Air Safety Fundamentals – Lessons Learned From the Deadliest Disasters in Aeronautics

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Abstract

Air safety regulation as we know it today has been shaped by aircraft disasters that have happened in the past. Any given aviation disaster can be attributed to human failure, technical failure, extreme weather, or sabotage. Human error is by far the leading contributor to fatalities involving aircraft. Any accident can potentially be avoided, and prevention is gained by learning from past failures. The goal of this paper will be to outline the causes of the most major aircraft accidents, how they could have been prevented, how they have affected modern air safety and regulation, and what measures should be taken to prevent future accidents.

I. Air Safety Regulation Authority and Flight Accident Inspection

The concept of a governing body to mandate standards for safe aviation procedures was not formally put into practice until the Air Commerce Act of 1926. By this time, numerous fatalities had occurred from powered aircraft crashes. The purpose of the Air Commerce Act was to ensure proper pilot education, inspect aircraft, manage airways, and investigate accidents. These responsibilities were divided into two separate organizations, the Civil Aeronautics Administration (CAA) and the Civil Aeronautics Board (CAB), the latter of the two being responsible for safety regulations and accident investigation. The coming age of jet engines brought about the transition of air safety authority to the Federal Aviation Administration (FAA) in 1958[*]. It should be noted however, that the purpose of the FAA was not to investigate aviation accidents; this was assumed by the National Transportation Safety Board (NTSB), which independently investigates all transportation related accidents which occur within United States territory.

The process of establishing regulations, including air safety regulations, by the FAA includes a proposal for a new regulation, a regulation change, or removal or a regulation. Throughout the approval process, the regulation can be petitioned by any individual or entity. The FAA holds public meetings for this cause.

Air safety is monitored and enforced by the FAA through Flight Standards District Offices. Inspectors verify the airworthiness of aircraft and that FAA regulations are being followed. They also have the authority to penalize rule breakers and can revoke pilots' licenses. Since the Pan Am flight 103 disaster of 1988, the FAA has conducted surprise "Red Team" inspections, which are for detecting fundamental weaknesses in safety and security procedures that may not turn up during routine inspections[1].

International air safety authorities take a similar role in world aviation conventions. The International Civil Aviation Organization (ICAO) is the division of the United Nations associated with air transport growth and order. Rather than acting as a regulatory body, efforts for air safety by the ICAO include developing safety standards for aircraft design and operation, and responding to aviation disasters. The ICAO also monitors global air safety trends. These statistics are sent Aircraft Crashes Record Office in Geneva, Switzerland for compiling and archiving.

In the United States, aviation accidents are responded to by the NTSB. Final accident reports and statistics are compiled by the FAA and released to the general public. The ICAO generally does not have a direct role in accident investigation unless the circumstances are of a hostile nature and involving multiple nations. There have been three instances when the ICAO has directly investigated a disaster, each of which involved sabotage.

[*] Unsurprisingly, this also is the year that NASA emerged from NACA.

II. Causes of Aviation Disasters

Even though aviation has revolutionized transportation, globalization, surveillance, and warfare, it has proven numerous times throughout its short history to be a very deadly invention. This is one of the reasons that flight technology is rapidly progressing; the high cost of human life demands immediate improvement, and improvement is happening. There were 824 aviation fatalities in 2011, significantly less than the 1,120 deaths in 2012.

Table 1: Main causes of aircraft accidents[2].

Principal cause	Percentage
Human Error	67.57 %
Aircraft Failure	20.72 %
Weather	5.95 %
Sabotage	3.25 %
Other	2.51 %

Table 2: Accident percentages by operation.

Operation	Percentage
Landing	50.39 %
Flight	27.73 %
Takeoff	20.96 %
Taxiing	0.64 %
Parking	0.28 %

As new goals for aircraft functionality are accomplished, limits tend to be pushed insofar as materials, avionics, and manufacturing capabilities. In retrospect, however, the majority of fatal aviation accidents are not due to aircraft failure. It is undeniable that human error is the leading cause of fatalities involving aircraft. Weather and sabotage comprise a small percentage of all aircraft crashes. Disasters in each of these four categories (technical failure, human error, weather, sabotage) can all be avoided. Common technical failures such as fuel tank explosions, decompression, and structural failure are design or maintenance issues and can be avoided during the design process and through regular inspection. Human error is harder to control, and is inevitable to some extent. A given incident involving human error can be categorized as a mistake, violation, mismatch, or lapse of attention.

III. Accidents Due to Human Error

It is arguable that the greatest aviation disaster of all time was due mainly to human error. The Tenerife disaster of 1977 claimed 583 lives, and could have been avoided if better crew resource management had been practiced. However, it was not only human error that caused the accident. Weather undeniably had its effect on the chain of events leading up to the crash. Also, a little ironically, sabotage was indirectly involved in the accident. This is in fact the sole event that started problems. After a bomb was detonated at Las Palmas International Airport in the Canary Islands, all aircraft scheduled to land there had to be diverted to the much smaller Los Rodeos Airport on the nearby island of Tenerife. The aircraft involved in the crash, both Boeing 747s, were forced to park on the taxiway due to congestion. The first of the two to arrive at Los Rodeos was KLM[*] Airlines flight 4805, which had departed from Amsterdam with 235 passengers and 14 crew. Pan Am flight 1736 had departed from Los Angeles and refueled in New York. It was carrying 380 passengers and 16 crew. Jacob Veldhuyzen van Zanten, the well-known captain of the KLM, decided to fully refuel during the wait. Five tons of fuel were pumped into the 747, which was an unnecessary amount for the flight ahead[3]. During the time the KLM was refueling, Las Palmas airport reopened. The Pan Am was prepared to depart, but was unable to with the KLM blocking the runway. With the taxiway full of other planes, both 747s were instructed by the ATC tower to taxi down the runway in the opposite direction of takeoff. This is known as back-taxiing. During this time fog began to cover the runway, and visibility reportedly decreased to 300 meters, less than half the legal requirement of 700 meters for takeoff. As the KLM neared the end of the runway and started to make the 180 degree turn to prepare for takeoff, ATC instructed the Pan Am to take the third exit from the terminals off of the runway so that the KLM could takeoff. The third exit, however, was a sharp 150 degree turn that headed back to the terminal. This confused the Pan Am crew, since it was nearly impossible for a large plane to make such a large turn.

[*] Koninklijke Luchtvaart Maatschappij (Dutch: Royal Aeronautical Society).

It is unknown why the air traffic controller instructed the Pan Am to take the third exit and not the fourth, which would only have required a 35 degree turn, and was in the direction of where they needed to go. During the same time, van Zanten did an unimaginable thing as the captain: he increased the throttle with intentions of taking off. His co-pilot, Klaas Meurs, was shocked and responded “Wait a minute; we don’t have an ATC clearance”. Van Zanten brought down the throttle and told the co-pilot to radio the tower for takeoff clearance. The communication error

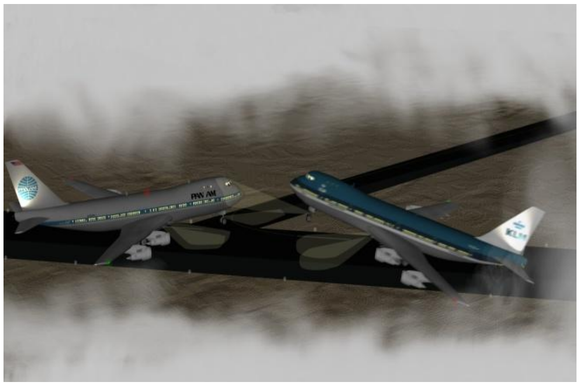

Figure 1: A computer simulation of the Tenerife disaster.

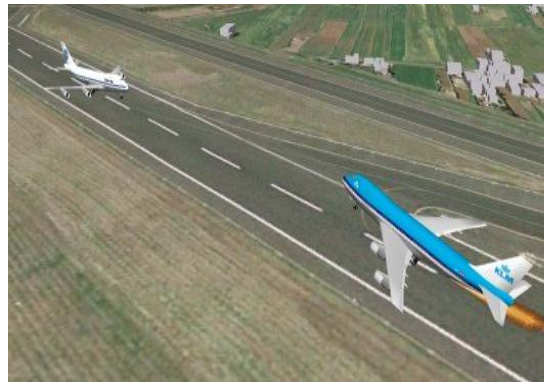

Figure 2: The tail of the KLM Boeing 747 made contact with the ground for 30 meters along the runway. This simulation does not portray the foggy weather.

that happened next between the KLM and the tower proved to be fatal. Meurs radioed the tower and said that they were ready for takeoff. The tower’s response was that they were cleared to fly their specified route after takeoff without giving them takeoff clearance. Meurs read the instructions back to the controller and said “we are now at takeoff”. A second time, van Zanten began to takeoff, and this time Meurs did not try to stop him. The Pan Am crew, aware that the KLM was preparing to taxi, radioed the controller that they were still on the runway. The controller responded by requesting that they give confirmation when they were clear of the runway. Meanwhile, the KLM was already going too fast to stop in time. The fog was so thick that the two pilots did not see each other until a collision was inevitable. The Pan Am pilot slammed the throttle forward and turned away, attempting to clear the runway by driving into the grass. The KLM pilot pitched the plane up, but did not become airborne until a fraction of a second before impact. The crash killed everyone aboard the KLM, and left only 59 survivors on the Pan Am, including the pilot, co-pilot, and flight engineer. A memorial dedicated to the victims was erected on Tenerife Island.

It’s obvious that there were several contributing factors to the accident. Primarily, the KLM captain deliberately attempted takeoff without ATC clearance. The fact that the co-pilot called him out on it the first time is also interesting. At the time of the accident, it was not common for co-pilots or flight engineers to question the captain. The Tenerife disaster brought about a worldwide change to where co-pilots and flight engineers are encouraged to question the captain and give recommendations. The actual reason why van Zanten didn’t wait for ATC clearance is probably because he feared the weather would worsen and they would be unable to takeoff. Flight regulations prevent pilots from flying without appropriate rest, and van Zanten was probably concerned that if they were delayed too long, he would have to stay at Tenerife for the night, along with his crew and the 235 passengers. It is arguable that van Zanten believed he had ATC clearance the second time he attempted takeoff, which uncovers the fact that the nonstandard terms used by the control tower and the KLM also could have played a critical role in disaster. This problem came from the carelessness of each radio operator. When the KLM co-pilot radioed “we are now at takeoff” the control tower came back with just “OK”. The KLM crew may have interpreted this as an approval for takeoff; the nonstandard terminology may have been overlooked due to tension in the cockpit. Flight communications regulations have been more strongly enforced after the Tenerife disaster. Another contributing factor to the crash was that the KLM had taken on more fuel than it needed. This caused the takeoff to be delayed for 30 minutes. In the meantime, fog rolled in. The extra mass also made it impossible for the plane to get enough lift to takeoff before colliding with the Pan Am. Unfortunately the extra fuel also caused explosions which killed everyone on the KLM. In response to the accident, airliner fuel requirements were more closely regulated.

Perhaps the most significant change to air safety regulation and control that was made following the Tenerife disaster was increased prevention and awareness of runway incursions. A runway incursion is defined by the ICAO as "any occurrence at an aerodrome involving the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and take-off of aircraft"[4]. Since 2000, runway incursions have accounted for 18 percent of all aviation accidents. There have also been numerous close calls involving runway incursions. A repeat of Tenerife almost happened in 2005 when an Aer Lingus Airbus A330 and a US Airways Boeing 737 (see Figure 3) were both given ATC clearance for takeoff at approximately the same time[5]. Logan

Figure 3: A US Airways Boeing 737.

Figure 4: The plane destroyed on the Japan Airlines flight 123 accident, a Boeing 747.

International Airport, near Boston, operates with dual control towers due to the large amount of air traffic dealt with. This is what caused the communications mismatch. The planes were on separate runways that intersected each other. As each plane began to taxi, they were unable to see each other because of the terminal. US Airways co-pilot Jim Dannahower noticed the other plane seconds before liftoff, realized that they were on a collision course. Dannahower told the captain to delay ascending, and the Aer Lingus passed above them with a clearance of an estimated 170 feet. The US airways pilot was then able to ascend further down the runway. Dannahower was awarded the Superior Airmanship Award for his quick actions. The incident may not have turned out so well if he had not felt free to take command of the situation. The co-pilot of KLM flight 4805 could have saved the lives of a lot of people if he had challenged the captain a second time when he attempted to takeoff.

IV. Accidents Due to Technical Failure

Fuel tank explosions on an aircraft are not common, but the few times they have happened on commercial airlines many lives have been lost. Trans World Airlines flight 800 departed from New York-JFK on July 17, 1996, destined for Paris-Charles de Gaulle. The plane, a Boeing 747, had flown from Athens, Greece the same day, and the plane's behavior was not out of the ordinary. Twelve minutes after takeoff from JFK, the plane exploded over the Atlantic, killing all 230 people on board. A terrorist attack was suspected, so the FBI was in on the investigation as well as the NTSB. The conclusion was that a short circuit caused the center fuel tank to ignite[*]. Following the disaster report from the NTSB, they issued a regulation for Boeing and Airbus commercial and cargo airlines to modify the fuel tank so that the empty portion is filled with nitrogen instead of highly explosive oxygen. The modifications were expected to not exceed 310,000 USD per aircraft, depending on the size, of course.

The deadliest aviation accident of all time involving only one plane was the Japan Airlines Flight 123 disaster of 1985. Although it is questionable whether the disaster, which claimed 520 lives, was caused solely by technical failure or involved human error, it is generally categorized as a mechanical failure. Flight 123 was a domestic flight from Tokyo to Osaka. Twelve minutes into the flight, the plane experienced mechanical failure. The rear pressure bulkhead, which keeps the cabin pressurized, and the vertical stabilizer both flew off [6]. The pilots were still able to keep the plane from plummeting towards the ground, but were not able to fully control it. The pilots sent out a distress signal and reported that they had lost control. All of the hydraulic fluid used to control the plane had drained

[*] There are, however, also many conspiracy theories about this accident.

out when the back end of the plane tore apart. After 32 minutes the plane crashed into the side of a mountain about 62 miles from Tokyo. The crash happened at dusk, and the reconnaissance flight that found the crashed plane claimed that there were no survivors. The next morning, rescue teams found four survivors. There were indications that many other people survived the actual crash, but died during the night due to their injuries and exposure while they awaited rescue. The cause of the mechanical failure was that the rear bulkhead had been damaged eight years earlier when it made contact with the runway during a landing. The repairs were not made according to regulation and the resulting structure's resistance to fatigue was reduced 70%, which resulted in the disaster. More strict and detailed maintenance and inspection procedures could have prevented such a disaster.

Many disasters are because of fire in either the cargo bay, engines, or cabin. There have been numerous causes of fires in aircraft. One example related to mechanical failure is LOT* Polish Airlines flight 5055. The aircraft was an Ilyushin Il-62, and was carrying 183 passengers and crew. The captain, Zygmunt Pawlaczyk, had completed almost 20000 hours of flight time[7]. The plane crashed into a forest shortly after takeoff from Warsaw-Frederic Chopin Airport. The cause of the crash was attributed to failure of the bearings that support the engine shaft. This caused one of the engines to catch fire, and also started a fire in the cargo hold. There were no survivors of the crash. The followup was an improvement in the bearings that support the engine shaft. The original design of the bearings incorporated too few rollers. The resolution was to double this number, so that the new design had 26. The accident remains the worst in the history of Polish Airlines.

V. Accidents Due to Weather

Perhaps the most astounding recent aviation accident involving severe weather was the Air France flight 447 incident. Even though the cause of the disaster is still being investigated, changes have already been made as far as how flight crews are educated to handle flying during storms and what to do when flight instrumentation becomes unreliable. Flight 447 was an Airbus A330, which utilizes fly-by-wire technology. Fly-by-wire replaces the conventional hydraulic method of controlling an aircraft with electronic actuation. The Air France departed from Rio de Janeiro on June 1 2009. It was destined for Paris-Charles de Gaulle Airport carrying 216 passengers and 12 crew[8]. As the airliner set off across the Atlantic, it routinely went out of range of Brazilian radar surveillance. When the airliner failed to enter Senegalese controlled airspace at its scheduled time, a search and rescue effort was began by the Brazilian Air Force. The wreckage was not located aerially until late the next day. By then French president

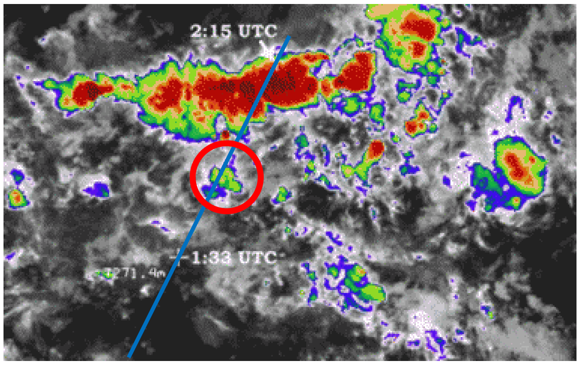

Figure 5: A satellite image of the storm Air France flight 447 flew into. The red circle indicates the smaller storm, which hid the larger storm from the plane's radar.

Figure 6: An Air France Airbus A330.

Nicolas Sarkozy had already spoken with the victims' relatives and announced that there was very little chance of any survivors. The first ships arrived at the crash site in the middle of the Atlantic on June 3. By June 26, more than 400 pieces of debris had been recovered and 51 bodies. French submarines continued to search for the flight data recorder boxes ("black-boxes"), so that more information on the cause of the crash could be obtained. The black-boxes were not located until April 2011 by a French submarine team. They were found with more debris and bodies

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* Polish – flight.

on the ocean floor in the mid-Atlantic. It is interesting to note here that even though the search for the Air France flight 447 black boxes took almost two years, the amount of effort and time put into it has been dwarfed by search operations for the black boxes of other aircraft. In some cases, millions of dollars and multiple years have been invested into finding them with no turnaround. On the other hand, the exact opposite has also occurred. During the height of the anti-apartheid movement of the early 1990's, many South Africans considered South African Airways to be representative of apartheid, since it was run and owned by the government. When flight 295 from Taiwan-Taoyuan Airport to Johannesburg mysteriously crashed into the Indian ocean with 159 passengers and crew, there was speculation that the cause was sabotage. With lots of pressure to find the black boxes, the South African government searched for two months within success. Not long afterward, an independent contractor was hired to locate them. Within two days of beginning the search the contractor had located them. This still holds the record for the deepest ocean recovery in history. Also, the area the debris was spread across in the ocean was significantly greater than that of the Air France disaster. Despite all of the effort put into finding the black boxes for South African Airways flight 295, there was never am official conclusion on exactly what caused the crash.

Initial speculation was that the crash was caused by a group of thunderstorms that had developed along the route of the Air France. Proper flight procedure would have dictated flying around the storms, but the pilots chose not to. The reason for the bad decision may have been because the size of the storm was not apparent; the plane's radar may have displayed the storm as not being dangerous due to a smaller storm in front of it. With the true size of the storm blocked by the smaller one, the pilots had no reason to change their route. Even though there is no empirical evidence that this is the reason they did not bypass the storm, satellite images have confirmed the existence of a smaller front of storms directly in the line of sight of the plane.

Until the location of the voice recorder boxes it was not fully known what happened the night of the crash. The information the voice recorder boxes contained revealed that the crew had in fact flow directly into the thunderstorm and lost control of the plane. The black boxes also contained vital information of exactly why they lost control. The fact that the pilot informed the passengers of the turbulent weather before they entered the storm indicates the deliberateness of the action. Shortly after entering the turbulent weather, the plane's autopilot disengaged

Figure 7: A pitot tube on a small aircraft. Although most pitot tubes are heated, there have been instances when they have iced over.

Figure 8: The vertical stabilizer of Air France flight 447 being recovered from the Atlantic within a few days of the crash.

systematically due to the inability of the computer to determine airspeed accurately. This was a shock to the pilots. The autopilot controls not only the pitch of the plane, but also the throttle. The pilots apparently panicked. Their response was to increase the angle of attack and the throttle. This caused the plane to stall and buffet*. Neither of the pilots had training for stall handling. The flight instrumentation warned the pilots of the stall, but not continuously. The stall indicator went on and off because of the computers inability to determine airspeed. This obviously confused the pilots even more. The plane descended rapidly and crashed in the ocean.

It should be obvious that there were several reasons for the crash. The weather was the primary issue, but was not the determining factor. The event that caused the mistakes to start escalading was the inability of the Air France

* Random violent vibration due to sudden impulse in shock wave oscillations.

to determine airspeed. Even with the autopilot disengaged, the pilots should have been able to fly the plane. But what caused the plane to cease to know the airspeed? One theory is that the pitot probes that measure pressure and convert it to airspeed froze over when the plane entered the storm[9]. Modern pitot probes are heated to prevent this type of failure, but some investigators believe that the air may have contained super-cooled water, which would have instantly frozen to the pitot probes. The autopilot must have an accurate airspeed to operate, so it shut down and things got worse from there. It is believed that the pilots did not carry out the unreliable airspeed procedure because they were unsure of which instruments, if any, were trustable. Before they realized what should be done, it was too late.

The black boxes gave lots of crucial information about what could have been done differently to prevent the failure. First of all, pitot probes with resistance to very low temperature and supercooled liquid are essential to a reliable autopilot. Air France flight 447 is not unique as far as failed pitot probes, there have been numerous flights that have reported a disengaged autopilot due to inaccurate airspeed measurement. Less than a month before the Air France disaster, a TAM Airlines Airbus A330 went through turbulent weather and the autopilot and autothrust both disengaged. A near crash, the pilots were able to recover the plane following a rapid descent. This may have been a repeat of Flight 447 had it not been for the better crew resource management and training.

VI. Conclusions

There is always room for improvement towards safety efforts. Even though airspace and airports around the world have experienced fewer and fewer accidents in recent years, accidents and near accidents are still happening. Air safety has been progressively improving as we learn from mistakes and regulations and procedures are being created and changed. As technology progresses we are able to find new ways of improving aircraft safety and failure prevention, mainly because what we've learned from our mistakes. The specific examples outlined in this paper are only a few of the many crashes that have claimed the lives of tens of thousands of people. This is a very high cost to pay that can be avoided by improving our engineering methodology, regulation authority, flight operations, and airport security.

VII. Acknowledgements

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