Weather-Related Mitigation Strategies and Technologies Used by the Federal Aviation Administration in the Presence of Hazardous Weather Conditions

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Weather-Related Issues in Aviation

Hundreds of thousands of airplanes fly in the United States (US) National Airspace (NAS) each day and cross different terrains and weather conditions. The Federal Aviation Administration (FAA) is the government agency that regulates the NAS, ensuring it is safe for airplanes to fly in. One of the primary goals of the FAA is to "provide the safest, most efficient aerospace system in the world" (FAA, 2019, p1). However, the presence of inclement weather creates hazardous conditions in the NAS, which is one of the largest causes of flight delays. These weather conditions cause approximately 70% of all delays with an hourly delay cost of \$1400 - \$4500 per hour depending on the airline (Jones & Takemoto, 2018).

Historically, one of the deadliest disasters in aviation was the collision of two Boeing 747 aircrafts, Pan Am Flight 1736 and KLM Flight 4805, at Tenerife North Airport in the Canary Islands in 1977. This accident was due to dense fog conditions and the result of this accident was 583 fatalities that could have been avoided through integration of advanced technology and mitigation strategies for aircraft operations in extreme weather conditions (Burt, 2014). Even in the past decade, one notable aircraft disaster was the crash of Air France Flight 477 into the Atlantic Ocean on June 1, 2009. This crash caused 228 deaths since ice crystals blocked the plane's pitot tubes, a necessary system for determining air speed (CNN Wire Staff, 2012).

The Air Transport Association has actually forecasted a total of 8.2 billion airline passengers will fly commercially in 2037, with a 3.5% compounded annual growth rate for the industry (Garcia, 2018). Over the past 20 years itself, passenger numbers have risen from 1.467 billion in 1998 to 3.979 billion in 2017. This is concerning, especially if 68% of extreme weather events stemmed from some form of human-caused climate change (Mcsweeney, Pearce, & Pidock, 2019). According to the FAA, most weather-related accidents are fatal because it is difficult to detect dangerous weather conditions (FAA, 2018). This is where technology can help detect such conditions. Thus, this research will explore evidence of weather-related technologies, understand the motivation for developing the technologies, and analyze their use in the Air Traffic Control (ATC) system.

Aviation Background and Connections to Human, Social, and Technology

To provide some context, the general public perceives the FAA as a government organization that ensures safe aircraft operation through enforcing rules and policies. According to FAA data, the Air Traffic Organization (ATO) services more than 44,000 flights or 2.7 million passengers daily (FAA, 2019). Within the ATO, the United States domestic route with the highest demand is from New York (JFK) to Los Angeles (LAX) with 3,531,613 fliers in 2018 (Radka, 2018). There is a general expectation that each and every one of these passengers will board a flight in New York and land safely in Los Angeles. This is important for frequent business travelers since New York and Los Angeles serve as the headquarters for many Fortune 500 companies. An externality such as the late arrival of an aircraft, air carrier delay, or weather, could actually impact the itineraries of passengers that have a connecting flight or important place to be at by a given time. Since air transport is an integral component of many people's lives, there are specific FAA initiatives that ensure air transportation is safe and reliable, especially in the presence of dangerous weather conditions.

The FAA's NextGen program, which aims to improve air transportation to make flying safer, efficient, and predictable, is developing new weather-related tools within the ATC System that affect all the actors present in the system. Some human-human interactions include pilots communicating with controllers, pilots communicating with passengers, and even flight crew communicating with passengers. The introduction of these new technologies introduces a non-human interaction as pilots and controllers have to interface with a tool through a technical medium. This research will focus on how the technology facilitates interactions to avoid weather impacts on the aircraft, while considering a social dimension behind the technical design.

Let us look at the use of the Air Traffic Management (ATM) Tool as an exemplary FAA technology that facilitates interactions between humans and nonhumans. The ATM Tool is a combination of a variety of departure management tools that aids in decision support during convective weather conditions (Webber, Evans, Moser, & Newell, 2007). This tool facilitates interactions between FAA and Human-Traffic Flow and interactions between pilots and FAA Ground Operations. These interactions provide user feedback and lead to further technology enhancements that benefit pilots and controllers. While this technology facilitates interaction among key stakeholders, there are some other implications in using this tool.

One of the critical requirements for pilots operating an aircraft is to maintain Situational Awareness (SA), as this impacts their ability to perform tasks in a focused way (Endsley, 1997). A change in the operating environment for pilots leads to potential operator overload since pilots have to monitor the performance of the technology. While these tools guide decision making and optimize task efficiency, NextGen must still design technologies to ensure they do not negatively impact the work of operators. This research has evaluated some of these extensively used weather-related technologies along with the social implications of their use on pilots and controllers.

Application of Actor Network Theory and Social Construction of Technology

To frame my research, my analysis will rely on *Actor Network Theory* by Bruno Latour and the *Social Construction of Technology* by Trevor J. Pinch and Wiebe Bijker. Latour (1992) argued that the development of technologies leads to achieving certain values and political goals as they shape the everyday lives of human beings. Given the development of newer technologies, Actor Network Theory (ANT) will be used to structure the analysis of how actors have to adapt to the introduction of new weather-related technology. Drawing specifically from Latour's discussion of ANT, my research will focus on the delegation of technology to nonhumans, or delegation of responsibility to weather-related automated tools and technologies.

Weather-related Decision Support Tools are now transitioning the decision-making process from certain actors in the network, such as pilots and air traffic controllers, to the technology itself. A program of action, as Latour defined, is a set of instructions that can be substituted by an analyst for any artifact. This leads to the delegation of different components in a program of action to both humans and nonhumans. The main program of action in the NAS, given the presence of hazardous weather conditions, is for aircrafts to avoid these weather systems. An antiprogram, on the other hand, is an aircraft traveling through a dangerous weather system. The weather-related technologies and tools are additional layers that support the program of action, ensuring aircrafts make well informed decisions and circumvent dangerous conditions, of course at the price of researching and investing in these technologies. However, paying the price could result in positive impacts measured by number of flight accidents avoided, amount of flight delay time reduced, and number of flight plan conflicts avoided. While this delegation shows system-wide impact, it should be acknowledged that actors still have to adapt to this technology-driven systematic change. Thus, ANT provides an umbrella for evaluating actor adaptation and system impact.

The Social Construction of Technology (SCOT) supports ANT through emphasizing how technology has a meaning defined by different social groups based on uses, meaning, and designs (Bijker & Pinch, 2008). Within the ATM system itself, there are several social groups such as passengers, pilots, and operators who helped shape the evolution of aviation. The roles of these social groups change through the introduction and presence of weather-related technologies, with some change in reflected attitude towards their use. As NextGen initiatives become increasingly technologically-driven, new social groups could emerge, such as a faction that is against automated decision tools and another faction in support of researching and developing weather-related tools. Thus, SCOT frames the analysis of key groups directly and indirectly impacted by the FAA's use of weather-related technology.

To summarize, the primary framework this research will use is ANT, focusing on the delegation of technology to nonhumans for weather-related Decision Support Tools. The SCOT will focus on the role and emergence of social groups or actors that influence the technological development.

Research Question and Methods

Through my research, the question I will address is *what are weather-related technologies and strategies the Federal Aviation Administration uses in the presence of hazardous weather conditions?* Since difficulty in detecting dangerous weather conditions has caused many recent aircraft disasters, I want to explore how aviation technology is used and developed to mitigate risk of such occurrences.

Research on this topic examined how the Air Traffic System uses technology and other tools to handle extreme weather conditions ranging from natural disasters to common storm systems. Two primary methods provide evidence from prior literature and content analysis to inform the case studies. The prior literature consisted of technical descriptions of weather-related technologies and instruments, drawn specifically from articles published by the NASA Langley and Glenn Research Center, Federal Aviation Administration, and NCAR Research Applications Laboratory. I reviewed each of the published articles pertaining to a technology or system, documented the technology, described technological functionality, and analyzed the technological use for a specific weather condition.

Beyond the technical details of each weather-related technology, I used content analysis of case studies to motivate technological development. For each weather condition, I researched historic aircraft accidents that motivated and connected to evidence of technological development. These accidents were documented as case studies by the National Transportation Safety Board (NTSB), a U.S. government agency in charge of investigating every U.S. civil aviation accident (USAGov, 2020). I queried the NTSB database for aircraft disasters that relate to a specific weather condition. For example, one important weather condition I decided to investigate was microbursts as this caused many airline accidents over the years (Smith, 2014). I queried the NTSB and found all relevant microburst-related aircraft accidents for analysis. From the resulting query, I chose a few case studies of aircraft disasters that preceded specific technological development. After linking the technology and case study, I analyzed changes in the role and relationship of pilots and affiliated stakeholders within the ATC system through the lens of ANT and SCOT.

Overview of Results

Through the analysis of several NTSB case studies and aviation technologies, there was an evident connection between historic aircraft accidents and technological developments. Table 1 summarizes eight devices developed and adopted, as well as the connections to weather patterns. These aviation technologies have changed the roles and responsibilities of pilots. Traditionally, pilots played an important role in the ATC system as they performed flight inspections, operated aircrafts safely, communicated with ATC, and monitored weather conditions. However, weather-related aircraft accidents led to technological development that transferred weather monitoring responsibilities from the pilot to the technology. Figure 5 shows the gradual transfer of pilot responsibilities to specific technical instruments. Traditional pilot training used to be something similar to "boy scout camp", but after gradually introducing more than 100,000 technological units, pilot training now emphasizes 4D situational awareness and prepares pilots for integrating their skills with automated devices and their potential issues (Zimmerman, 2017). Thus, pilot training and NextGen is preparing pilots towards an age of automation in pursuit of a safe NAS.

Instrument	Weather Condition	Metrics	Case Study	Technical Operation
Enhanced Turbulence Radar	Turbulence	Prediction Accuracy (%)	US Air Flight 427	Automated
Phase-1 LLWAS	Microburst	Probability of Detection	Eastern Airlines Flight 66	Semi - Automated
Phase-3 LLWAS	Microburst	Probability of Detection	US Air Flight 1016	Automated
NextGen Weather Processor	Precipitation	Identified Safety Level	Southern Airways Flight 242	Automated
Terminal Doppler Weather Radar	Microburst	Probability of Detection	Pan Am Airways Flight 759	Automated
Terminal Doppler Weather Radar	Microburst	Probability of Detection	Delta Airlines Flight 191	Automated
Ground Ice Detection System	Precipitation	Percent Correctly Found (%)	US Air Flight 405	Automated
Ground Ice Detection System	Precipitation	Percent Correctly Found (%)	Air Florida Flight 90	Automated

Table 1. A comprehensive list of technologies, their characteristics, and connections to a corresponding aircraft disaster. (Created by Iyer, 2020)

Microbursts

Since microbursts caused about 20 major airline accidents resulting in over 500 deaths, I decided to explore technologies that minimize risk of microbursts (National Science Foundation, 2003). For a background on the formation of microbursts, please refer to Figure 1. When researching technology used during the presence of wind shear and microbursts, one of the first technological instruments I came across was the Low Level Wind Shear Alert System (LLWAS). This system was first developed in the 1970s to detect large scale wind shifts as a part of Phase-1 LLWAS. It would flash wind data to the air traffic controller, have the controller read raw wind-related data from the sensor to the pilot, and have the pilot manually compute headwind/tailwind components via vector addition. The wind shear algorithm was automated and updated in 1996 through Phase-3 LLWAS, which minimizes the rate of false alarms and allows for a wider range of detection.

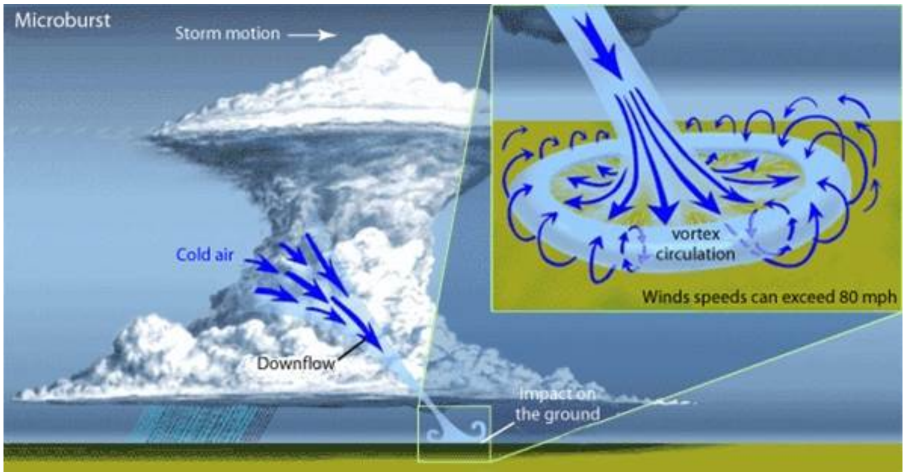

Figure 1. A formation of microbursts through a thunderstorm. (National Weather Service, n.d.)

However, the lack of predictive capabilities and long-term versatility of LLWAS led to the development of the Terminal Doppler Weather Radar (TDWR). The TDWR can characterize wind shear and report wind shifts to airport operations (Engen, 1987). In addition, the TDWR ensures a 0.90 probability of wind shear detection in the coverage area, has better spatial coverage and resolution of smaller scale events than LLWAS, and detects smaller size events that are farther away from the airport. Some important case studies related to wind shear and microburst-related aircraft accidents motivate the development and use of LLWAS and TDWR.

One of the first NTSB documented accidents related to microbursts was Eastern Airlines Flight 66 in 1975. The NTSB mentioned that the cause of the crash was the presence of adverse winds associated with a strong thunderstorm and delayed flight crew recognition and correction for the high flight descent rate, which was heavily reliant on visual cues (NTSB, 1976). In addition, the NWS issued a warning of gusty surface winds 50 km west of thunderstorms in the New York City area, which was not communicated to flight crews operating in that area.

Following this accident, Phase-1 LLWAS was implemented across several airports to flash wind data to controllers and pilots. 20 years later in 1994, a commercial airliner crash that occurred due to thunderstorms and microbursts was USAir Flight 1016, which resulted in 37 total fatalities. Some probable causes of this aircraft disaster include delay in flight crew's detection of wind shear, flight crew's decision to fly into the wind shear, and inadequate software on the flight wind shear warning system (NTSB, 1995). Two years later, Phase-3 LLWAS was subsequently launched as a more intricate and automated means of displaying microburst alerts to pilots and controllers. Thus, the LLWAS system gradually automated due to the occurrence of accidents from 1975 - 1994.

While some notable aviation case studies influenced the development of LLWAS, other accidents influenced initiatives for developing the TDWR. One accident is the crash of Pan Am Flight 759 on July 9, 1982. The NTSB identified the probable cause of this accident was a microburst induced wind shear causing a downdraft during the initial climb (NTSB, 1983). As a result, the pilots were unable to react in time, control the airplane descent, and utilize existing low-level wind shear technology for guidance during these conditions. The wind shear alert reported to the pilots and controllers also lacked substantial information as it did not specify the wind type, corresponding direction, and magnitude. Just three years later, Delta Airlines Flight 191 crashed on August 2, 1985 at a low altitude with severe microburst induced wind shear (NTSB, 1986). The probable cause for this accident was the lack of guidance to pilots and controllers for avoiding low-level wind shear and the lack of definitive, real-time wind shear information. Limitations in the LLWAS system for detecting wind directionality and obtaining on-demand, accurate, automatic, and specific wind information influenced the development of the TDWR, which has specialized microburst detection capabilities and reduces reliance on pilot judgment.

Turbulence

While microbursts are the leading cause of aircraft disasters, another important condition that 80% of commercial aircrafts face is turbulence (NTS, 2019). In general, turbulence is generated through relative movement of the disturbed air through which an aircraft is flying (SKYbrary, 2019). Turbulence can range from light turbulence, which is slight bumpiness due to changes in altitude, to extreme turbulence, where an airplane faces uncontrollable structural damage (Weather.gov, n.d.). When researching technology to mitigate risk of turbulence impact, I came across a National Aeronautics and Space Administration (NASA) publication on the Enhanced Turbulence Radar (Jarrell, Stough III, & Watson Jr., 2000). NASA developed the airborne radar with turbulence detection algorithms that uses past turbulence encounters as a predictive mechanism. Through this technology, moderate-to-severe turbulence hazards that are at least 25nm ahead of the aircraft could be predicted with 80% confidence and capability. Figure 2 shows a cockpit view of this radar in use. Adoption of automated turbulence reporting systems, such as the Turbulence Auto PIREP System (TAPS), has also increased since these systems provide timely and accurate reporting of turbulence encounters. This shows the transition from a highly communicative system between different ATC personnel to an automated reporting system, as it was integrated in 71 Delta Airlines Boeing 737-800 aircrafts by 2004. The need for the Enhanced Turbulence Radar arose from the analysis of a past turbulence-related accident.

One important turbulence-related accident in aviation history was US Air Flight 427. For background, this accident occurred on September 8, 1994 as the movement of the rudder surface to the blowdown limit made the airplane controllable (NTSB, 1999). According to the study, this was accompanied by wake turbulence as there were left roll and yaw effects, which are airplane rotations around different axes, due to the wake vortex. This was because Delta Airlines Flight 1083, a Boeing 727-200, was preceding US Air Flight 427 en route to Pittsburgh. These wake vortices occurred right around the initial upset of the aircraft before it did a nose-first dive into the hillside near Pittsburgh. Nearby wake vortices can be detected through intricate turbulence radar technology, showing the need for the Enhanced Turbulence Radar. Automated reporting capabilities to pilots and air traffic controllers can help circumvent effects of in-flight turbulence and wake turbulence from a nearby aircraft. Thus, the resulting fatalities from this crash subsequently influenced the development of the Enhanced Turbulence Radar in 2004, which provides an intricate display of turbulence patterns and on-demand information throughout the flight. NASA's efforts in developing this radar allows for integrated predictive technology in many fleets beyond Delta's Boeing 737's to minimize risk of impact from any degree of turbulence.

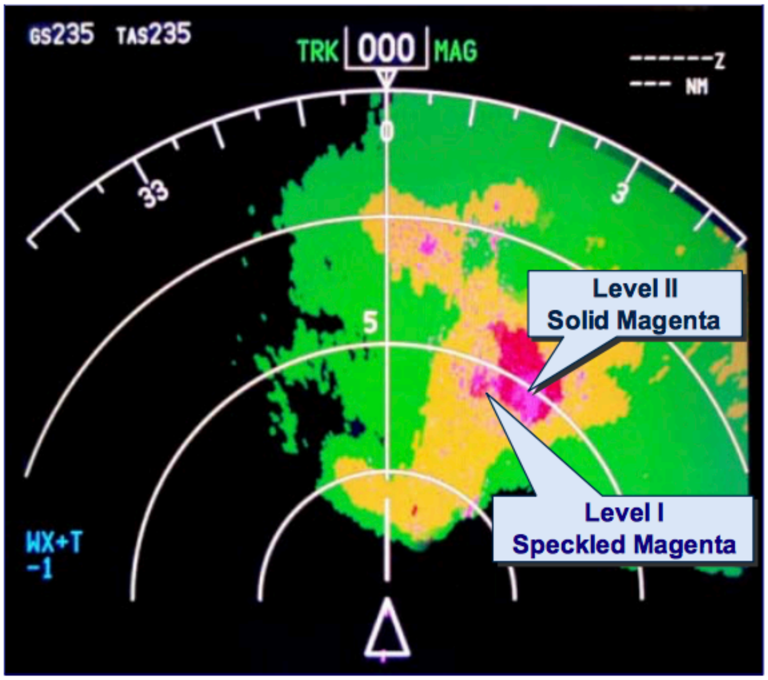

Figure 2. A cockpit radar display of turbulence. (Jarrell, Stough III, & Watson Jr., 2000)

Precipitation Conditions

Since aircrafts frequently face rainy and wet conditions for all phases of a flight, technologies emerged to support these conditions. Based on researching FAA NextGen initiatives, one main technology developed to detect rainy and wet conditions is the NextGen Weather Processor (NWP). The fully-automated NWP identifies both terminal hazards and en route safety hazards, integrates information from other devices, and provides translated weather information to predict route blockage and airspace capacity constraints up to eight hours in advance (FAA, 2015). Figure 3 shows the eight-hour predictive nature of the NWP for rain and even snow boundaries relative to major airports. Air traffic managers can use the NWP to communicate and achieve efficient, strategic, and tactical use of the airspace, while reducing the impact of rainy and wet conditions on flight delays.

Snowy and icy conditions have also negatively impacted aircraft operations, leading to technology to address these impacts. One recent FAA technology developed was the Ground

Icing Detection System (GIDS). Icing on an aircraft wing is detrimental to aircraft operation and its presence was determined by a human deicer on the deicing crew. In an effort to remove human visual and tactile inspections for icing on the wing, the GIDS uses infrared camera systems that scan wing surfaces of an aircraft. After scans are made, pictures of potential ice contamination are displayed through a remote-based interface, allowing ground crews to assess the presence and threat of ice (Bender et al., 2006). Images from the Ice Camera can be seen in Figure 4. The introduction of this system signaled a shift from visual inspections to infrared technology, thus displacing the role of traditional human deicers. Several historic aircraft disasters led to the integration of the NWP and GIDS in the ATC system.

This crash of Southern Airways Flight 242 in harsh precipitation conditions on April 4, 1977 ultimately influenced the development of the NWP. According to the NTSB, there were severe thunderstorms the flight encountered at an altitude between 14,000 and 17,000 feet and the probable cause of the accident was loss of thrust from both engines as the aircraft penetrated an area of severe thunderstorms (NTSB, 1978). NTSB also identified fault in the pilots as they relied heavily on the airborne weather radar, where dissemination of real-time weather information to the flight crew was difficult given ATC constraints. Even based on the recorded transmission, it is evident there was a lot of information communicated between controllers and pilots, making it difficult to provide timely weather information for pilots. Thus, the fully-automated and integrated NWP will ensure automatic information flow within the ATC system without pilot-controller communication over a transmission or complete reliance on an airborne radar.

Likewise, the GIDS was influenced from prior ice-related aircraft accidents. One of the first aircraft disasters related to poor icing conditions was the crash of Air Florida Flight 90 into the 14th street bridge connecting Arlington, Virginia to Washington, D.C. on January 13, 1982. The probable cause of this accident was the flight crew's failure to use engine anti-ice during ground operation and takeoff, decision to take off with snow and ice on aircraft airfoil surfaces, and failure to reject aircraft takeoff given anomalistic instrument readings. Even with the use of deicing fluid and a deicing crew, the lack of using an engine anti-ice system, which discharges an upstream of hot air to prevent ice from forming, and continual snowfall failed to prevent ice accumulation on the wings (NTSB, 1982). 10 years later, a similar accident was the crash of US Air Flight 405 in Flushing, New York on March 22, 1992. The probable cause of this accident was the flight crew's decision to takeoff without checking for potential ice accumulation after the completion of de-icing (NTSB, 1993). Even with the pre-departure application of Type 1 and Type 2 de-icing fluids, there was still ice contamination and accumulation on the wings that caused an aerodynamic stall and loss of control post-liftoff. 20 years later, the adoption of GIDS systems in aircrafts automates wing-based ice detection, aligns with modern de-icing procedures, reduces reliance on de-icing fluid, and reduces reliance on the flight crew's judgment in snowy and icy conditions.

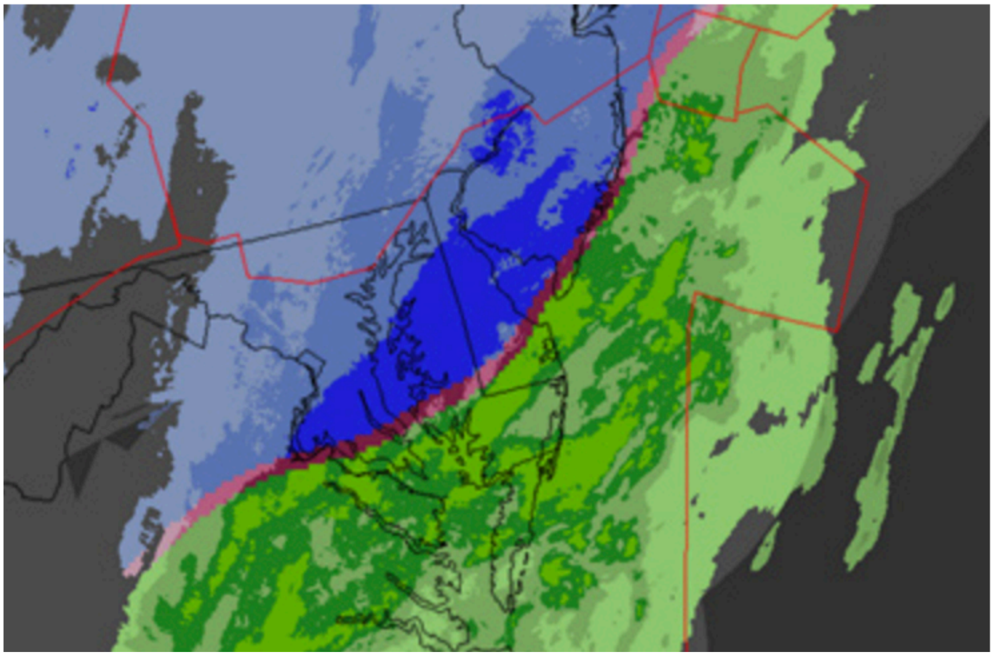

Figure 3. Display of NWP precipitation to show rainy areas in green, snowy in blue, and rainy-snowy mix in pink. (FAA, 2020)

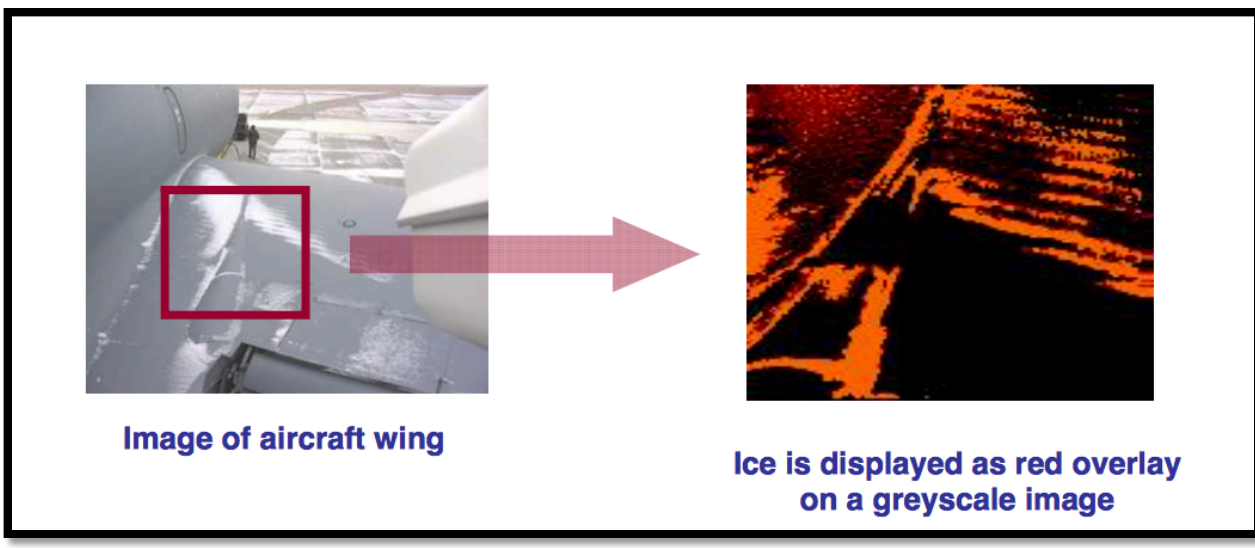

Figure 4. Ice Camera image of a wing that is contaminated with ice. (Bender et al., 2006)

Discussion

According to ANT, a program of action is a set of instructions applied by the analyst to an artifact where different parts are delegated to a human and nonhuman (Latour, 1992). This was evidently seen in the context of emerging weather-related technology to mitigate the impact of aircraft disasters. Human actors, or pilots, initially had control and judgment when operating aircrafts since the early 20th century. However, the rise in gradual threats to aircrafts, namely weather conditions, slowly delegated a larger proportion of the responsibilities to subsequent automated technology that emerged. Figure 5 shows the decrease in pilot responsibilities over a 30-year period with the introduction of each newly developed technology. For example, the introduction of the TDWR in 1987 enabled high accuracy wind shear detection and automatic reporting of wind shifts to airport operations, eliminating the need for pilot assessment and judgment. The gradual development of technology changes the communication infrastructure in the ATC network as it not only changes the role of pilots, but also changes the direct communication between pilots and ATC, Ground Control, crew, and passengers. Since the ultimate program of action is for aircrafts to operate safely and avoid dangerous weather conditions, the development of weather-related technologies creates additional layers to support this program.

Elements of SCOT supported ANT as relevant actors in the ATC network have a relationship with weather-related technology developed over time. Actors such as pilots, ATC, Ground Control, passengers, and flight crew play a critical role, either directly or indirectly, in supporting the program of action, which is to ensure safe aircraft operation in hazardous weather conditions. For example, during a weather disruption, ATC uses available weather radars to make strategic decisions and inform pilots in order to timely divert the aircraft. These are the kinds of interactions that are necessary to ensure the safety of aircrafts when they face weather-related threats. There is already evidence of a changing relationship between pilots and technology seen through the diminishing responsibilities of pilots in Figure 5, but some groups are particularly influencing these changes. FAA's NextGen is one of those external programs that have helped shape the rapid progression of long-term automation in the ATC system. The air traffic controller's role in the near-future will transition from tactically controlling each flight to managing traffic, where the relationship will shift towards a heavy reliance on technology as the supplier of information (Etris, 2018). Even though these technologies are being developed and relationships are changing, maintenance of technologies will eventually become a necessity, leading to the increased role and presence of technicians and engineers as a relevant "social group." While weather-related technologies have helped guide decision making, they have also initiated a gradual change in the meaning of aviation and change in interactions within the ATC system. In order to mitigate pilot and air traffic controller overload amidst these changes, weather-related technologies should only be introduced at the right time and to relevant actors. This ensures the technologies effectively serve their purpose, which is to guide decision making and ensure safe aircraft operation in the NAS.

While this research drew the connection between historic aircraft disasters in different weather conditions and subsequent technologies developed, there were some limitations in this research. Most aviation accidents that influenced technological development occurred before the 2000s, skewing a lot of the analysis towards older case studies. Recent accidents were either not impactful enough to influence technological development or not fully documented and analyzed by the NTSB. A second limitation to my analysis was the diversity of cases available. Many weather-related aviation accidents, such as the crash of Korean Air Flight 801 and collision of

Pan Am Flight 1736 and KLM Flight 4805, occurred in a different country and were analyzed by other global safety boards, rather than the NTSB. To maintain consistency, I used NTSB cases of accidents that only occurred in the United States. One recent evidence of a new hazardous weather condition for aircrafts is tsunamis, as five flights flew through high-risk tsunami clouds on January 1, 2019 in Makassar, Indonesia (The Jakarta Post, 2019). Thus, my analysis is not limited to three weather conditions as new conditions can emerge and impact aircrafts. Since FAA's NextGen program is increasingly developing technology to ensure public safety, a caveat to this paper is future weather-related technological development will occur and may not be directly motivated by a specific aircraft accident.

For future research, I would gather additional evidence from pilots regarding their technological usage. This would involve calling pilots who work at Charlottesville-Albemarle Airport (CHO) or Washington-Dulles International Airport (IAD) to gain insight on their interactions with weather-related technology and hear the transformation of their roles and responsibilities over the years. In addition, I would draw from additional case studies published by other organizations beyond the NTSB. Another future research prospect is self-flying planes and evaluating a complete transformation of the aviation industry, role of various actors, and role of pilots in the ATC system.

Through this research, I furthered my aviation and FAA knowledge by understanding the role of aviation technology in the ATC system. For the first two summers of my undergraduate career, I interned at the FAA as a Data Analyst Intern and gained a lot of exposure in general aviation, FAA systems, and the NextGen program. A few years down the road, I see myself working in the aviation industry again as either a Consultant or Product Manager. Given my enhanced knowledge on the background, role, and impact of aviation technology, I can apply this knowledge in my future aviation-based product management or technical consultant role.

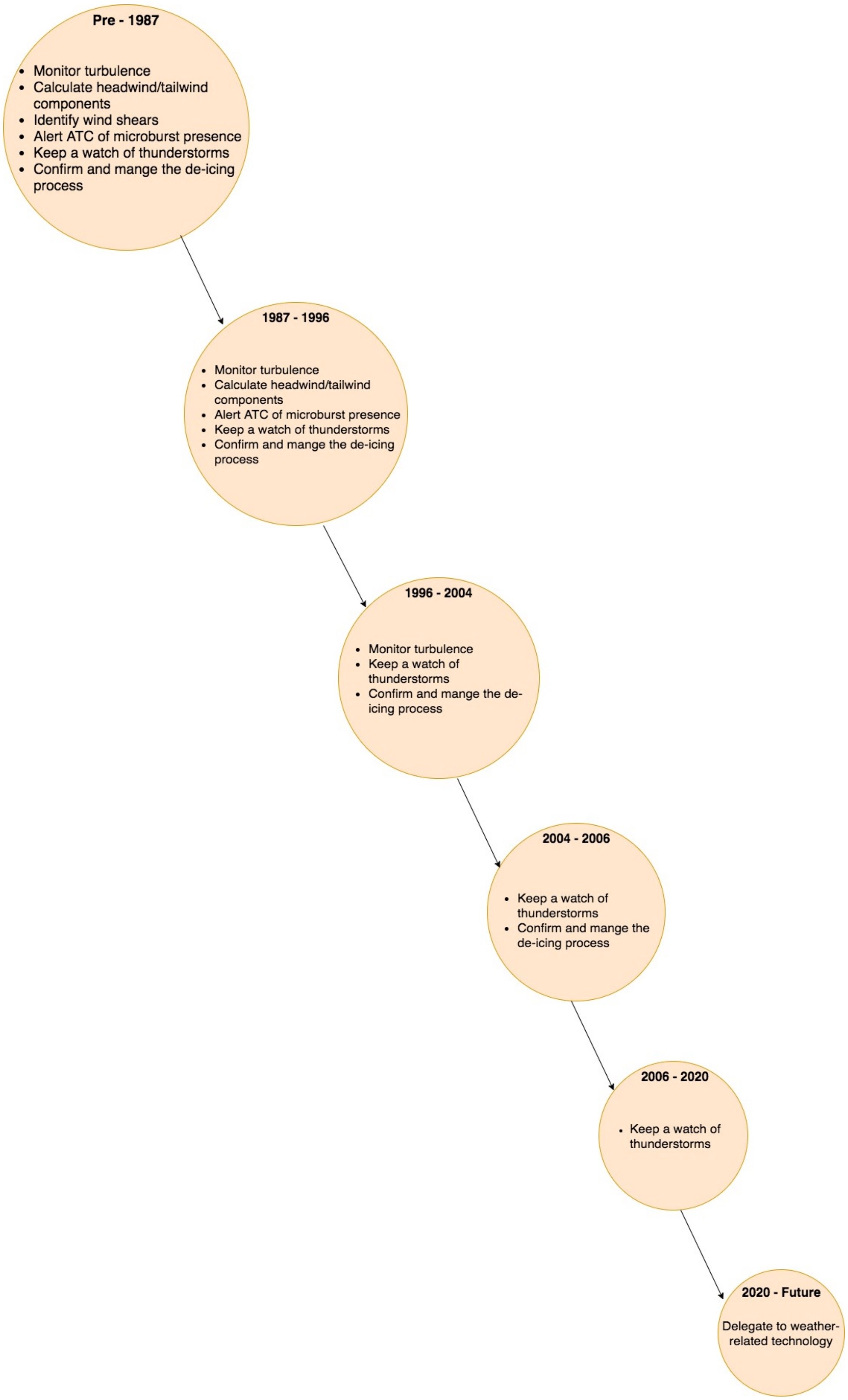

Figure 5. The transformation of pilot responsibilities over time as technology emerged. (Created by Iyer, 2020)

Conclusion

The occurrence of hazardous weather-related aircraft disasters influenced automated technological development with the goal of promoting a safe NAS. While automated technology minimizes risk of future accidents, it consequently changed the role of pilots and other flight crew. This is important as future technology developers need to be cognizant of the relationship between aircraft disasters, technology, and responsibilities of a pilot. Some next steps for NextGen Weather Program researchers are to continue developing aviation technology and maintain awareness of technological impacts on pilots and others. Future researchers may even reconsider whether or not certain technology should be introduced and if it is, how to mitigate the risk of impact on different actors. In addition, the gradual transfer of responsibilities could signal a shift towards a fully-automated aviation system, where the future role of a pilot is rendered obsolete. Future research on self-flying planes and the future of air travel may provide evidence suggesting this end result for current pilots. In conclusion, this research conveys to FAA researchers and other aviation specialists the motivation behind technological development, connection between different aviation accidents and technical instruments, and transformation of pilots' roles and responsibilities in the ATC system.

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