have been avoided, and economic consequences for BOEING would have been partly mitigated.**

RISK MANAGEMENT AND STRATEGY

- **Competitors are a strategic risk. Risk Management should appear at the very beginning, at the core of the strategy. The fact that Boeing was taken by surprise by its competitor Airbus, was a strategic mistake.**
- **If Boeing had a real Risk Management oriented infrastructure, it should have not decided hastily its new airplane, but analyzed all options, even that of leaving a temporary leadership to Airbus. All options should have been studied with accurate cost-benefit analysis. This includes the reputation and the confidence aspects.**

WHAT SHOULD HAVE BEEN DONE?

- **If using the 737 platform was a good decision, then BOEING should have accepted fundamental changes to the 737 airframe to raise its height to fit the larger engines.**
- **A new aircraft type certificate, reflecting and acknowledging the changes.**
- **Costs of training pilots for what is, essentially, a new aircraft.**
- **It seems that the estimated additional cost was around $ 5 B, with, of course, delays. This option was rejected.**
- **To day, BOEING has already a loss of $ 80 B. It is not clear that the MAX will ever be profitable, and BOEING has lost a considerable part of its reputation.**

WHAT SHOULD HAVE BEEN DONE?

- **Once a software solution was decided, the risks of an overall onboard computer system and embedded software should have been studied, in depth. It is clearly a sign of ignorance.**
- **The risks arise because of a confluence of user interface for the pilot, training, control engineering, aero engineering, engineering management, and, at the lowest levels, software. It is a matter of Systems Engineering.**
- **Systems Engineering requires to specify in depth the specifications, the appropriate design and the process of validation and verification.**

THE MAIN LESSON

- **The main lesson is that, without an extremely strong organization to consider risks aspects for any decision, strategic, financial or technical, even a company like BOEING can behave in a way which is unthinkable.**
- **The risk organization should be a decision of the CEO and the Board.**
- **Risk Management reconciles Engineering and Finance aspects.**
- **Savings in crucial design phases turn into huge losses in human life and in devastated reputation.**
- **The culture of safety is part of the culture of risk..**