Analysis of Automation in the Aviation Industry

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Introduction

Aviation safety has improved dramatically over the past 50 years. In the early 1970s, there were over 1,500 casualties per year worldwide due to aviation accidents with passenger traffic of less than a half-billion. By 2012, the number of annual casualties had declined by 67%, while the number of annual passengers traveling had increased more than five-fold.[1] This improvement in safety can be credited to multiple factors, including strong oversight from governing bodies, mechanical enhancements, pilot training, and increasing automation, including the use of autopilot.

Although automation has contributed to the substantial decline in the casualty rate over the past fifty years, catastrophic aviation accidents in recent years raise concerns of the industry becoming too reliant on automation in the cockpit. There are three different levels of automation in aviation. The lowest level is hand-flying the aircraft using the instruments for positioning, but not engaging the autopilot system. The middle level involves utilizing the flight guidance system and autopilot for short periods of time. The highest level of automation occurs when the autopilot is engaged and the flight management system is used to control the plane for long periods of time.[2] As more control shifts toward machines, the potential for pilots to lose some of their sharpness in the cockpit increases. With reduced acuity, pilots may panic and fail to implement the normal procedures when a crisis arises, ultimately causing accidents. This dynamic may explain the causes of several fatal accidents in recent years, including some that appear to be similar to previous incidents.

Artificial intelligence can be used to significantly improve the effectiveness of automation such as autopilot. Machine learning can be used to create autonomous machines that are less prone to mistakes. Research into accidents that occurred in less than ideal circumstances suggests that the vast majority of accidents were due to human error involving shortcomings in team coordination and decision making. Additionally, Crew Resource Management (CRM), a set of procedures that focuses on communication and leadership in the cockpit, as part of pilot training may help to mitigate errors. Machine learning can be integrated into the concept of Crew Resource Management by considering the automation (autopilot) to be a teammate. Any automation used as part of Crew Resource Management must have the ability to communicate with others in the cockpit. Also, the automation must be capable of detecting and learning from edge cases (that do not occur often) and correcting for them, sometimes even going off of incorrect data. The NASA Learn-to-Fly Initiative, Carnegie Mellon University, and Boeing Aerospace Data Analytics Lab, and University of London (research under Haitham Baomar) are all working to further develop the application of machine learning in the cockpit.

Evidence of Autopilot Shortcomings Today

"Modern airliners do a good job of flying automatically until something unexpected happens. At that point, a pilot takes control and typically resolves the problem with no drama or fanfare. Very rarely, though, a pilot must save the day or die trying."[3]

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[1] "Safe Skies," The Economist (The Economist Newspaper, March 11, 2014), https://www.economist.com/graphic-detail/2014/03/11/safe-skies)

[2] Katie Mingle, "Children of the Magenta (Automation Paradox, Pt. 1)," 99% Invisible, June 23, 2015, https://99percentinvisible.org/episode/children-of-the-magenta-automation-paradox-pt-1/)

[3] Keith Button, "A.I. in the Cockpit," Aerospace America, January 2019, https://aerospaceamerica.aiaa.org/features/a-i-in-the-cockpit/)

In 1903, only 20% of airplane accidents were attributed to human causes, with the remainder due to mechanical failure. Today, this statistic is reversed, with 80% of airplane accidents caused by human error. In 1997, American Airlines captain Warren Vanderburgh brought focus to the issue of human error when he dubbed modern-day pilots “children of the magenta line,” a reference to the overreliance of airplane pilots on automation within the cockpit. The magenta line refers to the area of the preliminary flight display that illustrates the horizon and the pitch of the plane with respect to the horizon. “Children of the magenta line” indicates how pilots are overly conditioned to the use of automation and that they may not be able to be effective without it.

In 2007, Air France Flight 447 from Rio de Janeiro, Brazil to Paris, France stalled and did not recover, crashing into the Atlantic Ocean and killing all 228 passengers and crew. Earlier in the flight, the autopilot had been shut off due to inconsistencies in the airspeed sensor measurements; the airplane’s pitot tubes had become blocked by ice formation. The crew did not perform the proper procedures when attempting to correct the aircraft, ultimately causing it to stall and crash. The pilots should have been aware of the pitch and throttle position of the aircraft rather than solely relying on the speed data that was being fed to the aircraft controls since the ice in the pitot tubes led to incorrect airspeed data. However, the pilots had been conditioned to rely on their instruments, so when the autopilot shut-off, the pilots were not prepared for how they should properly react. During the six months before the incident, the captain logged that he was only in control of the aircraft for about 4 hours out of a total of 346 hours of flight time, highlighting the heavy reliance on autopilot.[4]

In 2013, Asiana Airlines Flight 214 crashed during its final approach to San Francisco International Airport, as a result of flight crew mismanagement of the aircraft and a flaw in Asiana Airlines’ pilot training. The pilot unintentionally deactivated the automated airspeed control and failed to execute a holding pattern above the airport when he realized the aircraft was too low and not traveling fast enough to perform a landing. The flight crew did not manage to execute a visual approach correctly or adjust for the several issues they were aware of on the aircraft, and instead, the plane crashed just short of the runway, the landing gear and tail striking the sea wall that protects the airport from San Francisco Bay.[5]

Lastly, in 2018, Lion Air Flight 610 crashed 13 minutes after takeoff, killing all 189 passengers and crew. Poor pilot training was determined to be one of the main causes of the crash. Initial investigations revealed flight control issues in addition to sensor failures, such as the Angle of Attack sensor, and other instrument failures. Although there were several issues with the Maneuvering Characteristics Augmentation system, a faulty sensor, and poor aircraft maintenance, the most notable cause of the accident was poor pilot training since the pilot was not properly trained to overcome the automated system failures he faced. [6]

These accidents demonstrate how the airline industry is relying too heavily on the use of autopilot, which may save money (since autopilot is more fuel efficient than hand flying) and support improved safety when all is operating as planned. Pilots today are more prone to make mistakes because there is less emphasis on pilot training and more on automation within the cockpit. In addition, these crashes usually do not have novel causes, but there may not be sufficient communication between airlines, particularly across countries, so accidents with similar causes have a propensity to be repeated. To address the overreliance on automation, some

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[4] Keith Button, “A.I. in the Cockpit,” Aerospace America, January 2019, https://aerospaceamerica.aiaa.org/features/a-i-in-the-cockpit/)

[5] Ibid.

[6] Ibid.

airlines have started instituting a requirement that a pilot needs to hand fly a certain amount of time in the air. For example, a pilot may need to hand fly a certain number of hours every third flight. It is vital that pilots vigorously exercise their flying capabilities to ensure that if they take control of a plane, they are well prepared to do so.

Artificial Intelligence and Machine Learning

"For passenger planes to fly autonomously, software would have to be capable of handling these edge cases."[7]

Automation is progressing from simple instruments to increasingly cognitive agents that can work as teammates with humans. Artificial intelligence in avionics is significantly more complex than other artificial intelligence applications because the software is required to cope with three-dimensional situations, including a plethora of flight control surfaces, ambient conditions, and a wide range of data from numerous sensors. Edge cases, rare scenarios that are seldom incurred by human pilots and automation working together, must be contemplated and addressed. These edge cases may be similar to other scenarios, but any two scenarios are rarely identical, so the artificial intelligence must account for minute differences. Many accidents are caused by the autopilot receiving incorrect data, causing it to turn off and leaving the pilot with incorrect readings on their instruments. The artificial intelligence software needs to recognize which sensors are reading incorrect data and how to adjust for the failure in sensors. With all of the aircraft incidents occurring due to human error, effectively integrating artificial intelligence into the cockpit has the potential to wield the power to make flying even safer.

Machine learning, or the use of computer algorithms that improve automatically through experience, is currently the most popular way of improving technology within the cockpit. One of the main issues with artificial intelligence is that it is only as good as its input data. As many cases demonstrate, sensors may be defective to start or may fail mid-flight, so it should consistently be assumed that there will be incorrect input data as a principle. It is difficult to research artificial intelligence and machine learning due to the absence of available data. To program software that will resolve and overcome issues with incorrect data inflow, programmers need to study potential sources of incorrect data and how that data may impact different systems within the aircraft. They can also use this information to help the automation "learn" the processes to remediate. Capacity for machine learning is substantial and can be built to support vector machines, decision trees, and neural networks that can be applied to air traffic management, pattern recognition, computer vision, text processing and voice recognition.

There is a famous saying within the aviation industry that, "In the future, the cabin crews will be comprised of a pilot and a dog. The pilot will be there to reassure the passengers and feed the dog. The dog will be there to bite the pilot if he tries to touch anything."[8] This saying conveys that the willingness of passengers to allow control to increasingly or completely be turned over to machines is a significant barrier to the potential expansion of artificial intelligence and machine learning. In a BBC survey of 8,000 people, under the hypothetical scenario that automation would completely take the place of humans in the cockpit, 54% of people said they would be unlikely to board a plane without a pilot and only 17% stated they were likely to

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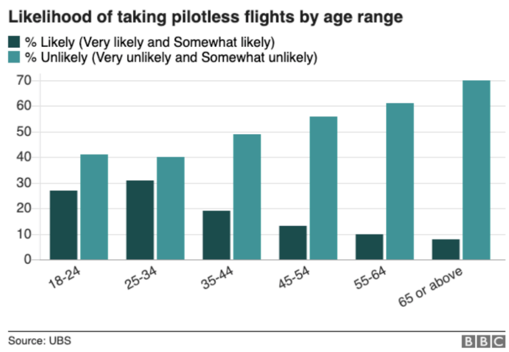
[7] Keith Button, "A.I. in the Cockpit," Aerospace America, January 2019, https://aerospaceamerica.aiaa.org/features/a-i-in-the-cockpit/)

[8] Pablo Hernandez, "A.I. in the Cockpit: Fact or Fiction?," Datascience.aero, July 5, 2019, https://datascience.aero/ai-cockpit-fact-fiction/)

board.[9] For autonomy within the cockpit to grow in popularity, there will need to be a cultural shift with both passengers and the crew. Research studies show that many passengers, particularly older generations, may not want to travel in a pilotless aircraft due to too many unknowns, especially when the technology is newer. For pilots, they typically have more power in the cockpit and the other flight crew members have less of a say, so eliminating pilots would require a new chain of command. Boeing and Airbus have already begun work on pilotless aircraft, but much persuasion and vigorous testing would be required to even convince passengers to travel on pilotless aircraft.



Crew Resource Management

"With advances in machine intelligence, processing speed, and cheap and plentiful memory, automation has advanced to the point that it can and should be treated like a teammate to fully take advantage of its capabilities and contributions to the system."[10]

NASA's Johnson Space Center has a Space Flight Training Division that developed a training program focused on successful human error management. Crew Resource Management (CRM) is one of the key components deployed to enhance the culture of safety. Early CRM training was heavily focused on practices based on psychological studies rather than specifically related to aviation. It was later found that to have successful CRM, the crew must focus more on skills and behaviors that will allow them to interact more effectively rather than on personality-based concepts.

For many years, automation has been becoming more prevalent in many aspects of daily life, with ever increasing complexity. While automation has evolved dramatically, it still is not perfect, and many people are still uncomfortable with the idea that artificial intelligence will have the power to make decisions that can impact lives. Within the aerospace industry, Crew Resource Management is one of the main programs that has been developed to reduce accidents. Born out of a time when accidents caused by fuel exhaustion and distractions were more common, the Crew Resource Management guidelines that all airlines follow helped to mitigate common errors. "CRM training is not a single fix for human error. Rather, it is a part of an organization's commitment to error management that includes building and nurturing a safety

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[9] Pablo Hernandez, "A.I. in the Cockpit: Fact or Fiction?," Datascience.aero, July 5, 2019, https://datascience.aero/ai-cockpit-fact-fiction/)

[10] Robert Shively et al., "Crew Resource Management for Automated Teammates (CRM-A)," NASA (NASA), accessed April 12, 2020, https://ntrs.nasa.gov/search.jsp?R=20180004774)

culture."[11] Crew Resource Management includes concepts such as threat and error management; verbalize, verify, monitor; and standard operating procedures. Merritt and Helmreich (1996) found that the cockpit of jets, space shuttles, and nuclear power plants are all places where team dynamics are integral, and therefore where Crew Resource Management may be deployed to improve effectiveness and reduce errors.[12]

In order to have automation that functions well with humans, it is important to have bi-directional communication or Verbalize, Verify, Monitor. The artificial intelligence needs to be able to verbalize an action to be taken, verify a statement made by others in the cockpit, and monitor the actions taken to make sure they are done accurately and taken correctly. The technology must be able to team up with the humans, answering questions when asked and proposing questions when the technology wants clarification on the actions of a human. The technology must be able to engage in conversation, share hypotheses and provide input. If the pilot were to deviate from the flight path, the technology may have the ability to question the pilot, contact air traffic control, and in extreme conditions, monitor the pilot's vitals and physiological state to ensure the pilot is fit to operate the aircraft. Both the humans and the technology must have situational awareness at all times, meaning they both must be aware of their surroundings at all times. Since Crew Resource Management procedures may differ between airlines, the automation and humans need to have working agreements. For example, the human and automation may decide that the automation has complete control unless potential hazards are detected in which case the pilot would take over or the automation and humans could have a conversation about what to do next. It is important to note that the automation needs to adapt to many different personalities in order to be most successful. Some pilots may be more accepting than others when it comes to automation.

CRM training is also focused on threat and error management and standard operating procedures. Threat and error management is "a continuum of safety ranging from safe operations on one side to an undesired equipment state on the other."[13] This training defines what the different threats are and how to properly mitigate them to ensure that threats are not mismanaged by pilots. This has a great impact on avoiding the negative consequences in aircraft incidents when pilots do the opposite of what they should do; many times pilots do not have up-to-date training that would help them properly manage the threats. Another widely used CRM concept is standard operating protocols and procedures. Standard operating procedures include checklists that all pilots go through before operating an aircraft. This is one of the most integral aspects of pilot training because certain safety protocols are put into place that have to be removed before operating. If the crew cannot work together, even with these extensive guidelines in place, an all human crew may still fail.

Development of Machine Learning for Aviation

"A learn-to-fly algorithm works like a baby bird leaving its nest. Eventually, they've got to learn how to make that jump, and then they learn how to control themselves; not just hit the ground but fly around and navigate their environment."[14]

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[11] David Rogers, "NASA's Space Flight Resource Management Program: A Successful Human Performance Error Management Program," Aerospace Research Central, March 27, 2013, https://arc.aiaa.org/doi/abs/10.2514/6.2002-T4-12)

[12] Ibid.

[13] Robert Shively et al., "Crew Resource Management for Automated Teammates (CRM-A)," NASA (NASA), accessed April 12, 2020, https://ntrs.nasa.gov/search.jsp?R=20180004774)

[14] Keith Button, "A.I. in the Cockpit," Aerospace America, January 2019, https://aerospaceamerica.aiaa.org/features/a-i-in-the-cockpit/)

NASA has been making strides in the field of autonomy within the aviation industry through the Learn-to-Fly initiative. This program developed a model airplane that was better able to perform tasks than human pilots. In this experiment, NASA researchers put a model airplane into unstable flight mode as if it were in turbulence, and after less than two seconds of going up and down, the plane leveled off without any human intervention. A human pilot was given the same task and was outperformed by the software.

In 2015, Boeing and Carnegie Mellon University created the Aerospace Data Analytics Lab with the mission of utilizing machine learning to analyze massive amounts of information. "Every aircraft now has thousands of sensors, each which generates readings about once per second. That's creating vast quantities of data that overwhelms any analytical strategy we now have. So we're developing scalable algorithms that process it in the cloud. Everything from safety and predictive maintenance to in-flight performance characteristics and the aging of aircraft can then be better tracked and understood," stated Jaime Carbonell, a project leader and CMU computer scientist.[15] This incoming data may range from very complex information from sensors, with each one having a particular format, or basic data left over from maintenance workers. The outcome of the projects at the Aerospace Data Analytics Lab could help Boeing and its airline customers develop monitoring, maintenance, and operational strategies that will limit downtime and save money in the air. CMU wants to produce artificial intelligence within the engines of the aircraft that are smart enough to identify holes in the data and request the data to fill the respective holes. "If you have two airplanes that fly the same route in the same configuration, but they're getting different fuel consumption readings, our systems will be able to cross-check all the parameters and dig down until it finds data that isn't present…" said Carbonell.[16]

Similar studies are being conducted at the University of London, where researchers are striving to increase safety by eliminating factors that cause human error, such as stress and lack of sufficient training. In their point of view, autopilot thrives in the simple, basic tasks in normal operating conditions, but fails for anything outside of this. There are a myriad of possible situations that may cause the autopilot to become disengaged, including strong turbulence. In these cases, pilots are trained to intervene to correct the errors, but they too are fallible. Haitham Baomar's Intelligent Autopilot System, currently in development at the University of London, encompasses the same training that human pilots receive. Using a version of a flight simulator, the researchers can train their autopilot to fly a Boeing 777 in severe weather conditions and teach it how to go about multiple edge cases, including engine failures and emergency landings. Treating the autopilot like a human pilot allows the automation to learn as it goes along, a different way of viewing machine learning. "The validation and verification process is very extensive, costly, and exhausting, but it might be applied to every new technology introduced to aviation, given the safety requirements."[17] Baomar's research is very extensive, as it goes into very specific instances the aircraft may encounter. Allowing the automation to learn as a human would allow it to become a better teammate in the future. The patterns in which a human and the

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[15] Eric Adams, "AI Wields the Power to Make Flying Safer—and Maybe Even Pleasant," Wired, March 28, 2017, https://www.wired.com/2017/03/ai-wields-power-make-flying-safer-maybe-even-pleasant/)

[16] Ibid.

[17] Eric Adams, "AI Wields the Power to Make Flying Safer—and Maybe Even Pleasant," Wired, March 28, 2017, https://www.wired.com/2017/03/ai-wields-power-make-flying-safer-maybe-even-pleasant/)

automation rationalize may be similar enough to allow them to work harmoniously to solve potential problems.

Governing Organizations

National Transportation Safety Board (NTSB)

The National Transportation Safety Board is a Federal agency that is assigned by Congress to investigate every civilian aviation accident within the United States. The NTSB is charged with determining "the probable cause of the accidents and issues safety recommendations aimed at preventing future accidents."[18] The mission of the NTSB as it pertains to aviation is to improve the safety of transportation by investigating accidents, pushing for improvements in safety, and determining pilot certification appeals. The NTSB does not have any rules or regulations pertaining to automation in aviation but the organization may call for certain changes within the industry. For example, the NTSB investigated the Asiana Airlines Flight 214 crash and concluded that the design of the aircraft was becoming too complex and therefore that it was imperative to enhance training for the aircraft autopilot system. The NTSB wants to reduce the number of repeated accidents caused within the industry by allowing all crash information to be accessed. The organization reports about 1,750 cases annually and works to recommend adjustments to prevent similar accidents from occurring and to improve overall aviation safety.

Federal Aviation Administration (FAA)

Within the FAA's Aviation Safety organization, human factor specialists work to promote aviation safety by attempting to reduce human error. These specialists create guidelines and strive to improve pilot performance in the cockpit. They oversee the certification of pilots and others who are involved in safety-related positions. Regarding airline operations, the process to determine whether Crew Resource Management is effective is installed by the FAA in two Advisory Circulars: The FAA Advisory Circular 120-51E discusses Crew Resource Management, and the FAA Advisory Circular 120-54A discusses the Advanced Qualification Program (AQP).[19]

National Aeronautics and Space Administration (NASA)

NASA has a multitude of aviation organizations, each with its mission and expertise. One of the main elements of the NASA Aviation Safety Program is Aviation Safety Officers (ASOs). These Aviation Safety Officers are experts in their respective Flight Operations departments and, when necessary, team up with the Safety and Mission Assurance organizations. The Office of Safety and Mission Assurance is comprised of the Mission Support Division, Safety and Assurance Requirements Division, and NASA Safety Center. The Office of Safety and Mission Assurance develops policies and procedures regarding reliability and maintainability that promote the safety and success of all NASA programs. NASA created the Safe Autonomous Systems Operations Project to determine the maximum capabilities of autonomous machines. This project aims to promote maximum safety and efficiency while keeping costs low and being sustainable.

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[18] "About the National Transportation Safety Board," National Transportation Safety Board, accessed April 12, 2020, https://www.ntsb.gov/about/Pages/default.aspx)

[19] Robert Shively et al., "Crew Resource Management for Automated Teammates (CRM-A)," NASA (NASA), accessed April 12, 2020, https://ntrs.nasa.gov/search.jsp?R=20180004774)

Bibliography

"About the National Transportation Safety Board." National Transportation Safety Board. Accessed April 12, 2020. https://www.ntsb.gov/about/Pages/default.aspx.

Adams, Eric. "AI Wields the Power to Make Flying Safer—and Maybe Even Pleasant." Wired, March 28, 2017. https://www.wired.com/2017/03/ai-wields-power-make-flying-safer-maybe-even-pleasant/.

Button, Keith. "A.I. in the Cockpit." Aerospace America, January 2019. https://aerospaceamerica.aiaa.org/features/a-i-in-the-cockpit/.

Hernandez, Pablo. "A.I. in the Cockpit: Fact or Fiction?" Data science.aero, July 5, 2019. https://datascience.aero/ai-cockpit-fact-fiction/.

Mingle, Katie. "Children of the Magenta (Automation Paradox, Pt. 1)." 99% Invisible, June 23, 2015. https://99percentinvisible.org/episode/children-of-the-magenta-automation-paradox-pt-1/.

Rogers, David. "NASA's Space Flight Resource Management Program: A Successful Human Performance Error Management Program." Aerospace Research Central, March 27, 2013. https://arc.aiaa.org/doi/abs/10.2514/6.2002-T4-12.

"Safe Skies." The Economist. The Economist Newspaper, March 11, 2014. https://www.economist.com/graphic-detail/2014/03/11/safe-skies.

Shively, Robert, Joel Lachter, Robert Koteskey, and Summer Brandt. "Crew Resource Management for Automated Teammates (CRM-A)." NASA. NASA. Accessed April 12, 2020. https://ntrs.nasa.gov/search.jsp?R=20180004774.