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OBJECTIVES

The University Aviation Association publishes the Collegiate Aviation Review International throughout each calendar year. Papers published in each volume and issue are selected from submissions that were subjected to a double-blind peer review process.

The University Aviation Association is the only professional organization representing all levels of the non-engineering/technology element in collegiate aviation education and research. Working through its officers, trustees, committees, and professional staff, the University Aviation Association plays a vital role in collegiate aviation and in the aerospace industry. The University Aviation Association accomplishes its goals through a number of objectives:

- To encourage and promote the attainment of the highest standards in aviation education at the college level
- To provide a means of developing a cadre of aviation experts who make themselves available for such activities as consultation, aviation program evaluation, speaking assignment, and other professional contributions that stimulate and develop aviation education
- To furnish an international vehicle for the dissemination of knowledge relative to aviation among institutions of higher learning and governmental and industrial organizations in the aviation/aerospace field
- To foster the interchange of information among institutions that offer non-engineering oriented aviation programs including business technology, transportation, and education
- To actively support aviation/aerospace oriented teacher education with particular emphasis on the presentation of educational workshops and the development of educational materials covering all disciplines within the aviation and aerospace field

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Resilience Attributes of Certificated Flight Instructors

David Cross
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The aviation industry has extensive vocabulary, data sources, and theoretical models to investigate human errors. However, the industry does not have commensurate ways to think about and analyze human success. Learning from successful routine operations is challenging because the corresponding common language and data streams are less robust. This paper explores the use of the critical incident debrief method to collect data on routine resilient performance among Certificated Flight Instructors (CFI). CFI thoughts and behaviors were coded in accordance with resilience theory. The critical incident debrief method is a valuable source of data for exploring resilient performance as it provides researchers with insights into CFI thoughts and intentions that may not be observable through their behaviors. CFI performance can be analyzed through the lens of resilience theory, but coding reliability remains a challenge.

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Cross, D., & Kiernan, K. (2022). Resilience attributes of certificated flight instructors. *Collegiate Aviation Review International*, 40(1), 1-24. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/8402/7727

The aviation industry has robust ways to analyze human errors but lacks corresponding widely accepted data sources, vocabulary, and models to analyze positive human performance. The overwhelming majority of flights across all facets of the aviation industry end successfully, yet the behaviors that lead to the successful handling of unexpected events in routine operations are rarely studied.

Because human error has been implicated in 80% of aviation mishaps (deSant'Anna & deHilal, 2021; Erjavac et al., 2018; Kelly & Efthymiou, 2019), reliable and valid models (Wiegmann & Shappell, 2017; Chen et al., 2019; Lower et al., 2018), reporting sources (NASA, n.d.), and observation techniques (FAA, n.d.) have been developed. Partly due to these efforts, the mishap rate in commercial aviation has been steadily decreasing worldwide (ICAO, 2021). However, continued gains in aviation safety will require new approaches that expand the data stream to include all operations.

Fortunately, the gap in knowledge concerning routine pilot performance is beginning to be addressed with the development of new models, data sources, and observation techniques (Broderick, 2021; Holbrook et al., 2019; Kiernan, 2019; Kiernan, Cross, & Scharf, 2020). The intent of this paper is to continue that trend and open a discussion about how best to study positive human contributions to aviation safety.

Purpose

The purpose of this pilot study was to identify behaviors that increase system resilience in university Part 141 school certificated flight instructors (CFI; commonly referred to as instructor pilots) and to explore whether CFI behavior can be categorized according to resilience theory.

Background

Traditional perspectives on human performance have sought to reduce error and variability. These approaches have successfully reduced aviation mishaps due to human error. However, as aviation systems become more complex, with more dependencies between subsystems, the notion that an error or failure in a single subsystem is the locus of hazard and risk becomes more difficult to defend (Leveson, 2020). Instead, it is the interaction between elements of a complex sociotechnical system where hazards lie. These hazards are difficult to identify and mitigate with traditional risk management approaches (Leveson, 2020). Therefore, as a complement to these traditional approaches, the properties of systems that make them more resilient to disturbances should also be studied. The concept of resilience engineering helps clarify and articulate the mechanisms by which systems can withstand disturbances, whether those disturbances are errors or exogenous events that are difficult to predict.

Resilience Theory

Resilience refers to "the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions" (Hollnagel et al., 2011, p. xxxvi). The role of resilience theory is to form a safety system that is flexible and can accommodate both expected and unexpected operational challenges.

At its core, the model posits four essential abilities, shown in Figure 1 and explained below, through the example of an instructional flight on a summer afternoon:

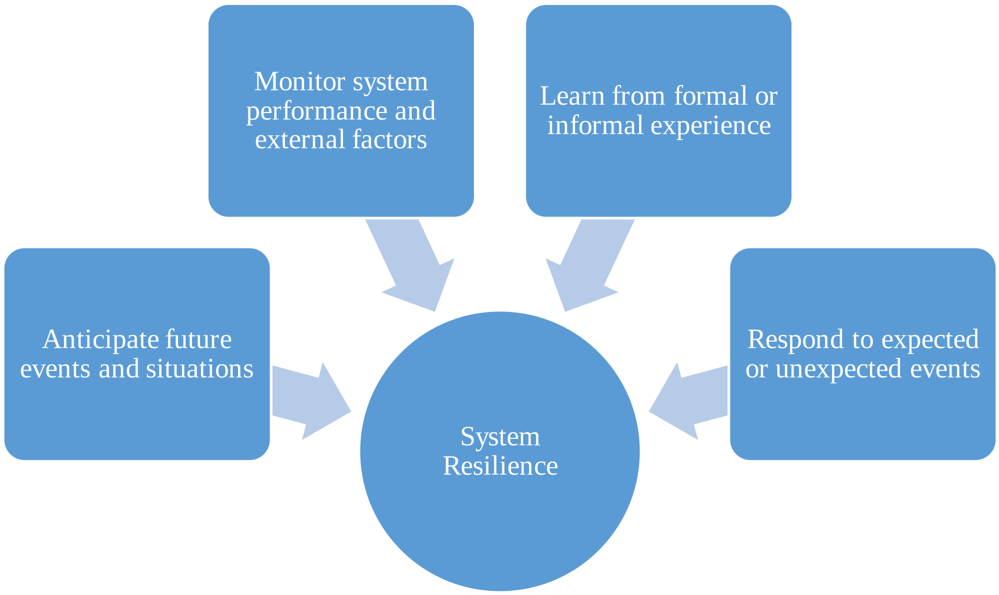
- The ability to anticipate future system states or events. A resilient system assesses its own adaptive capacity and whether or not it can meet upcoming challenges, and whether a sufficient buffer exists. A resilient system can shift priorities dynamically as the environment changes. Example: Knowing that weather can build rapidly in their area on summer afternoons, the instructor considers their own personal minimums and factors that into flight planning.

- The ability to monitor relevant indicators. A resilient system recognizes what needs to be known and uses objective, quantifiable, and available indicators to inform decision-making. For example, the instructor frequently checks home field weather during the flight.

- The ability to respond to disruptions or disturbances. A resilient system "must be both prepared, and prepared to be unprepared" (Hollnagel, 2011, p. 47). Inevitably, unanticipated circumstances will arise for which there is no template or procedure. The resilient system first recognizes these edge cases as beyond the boundary of what is expected and then combines readiness and creativity to meet the unexpected demands. For example: when the student suddenly gets airsick, the instructor accounts for both weather and unexpectedly flying single pilot with a sick crewmember.

- The ability to learn from success and failure. Learning in resilient systems can result from reinforcement of good decisions, not just from negative consequences of poor decisions. For example, the instructor learns that having a realistic plan of where to go if the weather closes in is an important preflight task.

Figure 1
Model of Resilient Performance (Hollnagel, 2011)



The defining drive of the resilience theory is anchoring models of successful behaviors by analyzing factors of human and system performance. It follows a logic similar to that of human behavior analysis, which analyzes and interprets not only errors and deformations but also successful patterns of cognition and information processing (Oster et al., 2013). Historically, models that are focused on analyzing accidents have typically been linear. They aim to prevent negative outcomes by identifying known factors that lead to mishaps. However, not all mishaps can be identified and understood through linear models. Such accidents are a result of a complex codependence of various events and factors that influence one another. Therefore, resilience theory provides a model that works through analyzing the accident causation and forming the ability to identify and accommodate the plausible due events (Hollnagel, 2011). Resilience theory provides a lens through which to analyze not just behaviors that lead to accidents but behaviors that improve the system's ability to withstand disturbances.

Examining human performance and its role in resilience is not without its critics. Leveson (2020b) points out that the safest systems are those which have taken a holistic approach to system safety, vice a narrow perspective that focuses solely on the operator. The intent of this research is not to deny the importance of the system within which CFIs operate, but rather to explore CFI behaviors that positively impact overall system resilience.

Data Sources and Observation Techniques for Studying Resilient Performance

Current data sources used in aviation safety include accident and incident investigations, the Aviation Safety Action Program (ASAP), the Aviation Safety Reporting System (ASRS), Line Operations Safety Audits (LOSA), and the Flight Operational Quality Assurance program (FOQA). Accident and incident investigations, ASAP, and ASRS generally collect data on adverse events. LOSA collects data on routine operations, but within a framework of threat and error management. FOQA collects data on all routine operations.

In 2018, American Airlines and the Allied Pilots Association initiated a Learning Improvement Team (LIT) to develop methods to capture data on routine resilient performance (Jeffries et al., 2020). The team used two methods to collect data: a LOSA-style approach to categorize and quantify commercial pilot behaviors according to resilience theory, and “shop talk” conversations with line pilots. The LIT team produced an observation tool and trained observers to collect data on routine flights. To date, the team has collected observations on hundreds of flights, resulting in valuable insights into resilient performance in routine operations (Glavan et al., 2021). The shop talk conversations provided more insight into pilot reasoning than was possible with the observations alone.

The critical incident approach has been used to study unexpected events in routine operations among commercial airline pilots (Kiernan, Cross, & Scharf, 2020). While these approaches represent great advances in data collection for routine operations, widespread adoption of these data sources and exploration of their potential is still needed.

Problem

Aviation has tremendous data sources and robust models to study error, but insufficient ways to identify, categorize, discuss, and train success.

Importance of the Study

Understanding successful behaviors will contribute to system resilience, especially in flight training environments. As these behaviors can result in increased levels of safety, learning more about how positive behaviors contribute to system resilience can help training organizations, especially CFIs, create a culture of resilient performance and train positive outcomes.

Research Questions

Can university Part 141 CFI pilot behaviors be classified according to the four key attributes of resilient performance?

Can a taxonomy of resilient performance be articulated from investigating university Part 141 CFI pilot behaviors in routine operations?

Methodology

This project used a qualitative, case study approach based on incident debrief interviews with university Part 141 CFIs. A case study methodology was employed to examine the various aspects of the pilots’ thought processes within the theory of resilient performance. From this case study, multiple perspectives were represented and analyzed, creating specific themes for the purpose of addressing the research questions.

The study was designed using a purposeful sample of 15 university Part 141 CFIs to glean their understandings and experiences regarding their decision-making processes in aviation. The case study method allowed the researchers a better understanding of CFI's thought processes within a resilient system.

Using research questions developed by NASA, we developed open-ended questions with follow-up questions to probe for deeper meaning (see Appendix A) (Holbrook et al., 2019). After receiving IRB approval, requests were sent to Part 141 CFIs. Every participant read and signed a confidentiality consent form and was assigned a code to ensure confidentiality.

The purpose of this qualitative research study was to explore the decision-making processes of CFIs within the theory of resilient performance. As a follow-on study of airline pilots' resiliency (Kiernan, Cross, & Scharf, 2020), this data is intended to support a foundational understanding of pilots' thought processes and behaviors within a resilient performance. As in any research, unintended or secondary findings, which are not the primary target of the planned procedures, can greatly contribute to the results of this study and, by proxy, that of the field. Further, understanding the thought processes in real-world situations was envisioned as a secondary function of this research.

The researchers voice-recorded each participant's discussion throughout the interview. A written transcript was developed for each participant after de-identifying each participant's information. Each of the participants' responses offered insight into their perceptions, opinions, and personal recommendations regarding the flight instruction environment. The MAXQDA qualitative analysis software was used to organize and analyze the data. The participants were identified as Participant 1 (P1), and so forth. Using the inductive approach to data analysis, the researchers then extracted key statements and phrases while organizing them into broad patterns that corresponded with the research questions and finally summarized what was being communicated within each statement. From this extraction, the researchers identified the primary themes.

While the researchers had specific interview questions that were asked during each of the semi-structured interview sessions, the interviewers allowed for the free flow of dialogue, which provided a broader set of information, yielding richer overall information than is presented in this discussion.

Limitations that could have been associated with the research study include whether the participants were available to be interviewed, the timing of the interviews, and that purposeful sampling was used.

Through the data collection process, the researchers were able to freely engage with the participants, which yielded additional unexpected findings. While not initially planned, the additional data provides a wealth of interpretive data to support the findings from the original structured research questions.

The data reduction process was helpful in further identifying these patterns and alignment to the research questions, and by proxy, the data aligned to the interview questions that support the research questions. In the review of these themes, the above connections are drawn based on their similar responses and the interpretation of this data. What is important to be mindful of is that qualitative data analysis is ongoing, fluid, and in fact, sheds light on the broader study questions as indicated below.

Participants

Fifteen CFIs from three Part 141 universities were recruited for participation in this study. The saturation of the data was met through this number of participants by ensuring that adequate quality data was collected to support the study; no new information was expected to be added to the emerging patterns that would enhance or change the findings of this study. The three participating schools represent a diverse sample in terms of location, school size, CFI experience, and culture.

Results

Research Question One

The first research question aimed to ascertain whether university Part 141 certificated flight instructor behavior may be classified according to the four key attributes of resilient performance, namely, Anticipate, Monitor, Respond, and Learn. The main objective was to categorize pilot behaviors in terms of strategies for resilient performance. Eight themes were identified from the data. The coding process used in developing the main themes for the first research question is presented in Appendix B.

Anticipate

Two themes were identified with regard to pilots' behaviors of anticipating incidences, that is, *considering and preparing* and *taking action in anticipation.* These correspond to two distinct aspects of anticipation: on the one hand, thinking about what might happen in the future, and on the other hand, taking action based what might happen in the future.

Considering and Preparing. The theme outlines how different pilots predicted the imminent incident and postulated their resilience. The participants highlighted that anticipation of unexpected incidents prompted them to consider obtaining all essential information about it, holding discussions regarding appropriate actions, and deciding on the best steps to take. For instance, Participant 2 mentioned:

> However, I knew it was cloudy. So the entire time I was out there, I was kind of watching that, knowing what we're going to one of these next.
> Similarly, Participant 6 explained,
> I mean clouds and stuff, especially here, I think I just, we talked thoroughly through it. We had a plan of action and then knew what we were going to do before that situation was to happen. So we talked about it before we even left.

Taking Action in Anticipation. The theme describes pilot behaviors relating to actions they take in response to anticipated events. From the interview responses, the participants postulated that they knew of the imminent flight disruptions, and thus they engaged in precautious activities in their anticipation. For instance, Participant 9 explained:

> I knew that (this airport) was an uncontrolled airport and people, a lot of times, would do what they wanted there. Especially the skydive planes, they'll go up and then they'll land on an inactive runway that intersects with the runway that three other people are using. So I wanted to be very intentional about looking out for parachutists.

Similarly, Participant 7 shared an almost similar opinion as Participant 9 and explained:

> So, based on the run-up that we did, and the fact that it had come out of the necessary limits on our first try and we had to do the burn off procedure, which is part of our normal procedures, it kept me more alert to the fact that something might be going on here. So when we were actually going full power on the takeoff roll, I was watching for that. And I was checking for it continuously.

Monitor

The category includes behaviors by pilots to keep a check on situations that might occur during flight. Two themes emerged from the interview responses, namely, *routine monitoring* and *increased surveillance*.

Routine Monitoring. The interview responses revealed that pilots routinely monitor aspects like weather, aircraft information, and flight areas or traffic. For instance, Participant 7 stated:

> So, I did go through the records of the airplane, which we do before every flight. Similarly, Participant 11 posited a response that highlighted how pilots monitor flight areas like airports. The participant explained that.
> Well, going into an uncontrolled airport. There's always a possibility traffic is a little more relaxed and people are doing their own thing. So yeah, I chose to go to (that airport). So I knew that was going to be an issue. It's always an issue at uncontrolled airports.

Participant 8 also posited a similar response regarding monitoring various aspects but focused on the weather issues. The participant said:

> Well, it was a little bit cold. So I mean, from the cold, it takes a little while for the engine to just actually act properly.

Increased Surveillance. Furthermore, the participants' responses highlighted that pilots might engage in certain activities in the face of situations that may arise during flights, such as diversion and bad weather. For example, Participant 7 said:

> Well, again, I knew from the trends of the (location's) weather. And then once I was in the air, I started noticing when it was about to happen. I was like, "Oh God, it's building."

Respond

This category describes pilot behaviors with regard to actions taken in response to unexpected events or situations. Two themes came up when the participants were asked about how they responded to the imminent event. The themes include *discussing and deciding* and *taking action in response*.

Discussing and Deciding. The interview responses indicated that when an event occurs, the pilots discuss it, identify the alternatives involved, and then decide on an action to take is made. For instance, Participant 6 said:

> We talked about it coming in, getting ATIS and everything. I took flight controls. He got ATIS and all that. We talked about it and then I flew us back and then once we were established on everything and we got everything done, then I gave him back flight control and he landed and did all that. So I think we cut up or divided work, I guess, in that sense.

Similarly, Participant 5 said:

> I can count on them. It's not like, "Hey, just sit down, let me think." I know I can count on them. They can help me. We can delegate tasks to each other. And that was the one biggest thing I got out of it. Me working alongside in par with my student, not as a source of authority, but like, "Hey let's think through this. What do we do now?"

Taking Action in Response. From the interviews, it was found that pilots take various actions in response to unexpected events or situations. For instance, Participant 8 said that,

> So that was just, it's all part of the checklist in our flow. So when it does sound weird, we always would look at the cylinder head temperatures, if... Because it's more with the cylinder and also with our exhaust gas temperatures.

Learn

The category describes learning as an aspect of resilient performance among pilots. It was the most discussed attribute of resilience performance by pilots. Under this category, two subthemes emerged, that is, *formal learning* and *informal learning*.

Formal Learning. Most interviews posited similar responses regarding how formal training of pilots helps build up a resilient performance that they display when they face unexpected situations mid-air. For instance, Participant 11, in response to the question on how he knew what to do when he faced the unexpected event, said:

> Training. When, yeah, from my training, through my flight instructors, if there's an issue always go around, always get altitude, always avoid traffic the best way you can.

Similarly, Participant 2 revealed that pilot training has theoretical and practical skills. The participant said:

> There's taught skills and there's untaught skills. The skill of climbing out at Vy is kind of here a theory, we talk about Vy.

Informal Learning. The participants indicated that they also learn from their previous experiences or from others. Most of the interview responses indicated that pilots discuss what occurred during an unexpected event to learn from it. For instance, Participant 2 explained:

> (The instructors) sit around and they talk about the flight they were just on and in that conversation, it's more than just like very basic textual information, and just a conversation. You get the (pilot report), you get advice on a student, you get an experience that they learned or had today. Going back, students do the same thing in their dorm rooms.

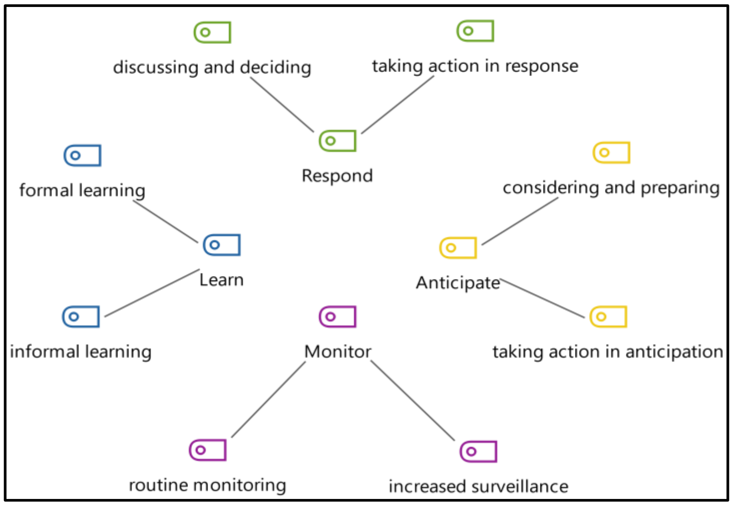
Based on the themes identified relating to the research question, the interviewees asserted that pilots inculcate resilient performance aspects in their behaviors in flight. The study found that anticipation, monitoring, learning, and responding enhance pilots' chances of safely and correctly responding to unexpected events. Besides, pilot training schools have procedures that promote the inculcation of resilient performance by pilots during flights.

Research Question Two

The second research question sought to ascertain whether a taxonomy of resilient performance can be articulated from an investigation of university Part 141 CFI behaviors in routine operations.

From the results obtained in research question one, it was possible to categorize behaviors in terms of strategies for resilient behavior, namely, anticipating, monitoring, responding, and learning. The model for the taxonomy of resilient performance is presented in Figure 2.

Figure 2
Taxonomy for Behaviors of Resilient Performance



However, as in our previous research (Kiernan et al., 2020) it was evident that some responses covered more than one aspect relating to resilient behaviors among pilots. For instance, Participant 5 explained:

> We know not to go into showers because it gets very bumpy. Like I told you earlier, a plane was brought down a month before that. So, I had historical records of what had happened that told me what to do. Also, just general flight training. Our flight training over here, they told you all the time, "Hey, be careful with this, be careful with that. In their weather classes, they tell you, with the thunderstorm, don't... Even if you're in a big…don't get in it. Stay clear of that. The planes are not made to fly through that." So I would say, overall, the training, and just historical records of what had happened, just work in conjunction to tell me what to do.

This response covered anticipation, learning, monitoring, and responding, making coding a challenge. The LIT team produced a validated taxonomy with mutually exclusive and collectively exhaustive categories for flight observations (Glavan, 2021). Because of the advantages of this taxonomy, we experimented with applying the LIT categories to the interview data, but as LIT focuses on observable behaviors, using the LIT categories resulted in data loss concerning attitudes and thought processes that are not relevant to LIT observations. Therefore, a categorization approach that incorporates both observable behaviors and the underlying attitudes and thought processes would be an important area for future research.

Enablers of Resilient Performance

Three factors that contribute to pilots' resilient performance were identified from the data, which include training, experience, and crew climate.

Training. The theme centers on the role that training plays in ensuring that a pilot displays resilient performance in the face of an unexpected event. The participants posited nearly identical responses regarding the *training* theme as an enabler of resilient performance among pilots. Multiple interview sessions revealed training as the aspect that guided one's response following an unexpected event. For instance, Participant 13 said:

> Based on my training, the instructor really taught me well and covered a lot of aspects of various different types of approaches.

Participant 6 also shared a similar response regarding the role that training plays in pilot's resilient performances. The participant said "I think my training prepared me."

Experience. The theme focuses on how pilots apply their experiences during routine airline operations. From the findings, pilots inculcate their professional expertise to raise their resilience when responding to an unintended event. Nearly all participants shared that their experience in the field drove their response to an unexpected event. For instance, Participant 10 said that "I guess correlating experiences to a new environment is the biggest thing I learned."

Similarly, Participant 5 explained:

> Because ATC alerted me coming in, like, “Hey, that wall of rain is moving in. Stop. Do something else.” So, imagine it was an uncontrolled field, someone who didn’t know, it would have been very easy to be like, “I can make it.” And because I had that image very clear in my head of the runway, the wall of rain just moving down the runway perfectly. So, someone with no experience and not knowing what to do, it would have been very, very easy for them to just be like, “Hey, let's go for it.”

Also, Participant 12 asserted:

> I wouldn’t say it’s common, but stuff like that has happened before or a lot of times, students will put their hands on the correct lever, but then say the wrong one.

Crew Climate. The theme focuses on how pilots’ resilient performance is enhanced by the crew members’ emotions and collective working strategies. Although not every instructor-student pair functioned as a crew, in the vast majority of cases the instructor and student worked together as a crew discussing options, formulating plans, and delegating tasks. The findings established that the crew climate and coordinative behaviors improve pilots’ resilient performance. For instance, Participant 5 mentioned:

> Just because one is stressed, doesn’t mean you have to go crazy. You have to keep your cool.

Additionally, Participant 1 posited a similar response and explained:

> We both saw that because the gauge was on the red straightaway. And yeah, that’s what happened. We ended up following the appropriate checklist and it came back to normal.

The interview responses revealed that training, experience, and crew climate drive pilots’ resilient performances when facing unexpected events. Moreover, resilient performance among pilots is enhanced when they include the above aspects in their behaviors.

Discussion

Anticipate

The pilots indicated that their resilient performance during routine flights was developed through their anticipation of events. The pilots showed that system resilience is increased by anticipating unexpected events, searching for all essential information, and discussing suitable actions and the best steps to take. Furthermore, the interviewees overwhelmingly showed that their resilient performance was enhanced by postulating that a flight disruption might occur, making them engage in preventive activities while anticipating it. The anticipate aspect of resilient performance reflected in the study fits well with the findings by Rankin et al. (2016). The authors asserted that pilots might adopt anticipation strategies that will enable them to counter being stuck or surprised by an unexpected event (Rankin et al., 2016).

The present study also revealed that a pilot’s resilient performance is enhanced by considering that an unexpected event may occur and preparing ways to respond to it. The above finding resonates with the assertion by da Silva and Nunes (2019). The scholars explained that resilience training entails using situation awareness techniques to teach pilots about anticipation (da Silva & Nunes, 2019). Situational awareness highlighted by da Silva and Nunes relates to the consideration and preparation actions that the interviewed pilots revealed to be necessary to anticipate an unexpected event in the present research. Similarly, Rankin et al. (2016) mentioned that anticipatory thinking helps pilots cope well with an unexpected event and enables them to avoid being caught in surprise by an event.

Monitor

In the interview responses, the pilots revealed that they enhance their resilience during flight operations by routinely monitoring the flight areas, airplane information, and weather. Besides, the respondents also demonstrated that pilots had enhanced surveillance as a monitoring strategy during flights. The pilots stated that an instructor needs to be vigilant towards the student's emotions to identify when to take the controls. The above findings on how pilots use the monitoring aspect to enhance their resilient performance correspond to the assertions by Rankin et al. (2016). According to Rankin et al., pilots may monitor their captain's cognitive demands, surroundings, and an aircraft's status and prepare to take complete control of the plane if the present situation requires it. Rankin et al. further explained that pilots might monitor an aircraft to ensure that they identify potential abnormalities and anticipate them earlier.

Respond

The response attribute was evident in the findings established in the present study. The pilots posited the significance of collaboration whereby the pilot trainers and their students discuss an unexpected event, identify alternatives, and decide on suitable action. Thus, the study indicates that team orientation is essential when responding to emergencies during flights. Additionally, taking action in response was also communicated by the pilots. The study showed that most pilots engage in different event-suitable actions in response to unexpected events. The above findings were also highlighted by Ohlander et al. (2019), who asserted that collaboration, where the flight team discusses how to respond to the event, enhances pilots' performances during stressful situations. Besides, the team orientation when pilots work together to respond to an unexpected event occurs because all on-board assume that they can trust anyone that has passed training and recruitment (Ohlander et al.).

Learn

The findings also revealed that training was a significant aspect of resilience performance whereby the pilots overwhelmingly highlighted that their formal and informal learning formed the basis for their decisions following an unexpected event during routine flights. The formal learning theme has been previously highlighted by da Silva and Nunes (2019). The researchers asserted that after aeronautical accidents, analysis of incidents occurrence enables pilots to learn from the mistakes and enhance successes of real unexpected situations. Similarly, Landman et al. (2017) also posited that when pilots are faced with an abnormal event during a flight simulation, they act based on previously learned mental knowledge structures. Therefore, pilots enhance their resilient behaviors during unexpected events by using what they learn during formal and informal learning sessions.

Limitations

It is important to remember that for this research, only CFIs from university Part 141 flight schools were interviewed. Although Part 141 certification entails a high level of standardization, each university may further define their individual operations. These considerations may limit the generalizability of the findings beyond the specific sample.

Conclusion

The resilient performance theory is practically significant in the aviation sector. The purposefully sampled university Part 141 CFIs revealed that they had exhibited resilient performance in more ways than one during flights. The pilots understand how they benefit from anticipating, monitoring, responding, and learning aspects of resilient performance. The study's findings provide evidence of the positive impacts of their behaviors on resilient theory tenets and how their experiences positively influence other pilots around them. Therefore, the results of this study support the principles of resilience theory regarding its application in the aviation sector. From the findings, the categories of Anticipate, Monitor, Respond, and Learn were exhaustive, but not mutually exclusive. Thus, the tenets of resilience theory are initially validated but operationalizing a taxonomy will require more work.

Recommendations

Recommendations for Practice

The present study postulates adequate information regarding the significance of anticipating, monitor, responding, and learning tenets in enhancing university Part 141 CFI pilots' resilient performance. Thus, we make the recommendations below for practice in instructional settings. First, it is important to enhance pilots' knowledge of responding to unexpected events by creating a myriad of such situations and the appropriate response strategies to improve their resilience. Instructors can build in-ground training scenarios where students need to think through a situation, such as abnormal engine indications, unexpected weather, and equipment malfunction. This gives the student the opportunity to chair fly (practice on the ground) the thought process and resources available. Enhancing pilots' understanding of techniques for responding to unforeseen circumstances may make them more confident when handling unexpected events during flight.

Second, instructors should ensure that all resilient performances are noted. Capturing positive performance gives pilots an opportunity to reinforce correct thought processes. Often, people critique negative or incorrect applications, yet fail to reinforce the overwhelming part of the process that was done correctly. This is a great opportunity to correct faulty thoughts, but also praise and reinforce correct thought processes. Pilots may benefit from identifying the best course of action used to handle an unexpected event successfully. Besides, the knowledge of mistakes made by other pilots during an unexpected event may form the basis for pilots' decisions about what they need to avoid when faced with similar situations.

Finally, curriculum developers and flight training organizations should build in opportunities for “hangar flying,” or the informal exchange of stories and experiences for students and instructors. While the majority of CFIs remarked that they learned a lot from the experiences they described, and they shared their stories and experiences with colleagues, none of them thought the events were important enough to file ASAP-style reports, even though they reported such avenues were available. This kind of informal training should be encouraged, as many CFIs also reported that they knew what to do as a result of such informal exchanges.

Recommendations for Future Research

Further research is recommended to develop a more robust taxonomy of resilient performance and behaviors, especially outside of the university Part 141 CFI environment, such as non-university Part 141 flight schools and Part 61 flight schools. Such an examination would enable instructors to understand how they can establish and encourage resilient performance among their students. Besides, the research will provide additional information to the existing literature on the human behaviors that enhance resilient performance among pilots. In comparing our results to the results of our previous study with airline pilots (Kiernan et al., 2020), we noticed that the quantity and variety of resilient behaviors seemed to differ between airline pilots and university Part 141 CFIs. This could be due to differences in the complexity of the operating environment, or to the increased experience level of the airline pilots. Further study of the effect of experience on the exhibition of resilient performance would be important.

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Appendices
Appendix A: Interview Guide

Initial Question: Unplanned and unexpected events happen routinely during operations in the NAS. We are interested in how pilots make adjustments before, during and after these unplanned or unexpected events in order to maintain safe operations. Can you tell me about a specific unplanned or unexpected event that you have experienced in the course of routine operations?

Follow-up Questions:

- Were there things you were aware of at the start of your flight that you thought increased the likelihood that this event might occur during that flight?
- How did you know that this event might occur?
- How else might you have been able to anticipate that this event would occur?
- Were there things that you experienced during that flight that you thought increased the likelihood that this event might occur?
- What signaled/indicated to you that this event was about to occur, was occurring, or had occurred?
- How did you know what indicators of this event to look for during your flight?
- What other indicators could have alerted you to this event?
- How did you respond to this event?
- How did you know what to do in response to this event?
- If you had not already known what to do to respond to this event, how would you have figured out what to do?
- What did you learn from this event?
- How did what you learned impact the remainder of your flight or that operation?
- How did what you learned impact how you prepare for future flights or operations?
- Have you shared what you learned with others in your organization? How did you do that?
- In general, what practices are in place in your organization for pilots to share lessons learned?
- Is there anything further you'd like for us to know about this event that we haven't already discussed?

Appendix B: Coding Table for Research Question One

Table 1

Codes, Interview Corroborations Used, and Themes

Categories	Codes	Interview Evidence	Themes
Anticipate	Pilots may consider the day's weather and prepare for the possible course of action in anticipation of an unintended event.	“However, I knew it was cloudy so the entire time I was out there, I was kind of watching that, knowing what we're going to one of these next.”	Considering and preparing
	Considering the imminent problem and preparing the options for responding to it builds on resilient performance’s anticipation aspect.	We called to (the ops desk), I asked the supervisor, and I was like, "Hey, what's going on?" Because he has way more tools than we have in a plane. He's like, "Yeah, it's building fast. You either have to come back or divert."	Considering and preparing
	Being cautious of an imminent problem in anticipation of it enhances resilient performance.	“I knew (that airport) was an uncontrolled airport and people, a lot of times, will do what they want there. Especially the skydive planes, they’ll go up and then they’ll land on an inactive runway that intersects with the runway that three other people are using. So I wanted to be very intentional about looking out for parachutists.”	Taking Action in Anticipation
	Constantly checking for signs that a problem may occur enhances resilient performance among commercial pilots.	“So, based off of the run up that we did, and the fact that it had come out of the necessary limits on our first try and we had to do the burn off procedure, which is part of our normal procedures, it kept me more alert to the fact that something might be going on here. So when we were actually going full power on the takeoff roll, I was watching for that. And I was checking for it continuously.”	Taking Action in Anticipation
Monitor	Pilots assess a plane’s records before a flight commences as a routine procedure.	“So, I did go through the records of the airplane, which we do before every flight.”	Routine Monitoring

	Routinely monitoring an airport enables pilots to be aware of what to expect in every different area.	“Well, going into an uncontrolled airport. There's always a possibility traffic is a little more relaxed and people are doing their own thing. So yeah, I chose to go to (that airport). So I knew that was going to be an issue. It's always an issue at uncontrolled airports.”	Routine Monitoring
	Routine monitoring of the weather enables pilots to predict a possible difference in how plane engines work.	“Well, it was a little bit cold. So I mean, from the cold, it takes a little bit while for the engine to just actually act properly.”	Routine Monitoring
	Monitoring is used to increase surveillance of the weather and make appropriate decisions pending harsh conditions.	Well, again, I knew from the trends of the Florida weather. And then once I was in the air, I started noticing when it was about to happen. I was like, "Oh God, it's building."	Increased Surveillance
	Monitoring enhances pilot trainer's surveillance of their student's reactions and aid in identifying when it is appropriate to take control of the plane from them.	“My student pointed out, "Hey, look at (that airport). It's clear." I'm like, "Awesome." So doing the approach, let's go into (that airport) this time. He shot the approach. Again, I think it's all the storms. They just have down bursts all the time. And he started getting hit pretty badly. And he got uncomfortable, I was getting a little bit uncomfortable. I was like, "Okay, I have the flight control. I took the plane from him at that point. I took the plane, flew around.”	Increased Surveillance
Respond	Discussing and deciding enables pilots to respond to unexpected events well.	“We talked about it coming in, getting ATIS and everything. I took flight controls. He got ATIS and all that. We talked about it and then I flew us back and then once we were established on everything and we got everything done, then I gave	Discussing and Deciding

		him back flight control and he landed and did all that. So I think we cut up or divided work, I guess, in that sense.”	
	Discussing and deciding enhances task delegation and togetherness among pilots during flights.	“I can count on them. It's not like, "Hey, just sit down, let me think." I know I can count on them. They can help me. We can delegate tasks with each other. And that was the one biggest thing I got out of it. Me working alongside in par with my student, not as a source of authority, but like, "Hey let's think through this. What do we do now?"	Discussing and Deciding
	Pilots use the appropriate procedures to determine the action they take in response to an unexpected event.	“So that was just, it's all part of the checklist in our flow. So when it does sound weird, we always would look at the cylinder head temperatures, if... Because it's more with the cylinder and also with our exhaust gas temperatures.”	Taking Action in Response
Learn	Formal training guides pilots' behavior when a challenge faces them during flights.	“Training. When, yeah, from my training, through my flight instructors, if there's an issue always go around, always get altitude, always avoid traffic the best way you can.”	Formal Learning
	Formal learning teaches both practical and theoretical skills among pilots.	“There's taught skills and there's untaught skills. The skill of climb at VY is kind of here at theory, we talk about VY.”	Formal Learning
	Pilots may display resilient performance due to what they learn informally via conversing with other scholars on their flight experiences.	“(The instructors) sit around and they talk about the flight they were just on and in that conversation it’s more than just very basic textual information and just a conversation. You get the pilot, you get advice on a student, you get an experience that they learned or had today. Going back students do the same thing in their dorm rooms.”	Informal Learning
	Pilots trade stories about experiences that	I've shared the story with some of my flight instructor friends, but it's	Informal Learning

	they consider interesting enough to convey in informal settings, but not 'important' enough to make a formal report.	not like I've stood up and spoken in front of a panel.	

Appendix B: Coding Table for Additional Themes

Table 2

Codes, Interview Corroborations Used, and Themes

Categories	Codes	Interview Evidence	Themes
Enablers of resilient performance	Training may enable a pilot's resilient performance.	"Based on my training instructor really taught me well and covered a lot of aspects of various different types of approaches."	Training
	Pilot training prepares pilots on how to behave when faced with a challenge during flights.	"I think my training prepared me."	Training
	Pilot experiences help them to respond well even in new flight environments.	"I guess correlating experiences to a new environment is the biggest thing I learned."	Experience
	A pilot's experience determines how they act if a flight problem arises.	"Because ATC alerted me coming in, like, "Hey, that wall of rain is moving in. Stop. Do something else." So, imagine it was an uncontrolled field, someone who didn't know, it would have been very easy to be like, "I can make it." And because I had that image very clear in my head of the runway, the wall of rain just moving down the runway perfectly. So, someone with no experience and not knowing what to do, it would have been very, very easy for them to just be like, "Hey, let's go for it."	Experience
	Pilot trainers' experiences build their resilient performance. It shapes how they respond to situations due to their experiences with students.	"I wouldn't say it's common, but stuff like that has happened before or a lot of times, students will put their hands on the correct lever, but then say the wrong..."	

	Pilots enhance their resilient performance by managing their emotions when they are faced with a challenge.	"Just because one is stressed, doesn't mean you have to go crazy. You have to keep your cool".	Crew climate
	Togetherness among pilots enhances their resilient performance.	"We both saw that because the gauge was on the red straightaway. And yeah, that's what happened. We ended up following the appropriate checklist and it came back to normal."	
Categories that are not mutually exclusive	Pilots' action in anticipation, monitoring, responding, and learning from an unexpected event enhances their resilient performance.	"First, trends of what has happened before. We know not to go into showers because it gets very bumpy. Like I told you earlier, a plane was brought down a month before that. So, I had historical records of what had happened that told me what to do. Also, just general flight training. Our flight training over here, they told you all the time, "Hey, be careful with this, be careful with that. In their weather classes, they tell you, with the thunderstorm, don't... Even if you're in a big, even if you were [inaudible 00:06:59], don't get in it. Stay clear of that. The planes are not made to fly through that." So I would say, overall, the training, and just historical records of what had happened, just work in conjunction to tell me what to do."	

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Analysis of Weather-Related Accident and Incident Data Associated with Section 14 CFR Part 91 Operations

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Onboard weather equipment has gained popularity in recent years, and various types of equipment have been introduced into the cockpit. Despite their effectiveness, they do not always handle all weather-related events, such as high winds, turbulence, and wind shear. This paper studied the mortality linked to flying phases and weather events. The data for the analysis came from the National Transportation Safety Board (NTSB) and the Aviation Safety Reporting System (ASRS) databases. The weather conditions associated with general aviation-related accidents and incidents were investigated to better understand the specific factors that were most frequently discovered for various weather-related events. The two databases yielded 30,877 accident/incident records. This study reviewed 17,325 accidents and incidents from the NTSB database under 14 CFR Part 91 General Operations and Flight Rules to identify which ones were caused by weather. There were 1,382 weather-related accidents and incidents throughout this investigation. The phases of flight with the highest deaths were maneuvering and en route (28 %). Of the 30,877 total accident/incident records, 13,552 reports were within the ASRS database. Three hundred fifty-eight were weather-related. En route (52 %) was the leading phase of flight with the most severe weather-related accidents/incidents.

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Despite the growth of aircraft with weather advisory capabilities and subscription services for a range of meteorological products, a review of NTSB Aviation Accident reports and NASA's Aviation Safety Reporting System shows that general aviation weather accident numbers have remained relatively stable from 2009 to 2018. The widespread availability of onboard meteorological equipment has substantially increased the ability to obtain extensive weather data while flying. Some of these systems deliver precise data instantaneously, while others may take a while to respond. However, onboard weather equipment is rarely mentioned in NTSB accident reports, making it difficult to determine whether the technology is alerting pilots to impending weather in time to avoid convective weather events.

The study aimed to quantify and describe weather-related accidents reported involving onboard meteorological equipment equipped aircraft operating under FAR Part 91 General Aviation Flight rules using publicly available government accident reporting sites.

Research questions of this study include: What were the most significant weather events that had the most predominant impact on general aviation flights? What effect has onboard weather equipment had during these weather events? What was the most dangerous phase of the flight? Were there any fatal accidents involving aircraft that had operational onboard weather equipment during weather-related events?

This study looks at five critical weather-related areas in the NTSB and ASRS reports to analyze the relationship between accidents and incidents: 1) fatalities that occur during each phase of flight; 2) accident reports by determination and category; 3) accidents and incidents to stage of flight operations, 4) impacts of onboard weather equipment on the survival of passengers, and 5) accidents and incidents to the type of weather-related events.

Literature Review

Between 1990 and 1996, small General Aviation (GA) aircraft were involved in nearly 85% of all aviation accidents and nearly 85% of all accident fatalities (Chamberlain & Latorella, 2001). Weather forces are powerful and unpredictable, difficult to predict and control, and physically demanding to avoid or control (Knecht & Lenz, 2010). In adverse weather conditions, pilots of all classes of aviation can spend a significant amount of time acquiring and analyzing the necessary weather data, both preflight and in flight (Crabill & Dash, 1991). Pilots of small GA aircraft currently have limited in-flight information about convective weather activity, especially when compared to pilots of larger aircraft (Chamberlain & Latorella, 2001).

According to the FAA Weather-Related Aviation Accident Study (2010), wind was the leading cause or contributing factor in weather-related accidents from 2003 to 2007. Within this FAA study, the FAA reported aircraft operating under Part 91 were involved in more weather-related accidents than aircraft operating under any other 14 CFR Part (FAA, 2010). Research conducted by Fultz and Ashley (2016) also found the wind to be the most cited weather hazard, from 1982 to 2013, as their study discovered 7.8 % of wind-related accidents were fatal. Between 2000 and 2011, Gultepe et al. (2019) noted that adverse winds were the leading cause of weather-related accidents for small, noncommercial aircraft (Part 91 class), followed by low ceilings. Capobianco and Lee (2001) discovered most wind-related accidents occur during takeoff or landing when the aircraft is at or near the surface, as these types of accidents occur at much lower speeds and altitudes. Many wind-related accidents happen when pilots lose control of their planes during takeoff or landing in gusty conditions (FAA, 2010).

Non-instrument rated pilots tended to fly the least weather-capable aircraft (Knecht & Lenz, 2010). Capobianco and Lee (2001) explained the most common probable causes of fatal weather accidents reported from 1995 to 1998 were VFR to IMC flight and flight into adverse weather during the cruise phase. Sixty-three percent of fatal weather events occurred during the cruise phase of flight (Capobianco & Lee, 2001). Between the mid-1970s and the mid-1980s, general aviation accidents involving VFR flight into IMC accounted for roughly 19% of all GA fatalities in the United States (Goh & Wiegmann, 2001). Approximately 76 % of VFR –IMC accidents appeared to involve intentional flight into adverse weather (Goh & Wiegmann, 2001).

Electronic flight displays (EFDs) were first installed in general aviation planes in 2003, and with a few exceptions, they are now standard equipment on all newly manufactured planes and available as an aftermarket upgrade for older general aviation aircraft (Boyd, 2016). These new products on the market display graphical weather data in the cockpit (Fraim, Cairns, & Ramirez, 2020). Even with today's technological advances, such as in-cockpit radar availability via satellite, weather remains a significant barrier to general aviation safety (Fultz & Ashley, 2016).

The goal of this research was to determine the most significant weather events that had the greatest impact on general aviation flight phases, the type of weather events, and the presence of onboard weather equipment. Research conducted by Capobianco & Lee showed the most dangerous phase of flight to be En Route (Cruise) phase. Researchers have discovered wind as the predominant factor in accidents.

Even though onboard weather equipment was mentioned in the literature, no studies mentioned weather-related accidents or incidents involving aircraft with onboard weather equipment. This study will look into onboard weather equipment accidents and incidents.

Methodology

The International Civil Aviation Organization (ICAO) Aviation Occurrence Categories (ICAO, 2013) and Phase of Flight Definitions and Usage Notes (ICAO, 2012) are used in this study to characterize accidents and incidents in both the NTSB and ASRS databases (Table 1).

Federal Air Regulations section 14 CFR Part 91 addresses noncommercial general aviation operations, including corporate aviation operations. The study reviewed Part 91 operations within two databases for 2009–2018: The NTSB accidents and incidents database and NASA’s ASRS database. All operations that fall within 14 CFR Part 91 were analyzed. A record that noted a flight into heavy convective activity would be considered one where the weather was a primary factor, whereas a record describing an engine failure due to carburetor icing would not be considered weather-related since ICAO classifies carburetor icing as a fuel-related issue. Weather, flying conditions (IMC, Marginal, Mixed, or VMC), lighting, flight plan, and flight phase were the primary search criteria for both NTSB and ASRS reports under 14 CFR Part 91 activities.

NTSB database

The NTSB has two areas analyzed within the database: the Aviation Accident Final Reports and the Pilot/Operator Aircraft Accident/Incident Reports (NTSB Form 6120.1) found under Dockets. Each year’s Aviation Accident Final Report data was downloaded into an excel datasheet to be analyzed for weather events that caused the accident/incident. All accident numbers were reviewed from the NTSB Accident Reports and screened for any mention of weather as a probable cause or findings. All those reports that were not weather-related were counted towards the total number of accidents and incidents for the year and not included as a weather event. There were also accidents reported that were listed as probable cause undetermined. Those reports were also only used for the overall accident count.

The NTSB reports were further filtered to find those that included onboard weather equipment. The number of NTSB accident reports mentioning such technologies is scarce and fluctuates from year to year. The accident numbers were then used to review those NTSB Form 6120.1 reports to determine if there were any mention of onboard weather equipment. These forms comprise factual reports, and the information investigators analyze to create a probable cause is stored in the NTSB database under Dockets.

In the event of an accident or incident, the surviving pilot of the aircraft is required to complete an NTSB Form 6120.1 and submit it to the appropriate NTSB office in accordance with 49 CFR Part 830.5(a). NTSB Form 6120.1. The NTSB uses data from this form to determine the facts, conditions, and circumstances to prevent aircraft accidents and compile statistics. Prior to 2011, the NTSB Form 6120.1 lacked an “Additional Equipment” list for pilots to make selections of additional equipment onboard the aircraft. After 2011, the pilot can choose from a list of options in the NTSB Form 6120.1 “Additional Equipment” listing to select onboard weather equipment, ADS-B, and satellite tracking devices.

Finally, a closer look at the downloaded accident report spreadsheet revealed fatalities, seriously injured people, minor injuries, and no injuries. The phases of flight were also investigated, despite the fact that a small number of accidents per year did not specify which phase of flight the accident occurred. These were counted as weather-related accidents/incidents but not as phases of flight in those cases.

ASRS database

The ASRS relies on self-reporting to detect anomalies in the National Airspace System. It's a completely voluntary program in which pilots can report safety incidents solely to alert the system. The Federal Aviation Administration (FAA) does not use these reports to impose disciplinary or other adverse measures against the pilot (ASRS, 2019). Because NASA does not accept ASRS reports involving aircraft accidents, pilots report such incidents to the NTSB.

A query was done on the database for the date and report numbers, environment, aircraft, person, event assessment, and narrative/synopsis. Each year's data was downloaded into an excel datasheet are reviewed for weather events, phases of flight, and the presents of onboard weather equipment. Non-weather reports were not evaluated but were included in the total number of events for the year.

Table 1
International Civil Aviation Organization - Phase of Flight Definitions

Phase of Flight	Definitions
Takeoff	The application of takeoff power, through rotation and to an altitude of 35 feet above runway elevation, or until gear-up selection, whichever comes first.
Initial Climb	From the end of the Takeoff sub-phase to the first prescribed power reduction, or until reaching 1,000 feet above the runway elevation or the VFR pattern, whichever comes first.
En Route	Instrument Flight Rules (IFR) From the completion of initial climb through cruise altitude and completion of controlled descent to the initial approach fix (IAF). VFR from the initial climb through the cruise and controlled descent to the VFR pattern altitude or 1,000 feet about the runway elevation or whichever comes first. This covers climb, cruise, descent, and holding. En Route is comprised of Climb to Cruise, Cruise, Descent, Change of Cruise Level, and Holding.
Maneuvering	Low altitude/aerobatic flight operations
Approach	Instrument Flight Rules (IFR), From the Initial Approach Fix (IAF) to the beginning of the landing flare. VFR from the point of VFR pattern entry, or 1,000 feet above the runway elevation, to the beginning of the landing flare. The approach covers Initial and final approaches as well as missed approaches/Go-Arounds.
Landings	The beginning of the landing flare until the aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing.

Results and Discussion

The author examined the phases of flight concerning fatal and non-fatal accidents in this study, then examined weather-related accidents and incidents before concluding with a connected analysis of onboard meteorological data utilization. The findings revealed the importance of weather as a cause or contributing factor in aircraft accidents at various stages of a flight and the link between the occurrence of accidents and the data provided by onboard weather equipment.

NTSB Records Analysis

The NTSB's Aviation Accident Final Reports database received 17,325 accidents from 2009 to 2018 (Table 2). During this study period, an average of 1,733 reports was submitted each year. The number of deadly occurrences has fluctuated over the study period, with the number of fatal incidents in 2018 falling to 36 fatal incidents. Weather-related deaths fell by 61%, from 113 in 2009 to only 69 in 2018.

The NTSB rarely mentions onboard meteorological equipment in the Aviation Accident Final Reports but reviewing the Pilot/Operator Aircraft Accident/Incident Reports indicates a different narrative. Until September 30, 2011, the title "Additional Equipment" was not included in the docket forms. As a result, there was no apparent onboard weather equipment in the cockpit. Between 9/30/2011 and 5/31/2017, additional equipment listing was added to include a checklist of ADS-B, Onboard Weather, and Satellite Tracking Devices. The forms within the dockets were only for the surviving pilots who had filed the proper papers with the FAA following an accident.

The rate of fatal weather-related incidents ranged from 2009 to 2018, with the highest incidence of 58 % in 2013. In 2016, only 11% of fatal accidents occurred, making it the year with the lowest fatal accident rate. Of the 276 weather-related accidents reported in 2009, 51 (18%) events were fatal (Table 2).

Table 2

Relation of NTSB Accidents to the type of injury in weather-related events occurring during 2009 - 2018

Year	Total Accident Records	Total Weather-Related Accidents	Fatal Events Weather-Related	% Fatal weather-related accidents	Fatalities # of people	Serious # of people	Minor # of people	Uninjured # of people
2018	1,745	146	36	25%	69	14	39	165
2017	1,693	182	40	22%	85	20	40	179
2016	1,748	119	13	11%	38	11	27	126
2015	1,635	115	39	34%	78	27	24	106
2014	1,579	172	44	25%	78	30	50	175
2013	1,606	55	32	58%	69	9	16	32
2012	1,871	73	36	49%	74	18	24	52
2011	1,866	126	70	56%	147	23	22	51
2010	1,797	114	46	40%	94	21	19	91
2009	1,785	276	51	18%	113	12	21	56
Totals	17,325	1,382	407	29%	845	185	282	1,033

From 2009 through 2018, general aviation accidents stayed relatively constant, averaging 1,733 per year. Weather-related events accounted for 8% of all accident reports. Four-hundred seven (29.4%) of the 1,382 weather-related accidents were fatal, resulting in 845 fatalities, for an annual average of 84.5 (34%) fatalities. Throughout the study period, 2009-2018, fatalities occurred on an average of 72% of IMC flights and 21% of VMC flights. (Table 3).

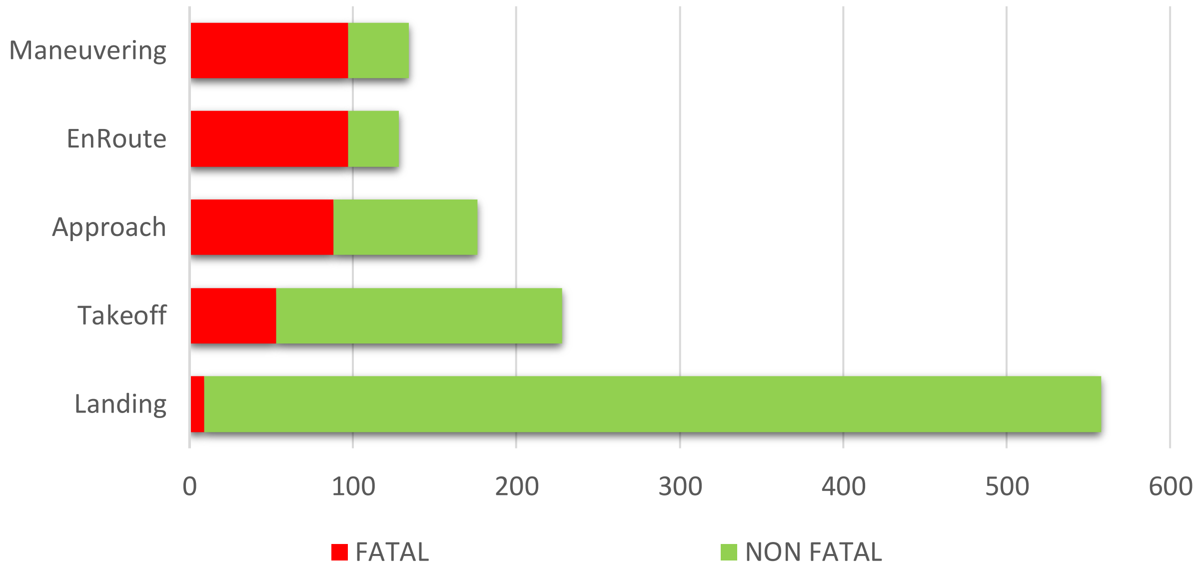
Table 3

NTSB Reports of accidents in which weather was the probable cause/contributing factor for years 2009 - 2018

Years	Total Weather-Related Accidents	Total IMC Events	Fatal IMC Flights	% IMC Fatal	Total VMC Events	Fatal VMC Flights	% VMC Fatal
2018	146	20	17	85	126	16	13
2017	182	35	26	74	147	14	10
2016	119	14	7	50	105	6	6
2015	116	26	21	81	90	18	20
2014	175	28	23	82	147	20	14
2013	55	14	12	86	41	18	44
2012	73	17	12	71	56	29	52
2011	126	22	16	73	104	54	52
2010	114	32	11	34	82	33	40
2009	276	63	51	81	213	24	11
Totals	1,382	271	196	72	1,111	232	21

During this period, 28% of fatalities occurred during the Maneuvering and EnRoute phases of flight. Landings had the lowest accident rate of any phase of flight, with fatalities occurring in 3% of those landings (Figure 1). The fatal rate on En Route in this study yields a lower finding than that of Capobianco & Lee, 2001), where they showed that among all the fatal weather causes, 63% occur during the cruise phase of flight during 1995-1998.

Figure 1.
Relation of weather-related accidents to phase of flight operations for years 2009 to 2018



Note: Not all reported events stated whether there was a phase of flight associated with the accident or incident.

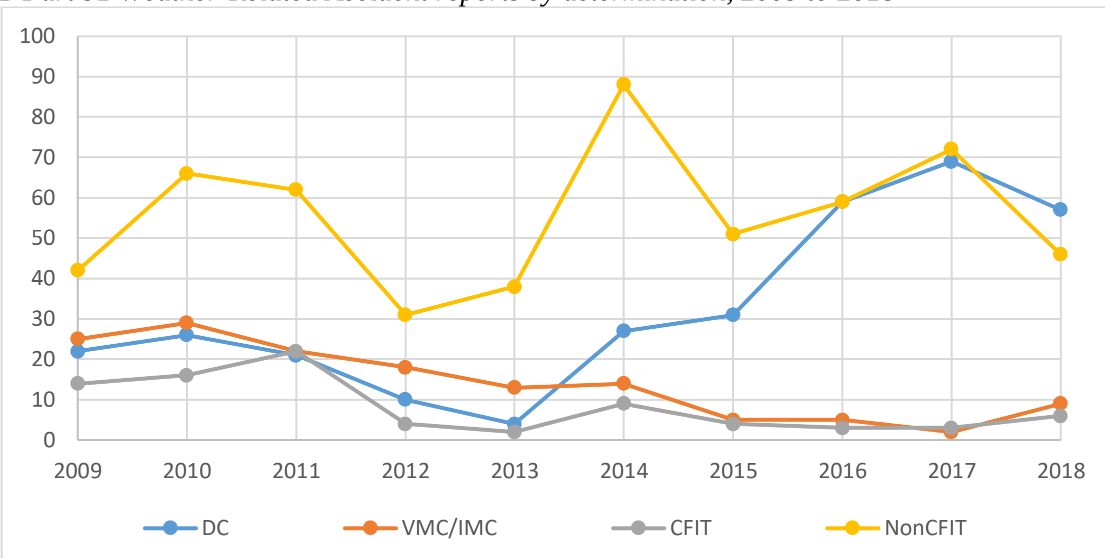
Accident Determinations

Non-Controlled Flight into Terrain (NFIT), Controlled Flight into Terrain (CFIT), Loss of Directional Control (DC), and VFR into IMC are the four types of accident determinations. From 2009 to 2017, an uncontrolled flight into terrain was the most critical determinant (Figure 2). Controlled Flight into Terrain (CFIT) occurs when an airworthy aircraft flies into the ground, water, or obstacles while under the control of a qualified pilot who is unaware of his position. Accidents involving uncontrolled flying into terrain occur when the aircraft is out of control at the time of the collision. An unintentional departure of an airplane from a controlled flight is a Loss of Control accident.

The proportion of VMC into IMC has been steadily decreasing since 2010, with a slight uptick in 2018 (Figure 2). Until 2018, the most common determination was a Non-Controlled Flight into Terrain. Several mishaps involving onboard radar were recorded in NTSB reports during this investigation. Loss of Directional Control and Non-Controlled Flight into Terrain were linked to 47 % of all weather-related accidents and incidents in 2016. Strong wind gusts caused the majority of these incidents. Throughout the study, 31 % of those accidents and incidents reported a loss of directional control.

Figure 2

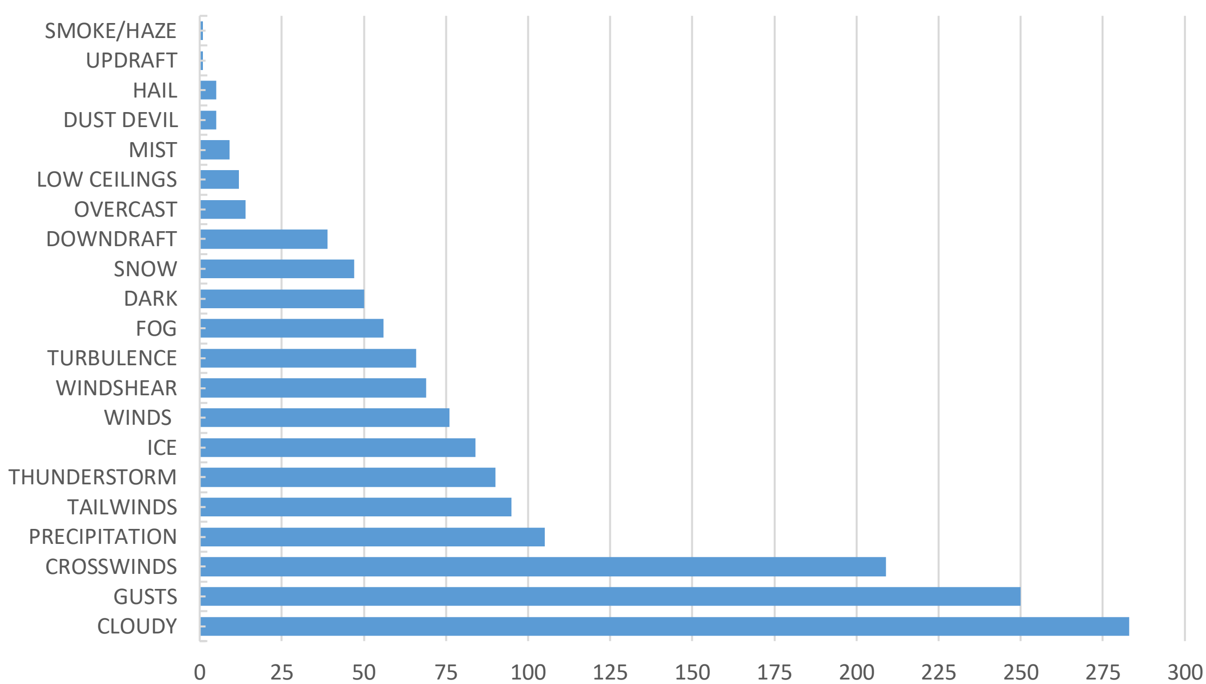
NTSB Part 91 Weather-Related Accident reports by determination, 2009 to 2018



The 1,382 weather-related incidents were categorized into 21 different weather-related categories (Figure 3). The overwhelming weather occurrences in the NTSB accident reports were cloudy, gusts, and crosswinds (Figure 3). Cloudy weather accounted for 18% of all weather-related incidents, with gusts accounting for 16% and crosswinds accounting for 13%. Precipitation made up 7% of the total.

Figure 3

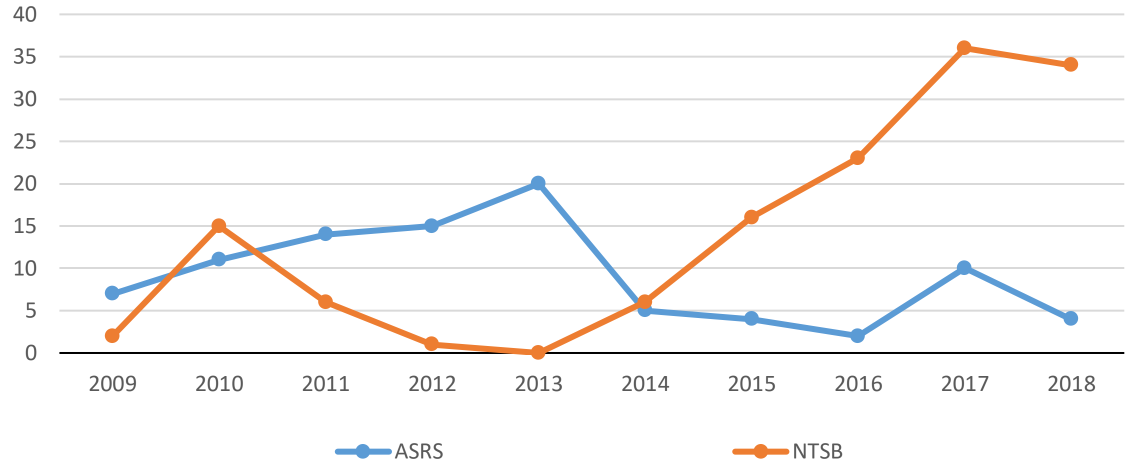
NTSB weather-related accidents and incidence experienced during flight for years 2009 through 2018



The NTSB recorded two fatal (2) events in 2009 in which onboard weather equipment was present. One had weather radar, a storm scope weather mapping sensor, and an XM satellite receiver. Weather radar was reported to be present at the second event. Both of these occurrences coincided with thunderstorms. According to the NTSB Form 6120.1 reports, three (3) of the 40 fatal weather-related events in 2017 featured aircraft equipped with onboard weather and ADS-B, but there was no indication that the pilot had used the onboard weather equipment during the accident.

Figure 4

ASRS and NTSB reports were onboard weather equipment reported from 2009 to 2018



ASRS Records Analysis

The ASRS database has 13,552 accident reports from 2009 to 2018, of which 358 (3%) were weather-related. Over this period, the annual number of reports fluctuated from 1,327 in 2009 to 1,166 in 2018 (Table 4). Only 358 (3%) of the 13,552 data filed between 2009 and 2018 indicated that meteorological conditions directly influenced the incident.

Since 2009, the percentage of ASRS reports where the weather was a primary factor in the incident has remained relatively steady, between 2% and 4% of each yearly report. Table 4 shows the most common weather-causative factors identified in ASRS reports. VFR into Mixed, IMC, and Marginal were the most common elements linked to these occurrences, according to those pilot reports within ASRS. The number of reports in which onboard weather equipment was referenced in the cockpit was counted.

Each year from 2009 to 2018, the percentage of weather-related incidence increased from 2% in 2009 to 4% in 2017-2018; however, the percentage of weather-related accidents to onboard weather equipment was widely variable, from a low of 4% in 2016 to a high of 71% in 2013. Table 4 suggests that the use of onboard weather equipment may be linked to an increase in total weather-related accidents and incidents. Adverse winds, turbulence, and icing are among the most common of these occurrences.

Of all the weather-related accidents each year, flights from VFR into IMC, Mixed, and Marginal weather conditions have shown to be extremely minimal. (Table 4)

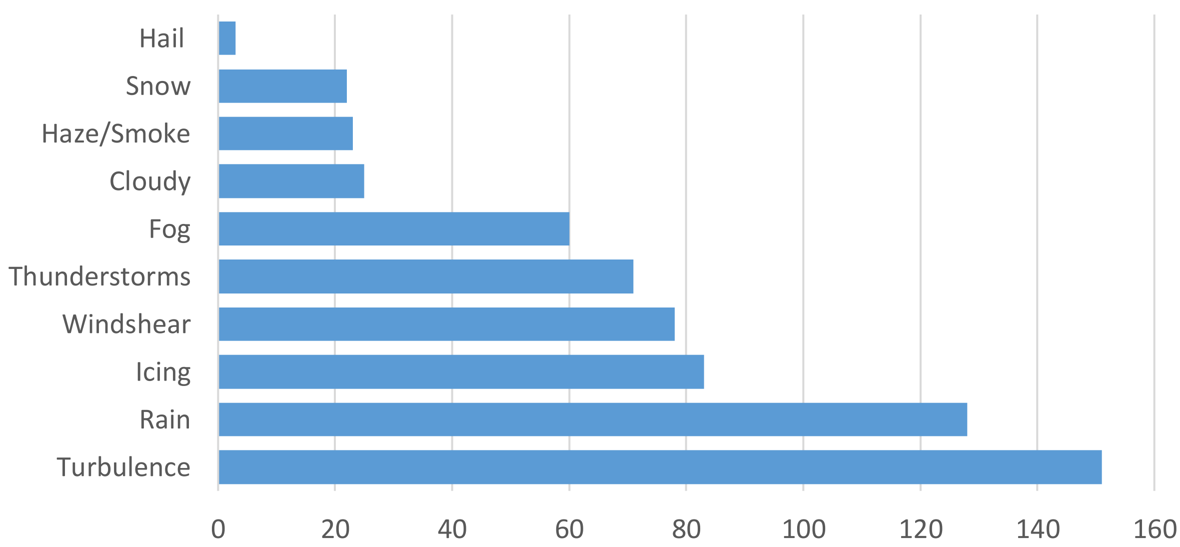
Table 4
Total ASRS Weather Reports showing VMC into IMC from 2009 to 2018

Year	Total Number of Reports	Total Weather-Related Accidents	Onboard Weather Equipment Noted	% OBWE to Total Weather-Related Accidents	VMC to IMC	VFR into MIXED	VFR into MARGINAL
2018	1,166	42	4	10	1	0	1
2017	1,547	62	10	16	2	4	1
2016	1,597	48	2	4	1	2	2
2015	1,580	30	4	13	2	0	0
2014	1,240	28	5	18	1	0	0
2013	1,174	28	20	71	0	0	0
2012	1,402	24	15	63	1	1	3
2011	1,338	42	14	33	0	1	0
2010	1,181	26	11	42	1	0	1
2009	1,327	28	7	25	1	3	1
Totals	13,552	358	92		10	11	9

Note: OBWE - Onboard Weather Equipment

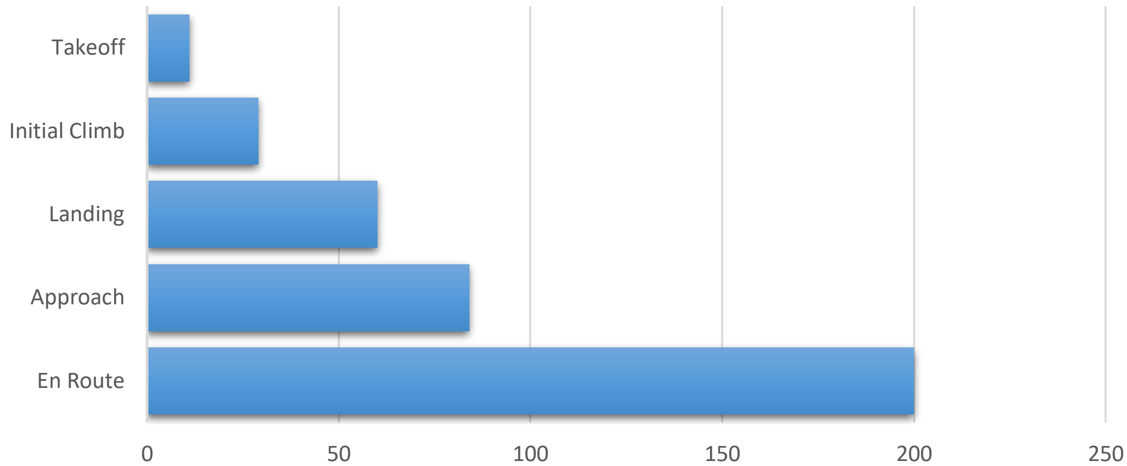
Turbulence accounted for 42 % of the total 358 weather events in the ASRS data, whereas hail accounted for only 0.8 % of the incidences (Figure 5).

Figure 5
ASRS Weather-related accidents and incidence experienced during flight for years 2009-2018



The different incidents that occurred during the various phases of flight are depicted in Figure 6. This was the most-risky flight section, with 52 % of all accidents and incidents occurring En Route. Approaches were responsible for 22% of all flights, while landings were responsible for 16%. The initial rise was responsible for 8% of all flights, while takeoff was responsible for 2%.

Figure 6
ASRS Weather-related accidents or incidents per phase of flight from 2009-2018



Note: Not all reported events stated whether there was a phase of flight associated with the accident or incident.

Conclusion

Interpreting and categorizing narrative data sources into standard categories with minimal bias is difficult because of subjectivity. The most commonly reported weather conditions in NTSB reports were cloudy, gusts, and crosswinds, whereas the ASRS analysis is consistent with widespread knowledge and possibly pilot intuition, with turbulence, rain, icing, wind shear, thunderstorms, and fog as the most frequently reported weather conditions. Winds and overcast conditions were not as dominant a weather-related factor in this study as previous studies suggested.

The use of onboard weather equipment is rarely mentioned in NTSB Accident Reports and even less so in ASRS reports. It was discovered that almost all of the accidents involving onboard weather equipment in aircraft resulted in minor to no injuries. In those accidents that resulted in fatalities, the NTSB made little to no mention of onboard weather equipment in their investigations. As a result, it is impossible to say whether the fatal accidents that occurred during a weather-related event had any operational onboard weather equipment.

After 2011, NTSB Form 6120.1 included a list of Additional Equipment, which included ADS-B, but did not specify whether the equipment had weather capabilities. In those accidents that resulted in fatalities, the NTSB made little to no mention of onboard weather equipment in their investigations. As a result, it is impossible to say whether the fatal accidents that occurred during a weather-related event had any operational onboard weather equipment.

Recommendations

More research into the definition of "onboard weather equipment" is needed. According to the findings of this study, such technologies have evolved in recent years, resulting in a significantly broader range of options. Prior to 2010, most technologies sent textual information, often in an audio format, such as flight service reports or Automatic Terminal Information Service (ATIS), Automated Weather Observing System (AWOS), or Automated Surface Observing System (ASOS) transmissions; or in-panel radar systems, such as onboard radar or storm scope systems. A new technology category has recently emerged, most notably the development of third-party radar.

There is no connection between the reported use of onboard weather equipment and any other criteria considered during the investigation, such as flight phase or final cause decision. Such findings necessitate further investigation into how the use of onboard weather equipment can be properly included as part of an accident investigation and consistently documented. With the availability of more affordable onboard weather equipment technology on the market, it was expected that the number of reports containing some narrative about the use of such products would increase, particularly for those reports in which weather was a factor.

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Airspace Deregulation for UAM: Self-organizing VTOLs in Metropoles

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Small-scale aviation has been driven extensively by recent technological developments. Distinct micro/small scale mobility modes are being interlined, where automated Vertical Take-Off and Landing Aircraft (VTOLs) are being conceptualized for Urban Air Mobility (UAM) in the form of air taxi, cargo, disaster relief, or medical help. This implicates many simultaneous flights over cities, which is a significant challenge. Traditional air traffic control is customized for commercial aviation, and it is not suitable for the dynamic variation in the flight routes of UAM. Consequently, a literature review is conducted firstly for air traffic management subject to UAM. Then, as a critical finding, a self-organizing model integrating particularly micro/small scale UAM is proposed utilizing the swarm concept to leverage the autonomous behavior of VTOLs. Rules for self-organization are set, which are then discussed in conjunction with available technologies such as Global Positioning System (GPS) and Traffic Alert and Collision Avoidance System (TCAS). Finally, the basic concept definition is elaborated to determine challenges and future research.

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Developments in energy storage and electric propulsion empower a new era for aviation (Al Haddad et al., 2020). New innovative Urban Air Mobility (UAM) applications are being deployed as an alternative to traditional mobility solutions (Rothfeld et al., 2018). Micro-/ small-scale mobility is being interlined in cities in the form of automated electrical vertical take-off and landing vehicles (eVTOLs). These are being conceptualized for urban transport in the form of air taxis (Rajendran et al., 2021), cargo, or personal air vehicles (Rothfeld et al., 2019). Consequently, UAM refers to all flight operations within geographical limits of cities with the perspective of carrying persons or cargo subject to the vision of "Anyone, Anywhere, Anytime" (Cotton & Wing 2018, p.2).

There are already many technology firms focusing on UAM with different platform designs such as eHang 216, 116, 184, Volocopter 2x, VC200, Lilium Jet, Airbus Vahana, CityAirbus, Pop Up, Boeing Aurora, Bell Nexus, Kitty Hawk (+Boeing): Cora, Flyer, Joby Aviation S4, S2, (eHang, 2020), Neva AirQuadOne, Joby S2, Opener Blackfly (Straubinger et al., 2020), NASA Puffin, Rolls-Royce eVTOL, Agustawestland Convertiplane, Kitty Hawk Cora, Terrafugia TF-2 (Zhou et al., 2020), Sikorsky, JetBlue, Amazon, Google and Toyota (Cotton & Wing, 2018). Uber predicted that 27,000 flights with 300-500 eVTOLs per day per city will be carried out over many cities of the USA by 2025 (Moore, 2017).

UAM is substantially expected to improve individual mobility that the arising transportation modality can potentially overcome urban surface transportation (Lowry, 2018). Incorporating new modes of transportation with VTOLs (Rothfeld et al., 2018) is becoming crucial. UAM can reduce travel time, disrupting travel patterns (Fu et al., 2019). It is a new transport mode within or between cities (Straubinger et al., 2020), and only the air taxi utilization is estimated to reach up to 10,000 commuters per day in peak times (Rajendran et al., 2021). Consequently, a market with more than 23,000 automated aircraft is estimated with a volume of $32 Billion by 2035, and various companies such as Uber have already included air taxi income in their business plans (Al Haddad et al., 2020). The drone volume of the airspace and the value of the drone industry are unpredictable in the future. However, according to the European Drones Outlook Study (SESAR JU, 2016), it is estimated that approximately 400,000 drones will be providing services by 2050, and the total market value will be over 10 billion Euros by 2035.

Rothfeld et al. (2018) applied the agent-based traffic simulation framework MATSim for UAM by using the same case scenario improved by Hörl (2016) for self-driving cars. A simulation for the economic feasibility is provided for 100 UAM vehicles at a 500 m (1640.42 ft.) cruise level with a speed between 10 and 150 m/s (22.4 and 335.5 mph) distributed around 10 UM stations resulting in only three times the price of a car.

Autonomous aircraft are already being used in search and rescue, surveillance, localization and mapping, military (Sargolzaei et al., 2020), monitoring, inspection, data collection, logistics, and recreation (Merkert & Bushell, 2020). UAM solutions are also conceptualized for disaster relief and medical help besides individual usage. Japan Airlines aims to deliver medical care in remote areas using eVTOLs (Sumitiomo Corporation, 2020). More than one million small drones are registered in the USA, and many well-established large organizations are focusing on UAM solutions (Cotton and Wing, 2018). The European Union defined the importance of such systems with the Warsaw Declaration as “Drones as a leverage for jobs and new business opportunities” and decided to invest in this field with the SESAR Joint Undertaking (2016).

Antcliff et al. (2016), Garrow et al. (2018), Lowry (2018), and Haddad et al. (2020) indicated that the market is ready to adopt UAM despite psychological and ethical concerns based on automation. The willingness to fly can be further enhanced by implementing remote control mechanisms or safety devices such as parachutes (Ward et al., 2021). The acceptance criteria for UAM are travel time, travel cost, and safety, where a certain price increase for this service is already accepted (Fu et al., 2019). Socio-economic factors, safety perceptions, and modality patterns have an impact on the adoption, but it is inevitable that UAM will be the reality of tomorrow (Fu et al., 2019), and feasible VTOLs can find usage easily with technology advancements (Rothfeld et al., 2019).

Currently, the assumptions for the application of UAM are mainly consisting of an on-demand travel model (Rothfeld et al., 2018). This situation yields a high travel frequency without any schedule in advance, which is also highly dynamic. Lowry (2018) assumes that pilotless aircraft in UAM will have a density of 100 aircraft per square km in 2035. Therefore, the safe integration of UAM into the airspace appears as a major issue (Katz, 2019). The challenges within a city are particularly difficult, i.e., “maintaining safety under all failure conditions while flying over people and property is daunting” (Cotton & Wing 2018, p.2).

Such a complex environment requires an intelligent system with a high level of perception (Floreano and Wood, 2015) integrating many stakeholders simultaneously. The frequency of the interactions among these stakeholders is simply too high that decentralized systems are preferred instead of centralized control (Airbus, 2018).

Air traffic management and infrastructure are key for UAM (Straubinger et al., 2020). There is a need for low-altitude airspace management to support drone usage (Merkert & Bushell, 2020). Current research focuses on decentralized multi-agent-based architectures used for coordination, mission management, collision avoidance, formation, and path planning (Mualla et al., 2019). This means a decentralized “self-” management of the air traffic. There, swarms are the highest level of autonomous capability (Gao et al., 2016), which theories were applied to air traffic management as well (Torres, 2012).

However, UAM is more than a collection of distinct vehicle concepts or singular technology applications. It requires an operational concept within an infrastructure connecting to existing transportation systems (Rothfeld et al., 2018) that “new regulations and air traffic control systems are needed” (Fu et al. 2019, p.428). Consequently, the following research questions do arise:

Q1: What are the challenges and requirements subject to ATC and UAM?

Q2: What are the appropriate rules for setting up a model for traffic organization in UAM?

Consequently, ATC for small and medium VTOLs in metropoles is discussed here, and a model is proposed facilitating the concept of a self-organizing swarm for urban air mobility. The structure of this paper is as following: Firstly, literature research was made for UAM traffic management, where the requirements were set. Secondly, the method is explained. Then, based on the literature, a model was conceptualized, which was then discussed in relation to set requirements. Finally, conclusions and future research areas were defined.

Literature Review

Air Traffic Management Attempts for UAM

The lesson learned by the fatal mid-air collision of two commercial flights in 1956 over the Grand Canyon leading the way to the Air Traffic Management (ATM) is also indicating the need for the regulation of future low-altitude small unmanned aircraft systems (UAS) (Kopardekar et al., 2016). There is already research about the infrastructure and regulations for UAM operations by Cohen (1996), Lowry (2018), Cotton & Wing (2018), Fadhil (2018).

Then, governmental bodies are also working on the Concept of Operations (Kopardekar et al., 2016) on the regulative side. FAA and NASA are working together closely on UTM research through a joint Research Transition Team (RTT) collaborating with other governmental institutions focusing on low altitude safe operation of small UAS also supporting beyond visual line of sight conditions (Kopardekar et al., 2016).

Particularly, NASA is involved in the management of UAM under the UAS Traffic Management (UTM) initiative, while FAA is only concerned with safety issues of UAS regulating remotely piloted aircraft, and their vision of Technical Capability Level (TCL) 4 is by far not pacing with the progress of the industry (Cotton & Wing, 2018). According to the NASA UTM Technical Capability Levels, UAM operations will be authenticated at the fourth level, which denotes beyond the line of sight, high density, autonomous, vehicle-to-vehicle, in-flight deconflicted (Bijjahalli et al., 2019) and internet-connected operations over metropolitan cities for miscellaneous purposes (Koperdekar et al., 2016).

Then, the Drone Helsinki Declaration in 2017 with the participation of EU institutions - EC, EASA, EUROCONTROL, SESAR concluded in support of Urban Space services for more autonomous vehicles in denser traffic adopting new digital technologies from all sectors and uses (EASA, 2017). This is an important milestone, indicating that solutions beyond traditional aviation concepts are required and supported by authorities as well.

Furthermore, Airbus and Singapore Civil Aviation Authority (CAAS) also signed an agreement on 12 February 2020 to develop unmanned traffic management (UTM) system to support the initial stage of urban air mobility by delivering a framework for safety, operating standards, and public acceptance while Japan Airlines and Sumitomo Corporation signed a corporation agreement with Bell Textron Inc. in 2020 to search out business opportunities for air mobility services, deploying Bell's eVTOL in Japan and Asia, which addresses the studies for UAM, its infrastructure, and regulations of the environment by centering on the use of Nexus 4EX eVTOL (Aviation Week, 2020).

U-Space: The first official deregulation attempt

EASA released an Opinion (2020) in U-Space, a set of services and procedures for drones. The airspace for both manned and unmanned aircraft are orchestrated for safe operation, preventing collisions and reducing the air and ground risks. Due to the local legislations of European countries, the harmonization across Europe is still being assessed, but in short U-Space airspace is below 500 ft. outside the urban airspace and below the minimum height within the urban environment or around the airport. U-Space authorities provide services to UAS like network identification, geo-awareness, flight authorization, traffic information, tracking, weather information, and conformance monitoring services (Annex to EASA Opinion 01, 2020).

Accordingly, air navigation service providers are designated to support manned as well as unmanned aircraft in the controlled air space and to provide flight information services only to manned aircraft in U-space territories, while *U-space service providers* are in charge of the U-space airspace. Although being still under development, this is particularly of interest because it leads the way to the establishment of private or governmental organizations for the management of the urban airspace.

So, U-Space is aiming to enable high-density operations accessible to all parties in a scalable manner (SESAR, 2017), but it relies on ATC for flight planning approval and tracking and is far away from setting up a model for unmanned aircraft in urban environments; in the short term, it aims to regulate the registration and drone missions of human-guided unmanned vehicles over an online system. In the long term, U-Space aims to figure out conflict detection and resolution and large-scale UAV management by 2027 and to achieve full integration of UAVs with manned aircraft by 2035.

Requirements of UAM Applications

The regulation is complicated by the variety of urban applications such as transportation, monitoring, and urban management. Different business models are being discussed for UAM, particularly focusing on ownership models, on-demand services, and commercial air taxi solutions such as UBER (Rothfeld et al., 2018). According to current regulations, the presence of a pilot is required for safety purposes, and UAV flights in urban areas are restricted (Lancovs, 2017). Then, there is also a lack of validated rules for airspace operations and integration requirements, which can cope with the projected future densities (Kopardekar et al., 2016).

The future applications of UAM implicate a high number of simultaneous flights over cities, which is a major challenge. However, air traffic control is mainly dealing with commercial flights, and their capability is restricted. UAV integration to the air traffic is enabled by small transponders (Lancovs, 2017), but only in regulated airspace. Then, there is a high variation in the flight routes of UAM, which also have a dynamic character, i.e., they can change during the flight. Furthermore, the traffic density and the interactions with other traffic modes or with the urban properties contribute to the risk of UAM. Consequently, unmanned flight in urban airspace requires new methods for traffic management (Balachandran et al., 2018).

Decentralization and UAM: Rules of operation

There are no explicit regulations related to the dense traffic requirements of fully automated aircraft subject to UAM. Cotton and Wing (2018) came up with the idea of UTM applying a decentralized approach by using airborne surveillance, self-separation, and a minimized *design separation* approach to provide the optimization and safety of each flight in very high traffic densities and close proximities. Today's technology is rapidly developing, and particularly collision avoidance for UAM applications has to be worked on (Lancovs, 2017).

Considering that landing and take-off are to be done on rooftops, car parks, or other urban structures (Cotton & Wing, 2018), the resulting dense traffic definitely requires a collision-avoidance system (Katz, 2019). Airbus (2018) relies on a system with a mix of managed separation and detect and avoid (DAA). Consequently, UAM operations in the urban environment will lead to new airspace concepts, which include stacked layers, dynamic 4D tubes, designated zones, and urban air corridors. UAVs in this new, smart urban air space access depend on some capabilities like accurate, precise, and reliable trajectory tracking and conformance and robust DAA systems (Bijjahalli et al., 2019).

Considering that UAM systems will operate within 3,000 ft of the ground, they will be in close proximity to one another, or obstacles that existing ATC systems neither support them adequately nor there are any clear plans for how to integrate them (Vascik et al., 2018). So, this makes low altitude airspace management a requirement (Merkert & Bushell, 2020). There has to be cooperative decision-making in the traffic regulation (Gillissen & Schultz, 2018) across the UAM participants because the scalability of Air Traffic Control (ATC) is limited and constrains UAM depending on traffic workload (Vascik et al., 2018). This means that the self-managed separation is a must, which implies communication among all stakeholders and the reporting routines to the air traffic control.

Collaborative Traffic Management

Lancovs (2017) proposed a collision avoidance system used in manned aircraft for small, commercial UAVs operating in unregulated airspace since the UAV technology in UAM lacks a reliable collision avoidance system. Lancovs (2017) concluded that a cooperative, infrastructure-independent solution, like ADS-B, regardless of the sizes and attributes of UAVs, was required. The focus of this approach for all potential collision avoidance scenarios is to design a system maintaining the required level of P, which demonstrates the failure probability $P<10^{-9}$ (Won Keun Youn et al., 2015). This collision avoidance system is classified as a Level A system due to the possibility of human injury and death. Experiments were finalized by showing different minimal safe encounters which did not end in a crash. Thus, the system is guaranteed to provide the failure probability $P<10^{-9}$.

Balachandran et al. (2018) proposed an approach for the collaborative behavior of the UAVs in UAM to enable merging and spacing by using a combination of scheduling and distributed consensus. UAVs approaching an intersection schedule their arrival time independently and maintain a safe separation to safely merge at and coordinate passage through the intersection in a decentralized manner. For this common intersection, UAVs consist of a network, and each of them broadcasts its arrival time. Distributed consensus algorithm elects a leader from the UAVs approaching the intersection. This leader synchronizes the information gathered from the UAVs. The required minimum separation time for the UAVs was 10 seconds, and each of them adapted its trajectory to cross the intersection safely by applying the separation constraints. For this application, Dedicated Short Range Communication (DSRC) and Cellular V2V technologies seem the most operable tools.

The Route Management

According to the Blueprint for Airspace (Airbus, 2018), which outlines a roadmap for the integration of autonomous air vehicles into the airspace, four routing strategies exist: (i) basic flight with the freedom to select the shortest route which is open to conflicts, (ii) free routing coordinated and deconflicted with others involving a central authority, (iii) corridors as the best option to separate dense traffic, and (iv) (dynamically) fixed route with full control by the authority. For unmanned aircraft, the concept of Airbus (2018) assumes the provision of basic traffic information by the authority that pilots and autopilots can facilitate self-separation and collision avoidance. Furthermore, it also assumes a networked collection of services within distributed authorities instead of centralized control, which also leads to the privatization of the service.

A conceptual architecture for high-density UAM with over a million aircraft operations per hour is given by Lowry (2018), where different streams of traffic can be merged. There, the ascend and descent planning is designated with airspace construct, and vertiports are planned as stations. To achieve flight safety, the need for surveillance sensors is underlined there, and to tighten spacing and sequencing, the computation is planned to be ground-based and vehicle-based. The UAM is planned there to separate over 400 ft. from UAS and below 4,000 ft. from the regular traffic. Then, the short travels are separated from long-distance travels over 10 nautical miles at below 2,000 ft. The system has free planning across territories, i.e., free direct point-to-point flights below 2,000 ft. that the aircraft are not following any roads or other geographical features. Between 2,000 ft. and 4,000 ft., long-distance travels are on enroute highways, nonintersecting with other travelers at a similar height. This also requires a centralized control mechanism, but there is no information about this in the paper. It is only mentioned that parallel corridors in cardinal directions are fixed, and either a centralized system or inter-vehicle communication can be facilitated. Over 4,000 ft., the flights are channelized in the classical ATC manner. To prevent interactions, the UAM traffic is planned (Lowry, 2018) to be below the commercial traffic or on the side of commercial flight corridors that only general aviation airports are accessible for UAM. The system predicts over 5,000 vertiports for operation for an area such as the San Francisco Bay to enable walking distances for the UAM beneficiaries. Vehicle-to-vehicle communication and mutual spacing, and de-confliction are planned there as well, avoiding collisions and conflicts. Then, aircraft are separated with a 30-second distance in general and a minimum of 10 seconds by monitoring the vehicle ahead. The paper also mentions bilateral control but makes no information available, whether and how it shall be used or not.

Cotton & Wing (2018) proposed Airborne Trajectory Management (ABTM) concept, which evolves UTM using a decentralized approach in very high traffic and close vicinities by applying self-separation, a minimized *design separation*, and airborne surveillance. The conflict resolution modes of horizontal, vertical, and speed are facilitated together along with comprehensive traffic operating rules. Consequently, flights are planned independently, and the concept manages the angular velocity of a passing vehicle and perceives the hazard of very close UAM operations by autonomous, tactical separation of the vehicles, which enables flexible navigation plans. The decentralizing rather than ground-based trajectory management is preferred there for its economic applicability and robustness against catastrophic failure potential of ground-based systems (Cotton and Wing, 2018).

Then the "best-equipped, first-served" model was proposed by Vascik et al. (2018, p.5) to replace the *first-come, first-served* model used currently by ATC. The scalability of ATC is designated as a constraint and concern for the UAM high-density low altitude operations that safe and efficient airspace management with current ATC methods is a challenge (Vascik and Hansman, 2017). Traditional voice-based communication, existing navigation and surveillance (CNS) technologies, and separation minima regulations are not appropriate for UAM. Free Flight Operations allowing manned and unmanned aircraft dynamically to define their trajectories require Vehicle to Vehicle (V2V) communication and self-separation. Besides, some navigation technologies are expected to develop to support this decentralized and flexible concept for the integration of the UAM vehicles into the airspace (Vascik et al., 2018).

Separation in UAM

Katz (2019) proposed a new collision avoidance system (CAS) by utilizing the Partially Observable Markov Decision Process (POMDP) according to the expected behavior of UAM vehicles operating at low altitudes. Therefore, the proposed collision avoidance system extended the previous methods (Kochenderfer et al., 2012; Olson, 2015) to provide safe integration of these UAVs into the airspace. Monte Carlo simulations were executed to assess the performance of the algorithm by simulating it on a set of 1,000 pairwise encounters. Since many obstacles exist at low altitudes, lateral deviations are undesirable. This collision avoidance system just makes the UAVs use the vertical maneuvers called Resolution Advisories (RAs). However, since these UAM vehicles fly close to the ground, the descent is prohibited. Actions in the airspace used in this system similar to the Airborne Collision Avoidance System Xa (Kochenderfer, 2015) are clear of conflict (COC), do not climb (DNC), do not descent (DND), climb (CL250), strong climb (SCL450). The foremost assumption in the case of two aircraft's encounter is that a UAM vehicle with CAS reacts with vertical acceleration while the intruder (any aircraft) keeps its current path. There is also a reward model balancing safety and alert rate in this collision and avoidance system. Since there is no lateral movement defined in this model, just vertical separation is defined 100 ft. as a near mid-air collision (NMAC) variable. Alerts, which are the actions, not COC, are penalized while the COC action deserves a reward.

Besada et al. (2019) defined three layers in the air space as time/height constraints calculation (lower layer), terrain avoidance (middle layer), no drone zones avoidance, and incorporation of airspace constraints (upper layer). It is aimed to analyze the integration of the planning phases into traffic management solutions. Two types of operations are assumed: 1.

Automated flight, following 3D waypoint by applying open-loop control approach which is dependent on trajectory prediction tools by drone dynamic models; therefore, the operation is not dependent on the information received from drone. 2. Manual/autonomous flight dependent on the data provided by drone sensors in real-time, which autopilot or human pilot takes decisions on the trajectory.

The consolidated report of SESAR JU (2020) over nineteen projects, launched in 2017 and 2018, with numerous stakeholders demonstrates that Europe steps forward to implement safer UAM operations on metropole cities and to lead full integration with manned aviation. Although all nineteen projects are valuable, CORUS (Concept of Operation for European UTM Systems), DroC^{2}om (Drone Critical Communications), PODIUM (Providing Operations of Drones with Initial ATM), and TERRA (Technological European Research for RPAS in ATM) projects, more relevant to this research, stand out and are mentioned here. CORUS developed a Concept of Operations (CONOPS) for very low-level airspace operations of drones. CONOPS elaborated drone operations in uncontrolled, very low airspace and in/around controlled and/or protected airspace. After identifying airspace types, services, and technical development as an initial architecture, this consortium quantified the levels of safety and performance by applying scenarios for contingencies and emergencies. DroC^{2}om project validated LTE C2 (Long Term Evolution Command and Control) performance in urban areas. It concluded a hybrid cellular-satellite architecture combining low latency and coverage of cellular including 4G/5G specifications on LTE usage by aerial vehicles. PODIUM project paid attention to U-space solutions to ease the flight authorization of drone flights. PODIUM demonstrated a web-based UTM system including an open cloud-based solution and a secure gateway solution using tracking systems based on ADS-B 1090 MHz, UNB-L Band, and mobile phone networks for the drones operating in low-level airspace. TERRA project concluded that current communication, navigation, and surveillance (CNS) technologies are sufficient to support U-space services in simple environments with a low density of drones. However, new technologies like 5G, Galileo, and EGNOS v3 will be necessary for complex environments.

All in one, it is obvious that the integration of UAM into the airspace must be done by air traffic regulations (Mualla et al., 2019). This requires specific procedures for origin/ destination route planning, separation management, etc. For micro/ small scale UAM, i.e., the rules of UAM have to be written. Then a system complementing the existing air traffic control has to be defined to manage this traffic. At this stage, it is foreseen that it will be a separate system, which has the self-organizing capability, preferably within the swarm behavior of VTOLs.

Method

The challenges of urban air traffic management made this research required, where self-managed separation of unmanned aircraft is leveraged without the interaction of any external control authority. Consequently, a literature review was first conducted in scientific databases by using the keywords as ATC, UAV, RPA, and VTOL in conjunction with UAM. Then, TCAS, ADS, and urban keywords were added to further increase the scope. Consequently, 45 journal and conference papers were isolated. In addition to that, grey literature research was conducted as well: the commercial websites of urban autonomous aircraft producers, magazines, and similar sources were searched for by Google with the same keywords to trace technological enhancements on the technology push side. Also, FAA, EASA JARUS, NASA, and European Union publications were searched to include the regulatory input. Then, literature not delivering any explicit VTOL, UAM, or airspace control concept was excluded ending up in 12 reports, declarations, drafts, and regulation opinions. After that, the swarm concept in unmanned aircraft was looked at by the keywords swarm, VTOL, and unmanned aircraft resulting in 36 papers, where only 16 were selected after excluding the remaining papers which were not related to the concepts of air traffic management.

The literature review delivered the challenges and requirements subject to ATC and UAM, which were isolated as constructs for an air traffic management model in a deregulated airspace. In other words, based on the requirements and technological solutions presented therein, an appropriate model was conceptualized by the function-based synthesis method (Wood & Greer, 2009) for the regulation of the air traffic for UAM. There, the function is what the system has to do, i.e., the requirements are set with it. The synthesis is then focusing on structural elements enabling these functions constituting the model. These elements were set here as the rules of the urban air traffic guiding the self-organization as described next.

The Model: Self Organizing Swarms

UAM is embedded in a complex environment, which requires perceptual intelligence and reactive forms of control autonomy for coordination (Floreano & Wood, 2015). For this reason, the problems of regulation and collision avoidance have to be resolved (Mualla et al., 2019). This means that individual autonomous UAM systems, i.e., agents, have to operate together safely, leading to a multi-agent problem. In multi-agent systems, multiple interacting computing systems autonomously take actions in the coordination of other agents to achieve specific goals (Wooldridge, 2009). Such cognitive, decentralized multi-agent systems are used today in UAVs, particularly for coordination, mission management, collision avoidance, formation, and path planning, with urban planning as a common application domain (Mualla et al., 2019).

Since sight is limited in UAM, continuous use of radar to track neighboring aircraft is impossible. A multi-agent coordination framework is required, such as in the Vehicle to Vehicle (V2V) communication proposals of autonomous driving in the automotive industry (Balachandran et al., 2018). For this purpose, centralized as well decentralized attempts find a place where distributed consensus algorithms are safer. (Balachandran et al., 2018).

A multi-agent system can be used to form a swarm of aircraft acting as autonomous collaborative robots for spatial tasks, whereas model predictive control can be used for collision avoidance (Tahir et al., 2019). So, cooperative UAVs have challenges in collision avoidance, velocity matching, and cohesion due to the nonlinear dynamics, where existing technologies are capable of addressing these challenges by using cooperative algorithms for consensus, guidance-law, and flocking in a swarm (Sargolzaei et al., 2020; Luo & Duan, 2017). Cooperative algorithms have to be distributed that complex tasks are divided into simpler tasks and assigned to each member resulting in collective performance such as bird's flight behavior as in nature (de Mendonca et al., 2016).

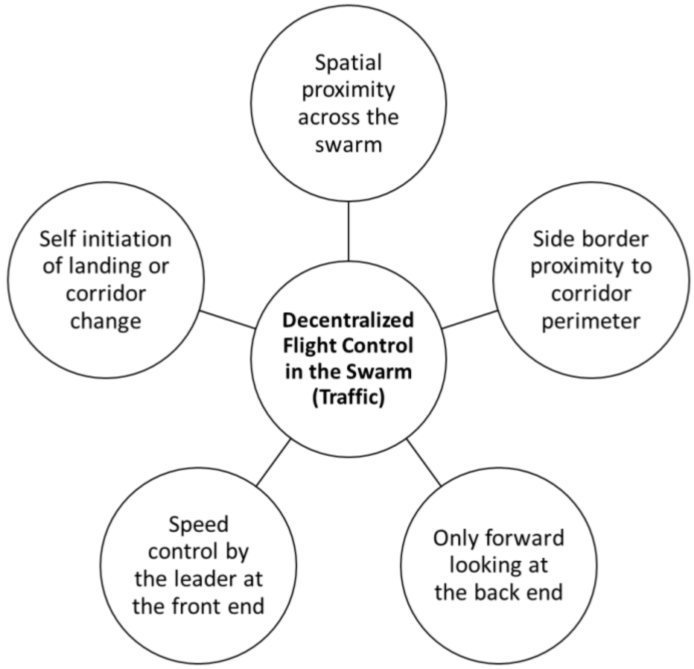
Such swarms are the highest level of autonomous capability in UAVs (Gao et al., 2016), where the dynamic task allocation can also be done with a distributed approach. Then, each member can operate only with limited information. It is also possible to have a task swap within the swarm (Wang & Rubenstein, 2020), e.g., two agents can change their positions. There are many algorithms from robotics that perform efficiently in systems with limited storage and processing power (de Mendonca et al., 2016). Each member of the swarm can operate alone or as a part of the swarm, where self-organization is achieved (Gao et al., 2016) in a resilient network (Jakaria & Rahman, 2018).

Torres (2012) applied the swarm theory in air traffic management, where airline pilots were designated as agents for optimizing the separation. Here, a distributed system is taking over the control enabling self-organizing swarms. Consequently, dense local traffic forms a swarm that each UAM system becomes a member of the swarm as soon as it goes into the traffic zone. Then, the UAM systems shall be capable of having distinct swarm and stand-alone states, and distributed algorithms control the individual agents controlling the traffic.

Biologically inspired by the birds, relative spatial proximity can be used in swarm state instead of explicit control of position and distances that a decentralized aircraft control can be realized on the trajectory tracking trying to remain in the middle of the surrounding members (Garcia & Keshmiri, 2016). Unlimited agents can be members of the swarm. Here, the stacked corridors over each other are utilized, which simply outline physical air volumes over streets or rivers with defined flight directions and minimum and maximum speed limits. These corridors are managed dynamically by the ground control unit, which most probably is assumed to be parts or subcontractors of a municipality.

Members on the side border of the swarm are controlling their distance to the flight corridor perimeter in addition, and those at the end only look forward, while those in front are adjusting their speed according to the limitations of the corridor. One of those on the front is also to be assigned as the leader that it can assign a task such as immediate deceleration in emergencies or upcoming obstacle warnings at certain points. The leader selection does not have to be optimal and can be done with submodular algorithms (Chung et al., 2018). All members, including the leaders, can also communicate that they want to initiate a landing or a corridor change (See Fig. 1).

Figure 1
Means of Control within a Flight Corridor

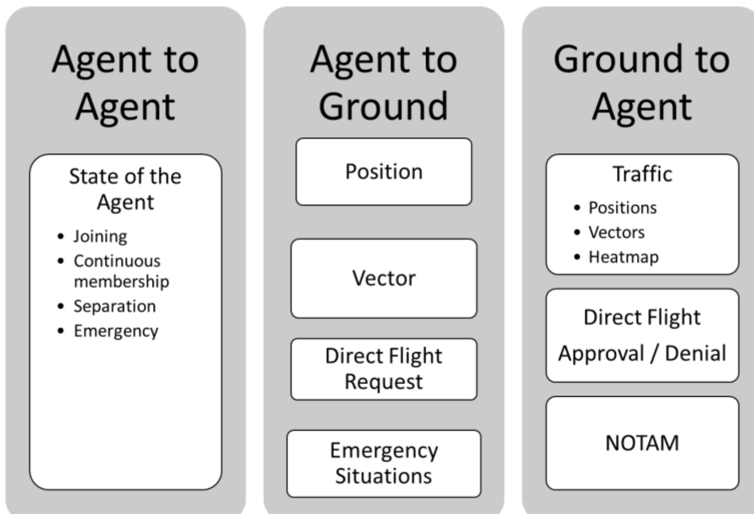


Just following the surrounding traffic, members of the swarming process only limited information from their neighbors. This requires a communication infrastructure for push notifications from agents to agents or for mission assignments (Rosalie et al., 2016). Here, the position and the flight vector do not have to be broadcasted to the swarm because the safe distance, which might be determined as a minimum as five times the span of the larger one among the neighboring UAM vehicles, is being used for the control within the swarm. Besides, going and returning courses should be separated by different flight corridors, one under the other, unlike the car roads side by side, since one-way swarm movement provides safer operations. The widths of these air corridors will be the same as those of the car roads followed. The depth/altitude of these flight corridors will be two-fold the width due to the need for extra vertical movement area. The interconnectivity allows distributed algorithms to change the state of the agent, which can be broadcasted as well, i.e., continuous membership, joining/ separation to/ from the swarm towards the stand-alone mode can be communicated that surrounding swarm enables a safe passage zone. Furthermore, a member of the swarm can also declare an emergency to have a safe passage as well.

As of today, distributed algorithms might be slower (Chung et al., 2018) than centralized algorithms, but they enable collision-free navigation. Then, the attacks to the network can be prohibited by aggregate signatures and associated algorithms (Hong et al., 2020) that safe operation requires further resources. However, considering the progress in hardware technology and the upcoming 5G cellular technologies for connectivity (Campion et al., 2018), it is simply just a matter of time that such a swarm approach involving a high number of stakeholders will be a reality soon. Therefore, new technologies mountable to the UAVs are needed to preclude the airborne collisions of these swarm operations.

To prevent such incidents and accidents, the position and the flight vector, including speed and acceleration data, is broadcasted to a local ground station, where the operator of the ground station only has the job of consolidating received information from all members to broadcast consolidated local traffic notifications. Then, the ground generates 3D heat maps indicating dense traffic zones to enable a better selection of flight corridors for economic and safe flight. Finally, the ground station can also send Notifications to Airman (NOTAM) to define restricted zones such as temporarily closed corridors (see Fig. 2), which enables a further safe environment.

Figure 2
Communication routines within the system

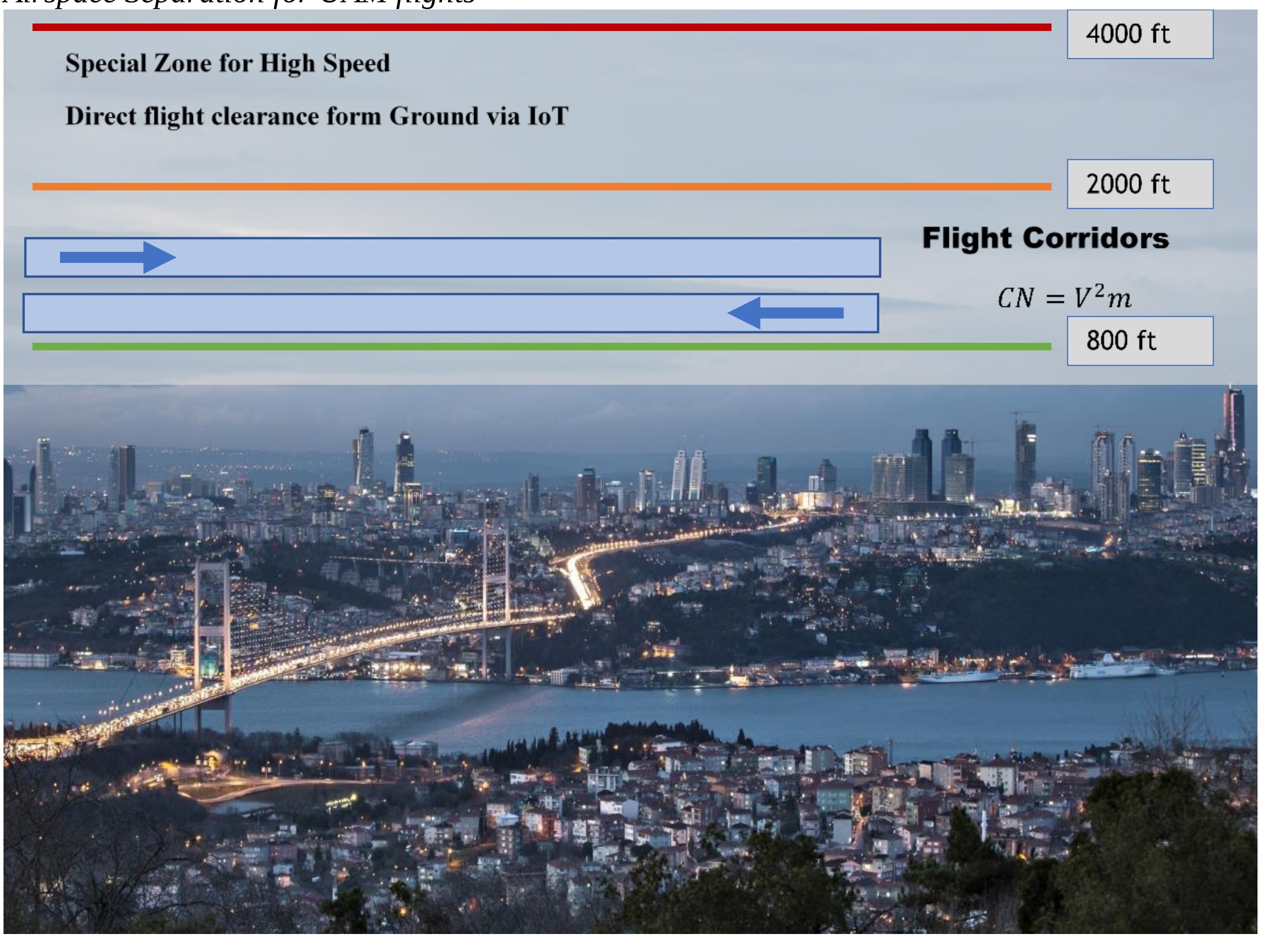


When flying alone, an aircraft is then free to choose any speed and height within the allowed interval of the corridor. Within a swarm, these limits are also applied in addition to the surrounding interaction. If a member of the swarm wants to get faster, this is possible depending on the proximity of the traffic: having a free passage ahead, the aircraft can move there with only a 10% speed increase until it is out of the traffic. This means that overtaking on any side is allowed by a set of rules similar to car traffic. This is possible only if there is no swarm formation but a free flow of traffic. In the case of existing swarm formation, members can separate from the swarm to a higher altitude to overtake. However, the required navigation performance (RNP) is a challenge. If RNP 0.001 can be enabled, approximately 5 m distance between aircraft can be realized, particularly in lower flight corridors.

Considering that existing VTOL concepts have a cruise speed up to 630 km/h with a capacity generally of up to six passengers (Rothfeld et al., 2018), there will be a high difference between small and large UAM participants. If the maximum speed of an aircraft is not suitable for a corridor, then it is not allowed to go in there. So there are unidirectional stacked air corridors over streets to fly through, such as utilized in RNP AR of NextGen. This means, in general, that slower aircraft remain low while faster aircraft will eventually climb to higher corridors, and to address privacy and security concerns of low altitude UAM (Kopardekar et al., 2016), the conceptualized model is intended to use the airspace above the streets and rivers. This new categorization for altitude separation is made with a category number (CN) as $CN = v^2m$ where v is velocity and m is mass. The higher the CN, the higher the flight corridor that can be chosen. These flight corridors are designated between 800 ft. and 2,000 ft. (see Figure 3). Considering this attitude gap, 2 or 3 pairs of flight corridors (each pair accounted for one going and one returning corridor due to the one-way swarm movement) might take place in this designated altitude. After this maxima, up to 4,000 ft. is a special zone for high-speed UAM vehicles, where direct line routes can be flown from A to B rather than following street patterns. However, this requires a direct flight clearance from the ground control by Internet of Things (IoT) connectivity subject to special handling and fee, which is compatible with the height separation schema of Lowry (2018). If only the aircraft is certified to land in regular airports, then a further climb over 4,000 ft. is allowed, where a flight is carried out according to regular civil aviation rules with ATC communication.

Figure 3

Airspace Separation for UAM flights



When not in a swarm operation, the UAV will simply fly in the middle of the corridor in the horizontal plane and separate linearly in height by the ratio of their speed and the allowable speed minima and maxima of the given corridor. This means simply that the faster aircraft will be higher compared to the slower ones. Then, if the CN is large enough, overtaking up to the slower UAV after climbing will also be acceptable. If there is any proximate traffic, all acceleration and deceleration limits are within those defined for the given corridor. Then, the aircraft can be commanded to take off from a vertiport at point X to fly via a charging station Y to a final destination Z.

However, due to having a control based on the swarm logic and having the possibility of fuzzy mistakes, there is no predictive coverage of all possible aircraft maneuvers, which makes escape maneuvers inevitable. To enable this, there are designated zones that can be used. There are already zones, such as for waiting, charging, and landing at vertiports, defined within the corridor maps, but in emergencies, all airspace over the private ground, i.e., gardens or houses, can be temporarily used. Then, the penetration into this private zone shall be kept at a minimum and as short as possible. In certain cases, landing in emergency areas such as some rooftops parks are also allowed, where the aircraft have to be equipped with sensors to check the existence of humans and other living creatures in these areas.

Due to the low altitude flight profile of the UAM vehicles over the cities, there is a line of sight (LOS) limitation problem, but since these vehicles are intended to total autonomous flight, this is not expected to be a problem. Different sensors and systems are going to be used within the system that detects and avoid systems are all on board (Kopardekar et al., 2016). There, traditional navigation systems (VOR, DME, etc.) might not be reliable, ADS-B might be susceptible to jamming, signal insertion, and deletion. Standard GPS might not be dependable because of signal multipath and urban canyon impacts at low altitude operations. All these are challenges of Performance-Based Navigation (PBN) (Vascik et al., 2018). A remedy for that is the usage of 5G technologies as proposed by Besada et al. (2019) together with Global Navigation Satellite Systems (GNSS) (Biijahalli et al., 2019) and inertia navigation. Then, all aircraft have to have TCAS and ADS-B/C capability of NextGen for interlines in airport regions. Furthermore, there will be a proximity sensor enhancement requirement for the TCAS, which is subject to further research, which could facilitate the Airborne Collision Avoidance System X (ACAS X) for quadcopters (Katz, 2019).

Discussion

The application of the self-organizing swarm system for the regulation of UAM is promising. While the rules are delivered to organize the swarms within high-density traffic, the same rules are also capable of guiding the traffic. The separation schema, confirmed by Lowry (2018), enables performance-based navigation according to ICAO PBN Manual (Doc 9613) and supports required escape maneuvers (Lowry, 2018).

Similar to the UTM ConOps scope class G (Kopardekar et al., 2016), a separation is made here with respect to auto-regulated operations in an uncontrolled area. Then, a transition to operations in controlled airspace is also allowed. Gillissen and Schultz (2018) introduced a System-of-Systems (SoS) concept for cooperative decision making, which is a formal integration attempt of the regular aircraft/ air traffic control for en route and airport operations. The same applies here: the decision-making during flight shall be cooperative and, in fact, also collaborative across the UAM systems within the swarm. However, due to the high traffic density, the control of the UAM traffic cannot be centralized. This is contrasting Straubinger et al. (2020), which relies on ATMs, but there it is also mentioned that drones can be assessed as networked cyber-physical systems. Furthermore, unlike regular traffic, the UAM systems can change their destination during the flight. Thus, all systems shall have a certain degree of freedom, collaborating during maneuvers by adjusting their speed and altitude, which is also strived by the industry (Merkert & Bushell, 2020).

Katz (2019) discussed the use of the Airborne Collision Avoidance System X (ACAS X), which relies on complicated Markov decision processes instead of the heuristic rules of TCAS in order to comply with NextGen. This is compatible with the approach here.

According to Rothfeld et al. (2018), UAM concepts have to include emergency landing areas, charging stations, vertiports for boarding, which are all included by the proposed system as well. This also can enable the usage of air taxis, as indicated by Rajendran et al. (2021). Lowry (2018) indicated that a VTOL such as the Volocopter can only deliver a 0.1 g acceleration envelope, while a car like the Tesla can achieve an acceleration up to 1.0 g on the ground that due to this difference in maneuverability, the existing roadways cannot be simply lifted up to virtual roads. However, it is obvious that these performance characteristics are not subject to be used in regular traffic. When a car is driven smoothly in traffic, the accelerations are by far lower, and we believe that with the correct speed limitations on the air corridors and the correct deceleration prior to direction changes, the aircraft can cope with the elevated air corridors over the streets.

eHang believes in a “centralized remote command-and-control platform to perform multiple tasks autonomously” (eHang 2020, p.9). Contrary to eHang, the model in this study proposes decentralized and uncontrolled air space for UAM. It is anticipated here that the traffic control system is only regulating the maps and enabling the transition from free flight zones towards regulated airspace because the workload at a centralized system would be simply too expensive, and such centralization is not necessarily required. The approach of eHang is partly based on the belief that “advanced avionics, weather-sensing equipment, and terrain avoidance capabilities remain too expensive or too heavy” (Kopardekar et al. 2016, p.5) to be included in UAM. However, technology has advanced so fast that even small UAVs can have radars anymore, and peer-to-peer communication devices are affordable as well. This can also be simulated in further research: There are distinct multiple demand modeling tools suitable for urban air traffic such as PTV Visum and TransCAD, but due to a high number of integrated stakeholders, an activity-based open structure with free licenses shall be preferred, such as in MATSim (Rothfeld et al., 2019) with an extension for autonomous vehicles (Bischoff and Maciejewski, 2016) based on the Dynamic Vehicle Routing Problem of Maciejewski’s (2016).

As of today, free flight in UAM is particularly enabled by “Global Positioning Systems (GPS), data link communications like Automatic Dependence Surveillance-Broadcast (ADSB), Traffic Alert and Collision Avoidance Systems (TCAS), powerful onboard computation, and automated conflict detection and resolution tools” (Bertram et al. 2019, p.1), which are utilized by the proposed system. Here, the ADS-C compatibility is also given since the aircraft can contact Air Traffic Service Unit by IoT requesting clearance for the high-speed zone. Furthermore, emergencies are also broadcasted to the air traffic controller. This is in line with the low-altitude airspace management system approaches (Merkert & Bushell, 2020).

Then, the communication among participants of the swarm is a key point. Collaborative algorithms with respect to consensus control have to be developed (Sargolzaei et al. 2020), particularly assigning the leader, which is a further research area. Markov Decision Processes (MDPs) can be used to solve collision avoidance in urban mobility (Bertram et al., 2019). Consequently, it seems possible for UAM to be realized with existing technology and appropriate development efforts.

At this point, security concerns might arise, which can result in costly disruptions (Merkert & Bushell, 2020). Al Haddad et al. (2020) points out this with respect to information sharing cyber-security. Furthermore, the smart city concept involves many IoT devices whose interrelations with UAVs have not been widely researched (Mualla et al., 2019). For instance, the emerging trend of mobility as a service (MaaS) and on-demand mobility (ODM) (Fu et al., 2019) can be addressed with this system as well. Such approaches will become a reality soon, which further complicates the safety assurance. However, it is too early to discuss the impact since this ecosystem is just being shaped; thus, it is a future research area.

Environmental considerations (Kopardekar et al., 2016) can be taken into consideration, particularly the noise and visual impact of UAM (Al Haddad et al., 2020) can be discussed. While the UAM application enabling new operations increases the environmental load, on the one hand, the electrified traffic enabling micro-mobility will provide a better load balancing preventing the circulation of empty vehicles on the other hand. Moreover, UAM is inevitable, and the scope should be rather how to enable it in a safe and efficient manner by the appropriate integration of UAM into airspace.

The focal point of this study is to determine an altitude separation among UAM vehicles moving in a swarm manner by applying the proposed category number (CN), which is a function of velocity and mass. While moving in a swarm, each UAV/agent might need individual movements to change their positions, like leaving the swarm, joining a different swarm, or overtaking the other UAVs in case of new tasks and any emergency situations. Therefore, it needs some different algorithms considering collide and avoidance from each other under these possible circumstances. Then, UAVs may have communication problems in low-altitude corridors of the air space when solely relying on satellite-connected GPS. Therefore, UAVs might be gained some specialties like feature extraction, certain point recognition algorithms, artificial intelligence (AI), and machine learning algorithms to carry out their tasks without GPS. Furthermore, ground stations to support the GPS resolution can be examined and improved. These are indeed hot research topics in the literature and are totally in line with the requirements of the proposed deregulation attempt.

Since the proposed model obliged the UAVs to use main roads and rivers between 800 ft. and 4,000 ft. altitude, a high traffic potential might be expected. Consequently, the optimum number of the UAVs in the swarm must be determined by simulations; even if relative spatial proximity might allow unlimited agents in the swarm that the sizes and types of UAVs within the swarm should be regulated according to their maneuver capabilities. Then, minimum and maximum speed limits of these stacked corridors at each separation should also be determined even if the UAVs are supposed to choose any speed and height within the allowed interval of the corridor and participate in UAM swarms according to their category numbers. This particularly requires further categorization of UAVs, especially high-speed UAM vehicles, probably preferring direct line routes over 4,000 ft. rather than following street patterns shall be investigated further. On top of this, technical concerns for charging stations and take-off & landing points should be determined to further elaborate rules for the deregulation of the airspace.

Conclusions

Micro and small-scale mobility has become a reality of today. Automated VTOLs are being proposed in various applications for urban transportation. The increasing number of UAM applications will result in a high traffic load, which cannot be managed with a centralized system. As of today, there are many initiatives actively trying to develop solutions, but so far, there is no specific framework yet.

As a result, the deregulation of the airspace in urban areas is a promising approach for this challenge, requiring certain rules capable of guiding the adaptive nature of small stakeholders, which are given here in detail. The integration of UAM into the airspace is assured here by specific procedures that a self-organizing capability is provided in conjunction with the swarm formation for the autonomous behavior, which is the contribution of this work to the literature. Deregulated airspace over the streets is also utilized together along with direct flight possibilities over buildings in spite of the existence of larger manned vehicles.

The main contribution of this proposed model is to create deregulated air corridors within determined altitudes (800-4,000 ft) over the main roads and rivers of the metropolitan areas and to assign each UAV to a corridor for UAM swarm movement by calculating their CN. Furthermore, this model also proposes communication routines for agent to agent, agent to ground, and ground to agent while it determines the control means of the UAM swarm within the corridor. This model undoubtedly tries to regulate the deregulated airspace without authorized air traffic control. Besides, this study also demonstrates the need for the most recent sense-and-avoid, navigation, and communication technologies and improved AI algorithms for the UAM integration into airspace.

The proposed model is successfully discussed but certainly has some challenges and limitations, which might also be considered as future studies. Particularly, collision avoidance and positioning are the challenges where the proposed model assumes that they are solved by the UAV community. Nevertheless, the realization of this model requires that robust swarm algorithms using AI and machine learning are developed to satisfy the needs of the proposed flight formation. While improving some mathematical models and algorithms for the emergent and early UAM operations by using recent technologies, all aviation stakeholders should also cooperate and improve the necessary concepts and regulations for airspace integration of high-density, high-speed, and safe UAM by utilizing the miscellaneous proposed models. In the end, the architecture of the airspace will inevitably undergo a new transformation.

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A Qualitative Review of the Relationship between Safety Management Systems (SMS) and Safety Culture in Multiple-Collegiate Aviation Programs

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Safety Management Systems (SMS) implementation is currently a voluntary pursuit for collegiate aviation programs. Some programs have implemented SMS and others are beginning to consider it. An understanding of the impact of SMS on safety culture at institutions actively implementing SMS and the potential challenges posed can be useful to the entire collegiate aviation community. The safety culture perceptions across three collegiate aviation programs with varying levels and types of SMS implementation were explored through semi-structured interviews of students, certified flight instructors (CFI), and safety leaders. Emergent codes and subsequent themes derived from the semi-structured interviews suggest an apparent knowledge gap among respondents on the SMS implementation phases and some essential attributes of a fully-functional SMS program. Another significant finding was that CFI plays a critical role in developing students' perception of safety culture by setting the example for desired safety behavior and exposing students to the safety processes within programs. The findings suggest that using practical or scenario-based learning in SMS training can ensure understanding and enhance a sensed ownership of SMS processes in the various programs. The results also suggest that actively engaging CFI in SMS higher-level processes such as safety risk assessments and audits can improve their safety leadership and empower them as effective mentors for their students. Active participation in the SMS process by aviation students can significantly improve their perceptions of safety culture, enhance desired safety behaviors, and bridge the knowledge gap required for entry into the aviation industry.

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Collegiate aviation operations in the United States (U.S) have been characterized by training environment complexity due to stringent airman certification standards, high accident potential as compared to commercial airlines (NTSB, 2019), and low levels of experience among pilots, which has implications for operational safety in this sub-set of general aviation (G.A.) (Adjekum, 2014). To ensure a sustainable culture of safety, there has been advocacy for the adoption of Safety Management Systems (SMS) in collegiate aviation operations (Adjekum, 2014, 2017; Friewald et al., 2013). Safety Management Systems (SMS) is a systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies, and procedures (ICAO, 2018), and its impact on safety culture within aviation organizations has been previously studied in commercial airlines, and airports (Chen & Chen, 2014; Gill & Shergill, 2004; McDonald et al., 2000; Remawi et al., 2011).

There seems to be a shift in research that focuses on safety culture and SMS in collegiate aviation programs and adding to the body of literature in that area (Adjekum, 2014, 2017; Adjekum et al., 2015, 2016; Adjekum & Fernandez-Tous, 2020; Canders, 2016; Freiwald et al., 2013; Robertson, 2016; Velazquez & Bier, 2015a; Velazquez & Bier, 2015b). It is imperative to build on prior research and continue the process of research updates. While SMS is not a requirement for collegiate aviation in the U.S, it can become a requirement at some point in the future, and some universities have already pursued SMS preemptively (Pinholster, 2019).

Safety culture is essential to an organization's safety performance and applies to those organizational aspects that relate to safety performance and is a product of the values and actions of organizational leadership and learning (FAA, 2015a). The Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) both consider a proactive safety culture to be an essential performance outcome of SMS, and periodic assessments of the relationships between these two concepts can provide valuable inputs for continuous improvements to safety policies and practices (FAA, 2015a; ICAO, 2018).

Adjekum (2014, 2017) utilized quantitative designs to research safety culture in collegiate aviation using the Collegiate Aviation Program Safety Culture Assessment Survey (CAPSCAS). The findings from Adjekum (2014, 2017) found that "years spent at the university" had a significant effect on the safety culture perceptions of respondents. However, this analysis was performed at one collegiate aviation institution, and there is a need to perform a similar analysis at other collegiate aviation institutions using either mixed or qualitative approaches.

Other research across multiple universities focused on how SMS affects safety reporting culture, but a quantitative approach was used (Adjekum et al., 2015, 2016; Robertson, 2016). The need to corroborate the findings of these extant research across multiple universities using other research approaches is warranted for generalizability purposes. This will provide universities with vital data-driven approaches when developing SMS in their aviation programs. Despite all these studies, specific inquiry into the relationships between SMS implementation and safety culture perceptions in collegiate aviation using a purely qualitative approach seems novel, and there have been recommendations for more research (Adjekum, 2017).

Purpose of the Study

This study qualitatively explores the relationship between SMS implementation and the safety culture perceptions of a cross-section of flight students, certificated flight instructors (CFIs), and safety management leadership in multiple collegiate aviation programs in the U.S. Specifically, the safety culture perceptions of respondents from these programs with varying types and implementation levels of SMS were explored through semi-structured interviews.

Previous research findings have suggested a difference in safety culture perception based on the “year group” of aviation students (Adjekum, 2014). Therefore, another goal of this study was to explore some of the reasons for such differences when the nominal assumptions are that safety culture is pervasive and should be almost homogeneous in an organization with effective SMS (Chen & Chen, 2014; Stolzer & Goglia, 2016) and find ways to continuously improve the safety culture.

A detailed understanding of how research respondents perceive safety-risk factors in flight operations could provide relevant information needed for hazard identifications and effective safety risk management. These processes are vital for sustaining a proactive safety culture (ICAO, 2018; Reason, 2008). Finally, as part of SMS implementation, safety communication and promotional strategies are very important in framing the safety culture perceptions of respondents. The study aimed to get a better understanding of the effectiveness of these strategies using a semi-structured interview approach.

Research Question

The over-arching question and sub-questions were obtained from Adjekum (2016). The detailed questionnaire with demographic details was initially sent to three subject-matter experts (SMEs) who are faculty members with extensive research portfolios in safety culture and SMS research. These SMEs reviewed the questionnaire for comprehensibility and face validity and provided meaningful comments. An example of a suggestion provided by one SME was the need to probe deeper into the understanding of SMS types and implementation levels among respondents. The final over-arching research question was:

> What are research participants' perceptions of the relationship between safety culture in their collegiate aviation programs and SMS implementation?

The following sub-questions delved into specific aspects of the over-arching research question:

- What are the differences in perceptions of a safety culture based on years spent in the program?
- What are the differences in perceptions of SMS implementation?
- What are the perceptions of safety communication and promotion?

Details of the question guide used in the semi-structured interviews can be found in Appendix A.

Literature review

SMS in Aviation

Remawi et al. (2011) investigated the effects of SMS implementation on employee attitudes toward unsafe acts at two airports in the Middle East, and their findings suggested that SMS resulted in improved perceptions of safety rules, supportive environment, personal risk appreciation, work environment, and involvement. In terms of assessing the dimensionality of SMS, Chen and Chen (2012) developed a scale to evaluate an airline's SMS performance. Five factors were identified in their analysis: documentation and commands; safety promotion and training; executive management commitment; emergency preparedness and response plan; and safety management policy which can be used by management to determine how well SMS performs based on their employee perceptions.

Chen and Chen (2014) sought to analyze multiple antecedents that are suggested to influence pilot behavior in an SMS environment. Three factors were considered for the model: Perceived SMS Practices, Morality Leadership, and Self-Efficacy. Safety Motivation was also included to assess the mediating effect. The outcome variable was safety behavior, which is broken down into two constructs: Safety Compliance and Safety Participation. Perceived SMS Practices were shown to affect both safety behavior outcome variables directly and were further strengthened by the mediating role of safety motivation.

In a review of the conceptual similarities of crew resource management (CRM) and SMS in the collegiate aviation environment, Velazquez and Bier (2015a) suggested that continuous education and guidance to upper leadership will lead to a more SMS specific invested culture as it did for CRM and that some of the challenges to SMS implementation in collegiate aviation programs include lack of scientific validation, absence of clear guidance from regulatory oversight agencies, and shortage of data tracking, sharing, and monitoring for improved overall system safety.

In another review of SMS education in various Aviation Accreditation Board International (AABI) accredited collegiate undergraduate aviation programs, Velazquez and Bier (2015b) evaluated more than 70 AABI-accredited collegiate aviation programs (e.g., flight, aviation management, and air traffic control) in 30 institutions. The review consisted of aviation safety course descriptions found in university catalogs.

Velazquez and Bier (2015b) suggested that SMS is not generally included in undergraduate aviation-accredited programs. While many courses cover SMS-related concepts, only 13% of the evaluated programs have an SMS course or SMS as a topic in an aviation safety course description. This finding suggests a gap in the introduction of SMS concepts at the foundational levels in collegiate aviation programs in the U.S.

Brady and Stolzer (2016) evaluated the effectiveness of SMS utilizing the approach of Input-Output (I.O.) economics theory along with Data Envelope Analysis (DEA). The initial findings supported the efficacy of such a method in evaluating SMS implementation in different organizations. In the sample, inefficiencies were able to be identified to give feedback and direction to the management on where these inefficiencies exist to improve the SMS.

Stolzer et al. (2018) continued to explore the use of DEA as a method to measure the effectiveness of SMS. Interviews were initially conducted on Subject Matter Experts (SMEs) in SMS. The findings from these interviews and relevant research literature were used to develop a survey instrument to collect the data necessary to utilize DEA as a tool for evaluating SMS effectiveness in organizations.

Safety Culture in Collegiate Aviation

Safety culture and safety climate have been actively studied for years (Gao et al., 2013; Liao, 2015; Taylor & Thomas III, 2003; Wang, 2018). There has also been extensive research performed on safety culture and safety climate in industries outside aviation (Barbaranelli et al., 2015; Brondino et al., 2012; Fugas et al., 2012; Groves et al., 2011; Kapp, 2012; Neal et al., 2000; Stemn et al., 2019; Wu et al., 2010). An area of research that is developing is safety culture in collegiate aviation and similar flight training organizations (Adjekum, 2014, 2017; Adjekum et al., 2016; Chiu et al., 2019; Dillman et al., 2010; Gao & Rajendran, 2017; Robertson, 2016). A behavioral component of safety culture that is relevant to this study is safety reporting behavior. Effective safety reporting is a critical component of an effective SMS (FAA, 2015a; ICAO, 2018).

Given the importance of participation in reporting systems and related safety behavior, Dillman et al. (2010) investigated perceptions surrounding reporting systems and why some students in collegiate training institutions fail to file a hazard report for actions or any other hazardous condition a safety department would need. Their findings suggested that a lack of time, ridicule from others, and embarrassment from peers were driving forces for students not participating in the provided reporting systems.

Freiwald et al. (2013) performed a safety culture assessment in collegiate aviation using a quantitative instrument called the Commercial Aviation Safety Survey (CASS), which was initially developed and validated in commercial aviation (Gibbons et al., 2006). Significant findings from this study were a lack of accountability for safety and a belief among respondents that safety reporting programs were critical, even though many had not participated in them.

Adjekum (2014) assessed the safety culture of a single collegiate aviation program using a new instrument developed from the CASS, referred to as the Collegiate Aviation Perception of Safety Culture Assessment (CAPSCAS), to determine if SMS implementation affected safety culture perceptions. The findings suggested that the year group had an effect on safety culture perceptions among students and that students who have been in the program longer had a better understanding of safety culture within the institution than newer students without the same level of experience or exposure. In another study among multiple collegiate aviation programs, Adjekum et al. (2015) found that safety culture perceptions could predict safety reporting behavior, and respondents' age was a significant predictor of safety reporting behavior.

Adjekum et al. (2016) evaluated the effects of safety culture perceptions concerning non-flight students. Adjekum et al. (2016) sought to investigate safety culture perceptions for Air Traffic Control (ATC), management, and Unmanned Aircraft Systems (UAS) students. The findings suggest a relationship between non-flight majors and the general trends, attitudes, and perceived safety values in their collegiate programs (Adjekum et al., 2016). This finding suggests that interaction with flight majors influences safety culture perceptions for the non-flight majors and supports the need to include non-flight majors in safety training and other related safety promotion activities.

Another significant finding from this study was the influence of response and feedback. Providing feedback promptly was shown to have a strong relationship with safety behavior, which includes filing safety reports (Adjekum et al., 2016). The findings suggest that when new students receive their initial safety training in collegiate aviation programs, they may feel more inclined to participate in the safety program by filing safety reports. However, a lack of response and feedback from the collegiate aviation safety office may lead to students not seeing the value in filing the safety report.

In a study on safety reporting among collegiate aviation programs with SMS, Robertson (2016) suggested that trust in a confidential safety reporting system is a sign of positive safety culture, and Jausan et al. (2017) suggested that assessing safety reporting behavior can be beneficial in improving the performance of SMS. Gao and Rajendran (2017) assessed students from an Australian collegiate aviation program using a self-constructed instrument from an earlier study (Gao et al., 2013) and identified four themes: safety reporting culture, safety reporting procedures, organizational culture practice, and general safety knowledge relevant to the topic of safety reporting behaviors. A more in-depth analysis suggested that first-year students had a more positive perception than the students who have been in the program for longer. The vertical mingling of the students was suggested as a means to integrate these differing perceptions.

Robertson (2018) conducted a quantitative assessment of the relationship between SMS implementation and safety culture, safety promotion, and management commitment using a study population of 453 students and employees from 13 collegiate flight schools. Data were gathered through an online survey at collegiate flight schools within the University Aviation Association (UAA) utilizing the Collegiate Aviation Program Safety Culture Survey (CAPSCUS) developed by Adjekum (2014) to measure safety culture at those collegiate flight schools. The results indicated that a relationship existed between SMS implementation and safety culture, safety promotion and safety culture, management commitment, and safety culture. The relationship for all three was more prominent within the Formal Safety Program major scale of the CAPSCUS.

Adjekum and Fernandez-Tous (2020) assessed the perceptions of aviation students, flight instructors, academic faculty, and collegiate administrators in a large U.S. collegiate aviation with a fully implemented SMS program on the relationship between four (4) organizational management factors (*Principles*, *Policy*, *Procedures*, *Practices*) and resilient safety culture using an online survey instrument. The results suggest all four management factors had a significant predictive relationship with resilient safety culture. *Practices* had the weakest predictive relationship, and *Policy* had the highest. Results suggest that more focus should be placed on resilient safety practices to sustain a resilient safety culture in a collegiate aviation program.

Byrnes et al. (2022), in a recent longitudinal study of the effects of safety crises on safety culture in a collegiate aviation program, suggested that various safety culture and safety climate variables were impacted during the COVID-19 pandemic. Based on these results, the leadership of the flight training program was able to mitigate and adjust safety policies and procedures to improve the safety culture and climate and ensure continuous accident-free performance.

It becomes apparent that most of the studies reviewed were quantitative and suggest an apparent gap in the qualitative research approach that probes deeper into the relationship between SMS implementations and safety culture among multiple stakeholders in collegiate aviation operations. As an example, much of the work done by Adjekum (2014, 2015, 2016, 2017) and Adjekum and Fernandez-Tous (2020) have been primarily quantitative. While there have been qualitative components in some of the studies (Adjekum, 2016; Robertson, 2016), the semi-structured interviews were restricted to collegiate aviation leaders and safety professionals in these collegiate aviation programs respectfully.

The current research expands the research paradigm by including multiple programs with varying types and implementation levels of SMS using semi-structured interviews of key stakeholders in the collegiate aviation programs. The current study also focuses on an in-depth understanding of the potential effects of SMS types and implementation levels on the perceptions of safety culture among research respondents. The current research adds to the extant literature on the relationship between SMS and safety culture in collegiate aviation operations in the United States,

Method

Research design

This qualitative research design was used to explore the perceptions of respondents on how collegiate aviation program's SMS implementation was related to the safety culture within their various programs. Safety culture perceptions of respondents from multiple collegiate aviation programs and at varying levels and types of SMS implementation were explored. Saldana and Omasta (2017) have suggested that a qualitative approach using interviews that seek to explore a subject's personal experiences related to the study topic based on their values, attitudes, and beliefs can be an effective empirical tool for such probes.

Semi-structured interviews of a cross-section of students, certified flight instructors (CFI), and safety management leaders were conducted to gain an in-depth understanding of their perceptions of the study constructs. It was envisaged that such an in-depth probe of perceptions of SMS implementation effectiveness, potential effects of varying levels/types of SMS, and year-group effects on the safety culture in collegiate aviation could provide pragmatic safety improvement strategies.

Past research has found significant variations in safety culture perceptions within a collegiate program based on the demographic variable “year group” (Adjekum, 2014; Gao & Rajendran, 2017). However, most of these studies did not comprehensively articulate a rationale for such significant findings, and that provides an opportunity to use a semi-structured interview format to understand how and why such variations exist, especially within the framework of SMS implementation. Attempting to gain perspective on what has made the most significant impact and how these perceptions may have changed were key in investigating the first sub-question.

Research sub-questions two and three explored perceptions of respondents on SMS implementation and how components such as safety promotion and communication influenced safety culture in the collegiate aviation program. Given the relatively recent introduction of SMS into collegiate aviation, exploring the related impact on stakeholders is needed. The semi-structured interview outline can be found in Appendix A.

Population

This qualitative study was limited to three collegiate aviation programs. These three universities have different types of SMS and are at varying levels of SMS implementation. One of these universities had just commenced the implementation process of the FAA-recognized SMS voluntary program (SMSVP) and was considered in the *active applicant* stage. The second university had attained the *active conformance* level of the FAA's SMSVP. The third university had reached the third and final stage of the International Standard for Business Aircraft Operations (IS-BAO™) SMS program, which is a third-party vendor for SMS implementation. It was envisaged that this sampling pool would provide insight into any potential differences in the SMS type. Additionally, the varying levels of implementation (e.g., *active application* versus *active conformance*) will provide insight into any potential differences based on the implementation level required by the FAA.

Sampling procedures

Sample size selection. The sample (n=12) for the study was derived from two lower-class members (a first-year student or sophomore), four upper-class members (junior or senior), four CFI, and two safety management leadership personnel from the three universities (See Appendix B for details of demography). Sampling students from different year groups were meant to assess varying perceptions across these levels of academic and flight training experiences at their universities. Given that past research has posited significant variations in safety culture perceptions based on year group (Adjekum, 2014; Gao & Rajendran, 2017), recruiting representatives from varying levels was desired. Moreover, it was required that the CFI respondent in each university was a previous student and has been at the institution for potentially longer than four years. These requirements for the CFI, along with the change in the role from a senior student to an employed CFI, provided insight into any potential effects on perceptions of SMS and the safety culture associated with such transitions.

Interviewing safety management leadership provided strategic perspectives on safety and levels of perceptual alignments with student and CFI perspectives on SMS and safety culture. Since those in safety leadership positions are responsible for promoting their institution's safety culture, they will provide insight into their desired cultural perception. A comparison between those in safety leadership positions to the frontline personnel (i.e., students and CFIs) will provide helpful insight into how and how well safety culture is being promoted, communicated, and instilled throughout each organization.

Procedures for recruitment, participation, and data collection. The University of North Dakota Institutional Review Board (IRB) provided approval for all the research protocols. Representatives, namely the chair/ head of the aviation program from each institution selected to participate in the study, were contacted to provide permission and access to students, CFIs, and safety management leadership personnel in this study. After permission was granted by these representatives, a formal invitation letter outlining the research and requesting volunteers to participate in a semi-structured interview was sent to the student and CFI population. The letters were sent via emails by the various representatives. Participation was voluntary, and there were no financial or material incentives offered in any case.

A purposeful sampling technique was utilized, and this approach allowed the researchers to specifically select respondents for the interviews based on an equitable representation of various year-groups and CFIs. Despite the approach, there were challenges due to time constraints and scheduling during the COVID-19 pandemic period. Individuals designated in a formal safety management leadership role, such as the Director of Aviation Safety or Flight Safety Officer, were interviewed at two institutions. Given that one of the researchers currently worked at one of the institutions where responses were being sought and had a recent role in a safety leadership position, it was deemed redundant to interview someone within the institution.

Interviews were conducted using the Zoom® video conferencing tool. Before conducting the interview, each participant was sent a copy of the interview outline to review the questions ahead of time (Two weeks lead time). Participants were also sent the consent forms for electronic signature before conducting the interviews. The interviews were recorded, and the audio files in the form of mp3 files were stored in a secured folder for transcription. Before concluding the interview, participants were informed that interview transcripts would be sent to them for member checking and validation.

Saturation is viewed as a point where the researcher feels they are learning nothing new about the participants (Saldana & Omasta, 2017). After 12 interviews, participants provided consistently repeated responses to the interview questions, and no further interviews were conducted. Field notes were compiled during the interviews, and analytic memo writing was done after the interviews.

As part of the transcription process, the researchers listened to the entire recordings of the various interviews and made corrections to a draft transcript in text format produced by the Zoom tool. The trustworthiness of qualitative content analysis is defined in terms of credibility, dependability, conformability, transferability, and authenticity (Elo et al., 2014). The semi-structured interview data meets the trustworthiness factors based on the experiences and background of the respondents regarding the study constructs. Also, the interview transcripts were verified for trustworthiness using member-checking. All the respondents provided feedback to confirm that their interview transcripts were a credible reflection of their perceptions of study constructs.

The transcripts were analyzed through the use of a computer-based qualitative coding software tool (Nvivo 12 ®) and manual coding. "Coding is the process of organizing the material into chunks or segments of text before bringing meaning to information" (Rossman & Rallis, 1998, p. 171, as cited in Creswell, 2009). A deductive or theory-driven coding was used in the analysis. Deductive coding can be used when there are particular topics of interest (Vanover et al., 2021). In this case, three primary areas of concern were explored: safety culture development, SMS implementation, and safety promotion and communication. The coding was developed around these topics for analysis.

As stated earlier, field notes and analytic memo writing were additional methods employed for the qualitative analysis. The analytic memos were written after each interview, or sometimes after a series of closely conducted interviews, to develop connections (Saldana & Omasta, 2017). After multiple interviews, reflecting on common themes to determine associations between the interviewees' data helped the researcher condense the qualitative data to derive themes effectively. These field notes and analytic memos were instrumental in the development of the deductive coding strategy.

A codebook containing all the emergent codes and their over-arching themes was developed from the nodes of Nvivo® software and corroborated by complementary codes derived manually through open coding of selected extracts from transcripts by each researcher. To further consolidate the trustworthiness of the coding and theming process, the verified transcripts and codebook with emergent themes were sent to a team of research advisors who did an audit of the codes/emergent themes. There was generally an acceptable level of agreement on all the codes and themes among the three research advisors who have considerable experience as aviation safety researchers.

Results and Discussion

The semi-structured interviews were meant to probe deeper into previous findings of similar research on study constructs. Three primary areas were considered for the qualitative portion of this research: safety culture, SMS implementation, and safety promotion and communication. These themes are provided below to relate to the elements in question in these interviews.

Safety Culture

The first series of questions in the semi-structured interviews were aimed at perceptions of safety culture. These questions were designed to gauge their overall perception of safety culture at their institution, what factors have had the most influential impact on their perception of safety culture, how their perception of safety culture may have changed over time, and what their organization could be doing to improve how students and CFIs perceive the safety culture.

The role of the CFI. Two questions from the interviews regularly referenced the CFI's role in their responses on the perception of safety culture: *How has your perception of safety culture at your institution changed over time,* and *What has had the most significant impact on your perception of safety culture*. The CFI's role was more frequently referenced compared to Directors of Safety, Accountable Executives, or the presence of an SMS.

The interviewed students and CFIs would refer to how the CFI set the example for behaving. While it was noted that those in Safety Leadership would advocate for certain behaviors, the CFI had a more considerable influence over the day-to-day behavior. In addition, many of the interviewees had experienced multiple CFIs during their flight training, which exposed them to various perspectives on how to approach safety. These varying experiences further confirmed that the CFI significantly influenced the student's development of essential attributes of a safety culture, such as proactive hazard identification and safety risk reporting during their time in their program.

The interviewees would sometimes reflect on differences in CFIs and how that affected their behavior. In some cases, a given CFI may show a disregard for particular safety policies or procedures, and that leads to a situation where such disregard for existing safety policies by these CFIs adversely impacts the perceptions of their students on the relevance of such policies and procedures in ensuring safety in flight operations.

Later, after transitioning to a new CFI, they would gain a new perspective. This could be differences between instructors on the importance of safety reporting or the risk associated with specific hazards in the flight training environment. The reflection on their past experiences highlighted the influence of the CFI. Regardless of written policy and procedure, the CFI's influence could supersede these policies and procedures promoted by those in Safety Leadership positions.

The role of the CFI in safety culture also highlights the importance of people in an SMS. Multiple interviewees noted that a written policy is not enough to encourage the desired behavior. The people involved in the system must execute that policy. This sentiment was echoed by students, CFIs, and those in Safety Leadership positions. While a Safety Policy is a vital component of an SMS, it needs to be understood and implemented by all organization stakeholders. Consider the following quotes from flight instructors reflecting on their past CFIs and students reflecting on their recent experiences from varying institutions generating the theme for the *Role of the CFI*:

> Flight Instructor A:
>
> Oh god, without a doubt, without a doubt, it's definitely [the CFI]. I feel like even if you can't if you got a student who wasn't very safety-oriented, I feel like if you had the right CFI and the right mindset. I think you could change that, so without a doubt, the CFIs are that frontline, backline, middle on everything. Honestly, at least in my opinion.
>
> Student A:
>
> I think maybe if there was more encouragement from our instructors. I know, like in the beginning of my training. It's just at the beginning, my training is a lot different than it is now, and I was with a different instructor at the time. So, I think the perception that I was given from that individual really shaped what I thought to be a bother. And so, it took something. It took something small happening and me coming out and talking to safety individuals to realize that it's okay, and as long as you're safe and it pertains to your

> safety that it's okay to do that and bring that up rather than to not and hide it and have something worse happened to you.
>
> Student B:
>
> That’s where you have to have flight instructors that do that because the first flight instructor I had always… he didn’t want to admit his mistakes and you always want to put these mistakes on students. So you kind of had this like, okay, you don’t want to. You don’t want to seem stupid. You don’t want to make mistakes. But then I had a bunch of other flight instructors. After that, those who were kind of echoed that and they were great. And then it just kind of made you see what it really was. So yeah, it’s definitely having the flight instructors to iron out all the creases and give the students more of a look under a magnifying glass like a more specific.
>
> Student C:
>
> I would say like the biggest influence is instructors and students just because if we don’t abide by the... because it’s, I mean, it does come from the top, but if it’s not being adhered to by like the I mean, there’s only one Director of Safety and then there’s hundreds of flight students and instructors, you know, so it’s up to the moving pieces more. So I’d say in terms of the day to day.

The role of safety leadership. Students and instructors were interviewed across varying points on their institutional experience. When asked who or what played the most significant role in shaping their perception of the safety culture, the Director of Safety was often cited as a critical individual. Although, Safety Leadership was admittedly not as crucial of an influence as the CFI. Moreover, students earlier in their experience at a given institution were more likely to reference those in safety leadership positions as having a powerful influence on their safety culture perception. However, once the students have been in the institution for a longer time, the CFI became the predominant influencing force for safety culture perceptions.

First-year and sophomore students at one of the institutions would reference safety leadership as having the most profound influence. Upper-level students referenced their CFI as having a more powerful influence. This seemed to suggest that a CFI’s influence could overpower the influence of safety leadership. Even the CFIs that were interviewed would refer to their past CFIs and how they influenced their behavior. This finding supports findings from Brondino et al. (2012), suggesting the stronger role co-workers play over supervisors when assessing safety climate perceptions. Their findings suggested that co-workers’ safety climate can reduce or cancel the effects of the group level association between the supervisor’s safety climate and co-worker’s safety climate (Brondino et al., 2012). This, along with findings from Chiaburu and Harrison (2008), suggest that co-worker support was a better predictor of employee outcomes than leader support.

The role of safety policy. The organization’s safety policy would come into consideration when students and CFIs were asked how they would describe the safety culture at their institution. Students and CFIs often mentioned that the policy clearly articulated non-punitive reporting and just culture philosophy. The students and CFIs relate the safety policy to the reporting system. This finding makes sense at an intuitive level. Since the primary interaction students and CFIs have with the SMS is through reporting, both groups relate their perception of the SMS and prevalent safety culture to their collegiate programs' safety reporting system.

When asked if this policy were enough to encourage reporting, students and CFIs both said it took time to build trust in the system to begin reporting. Despite a clearly stated policy, it took additional influence to facilitate participation in reporting systems. This additional influence was typically a first exposure to the reporting system through their CFI or hearing of other students' experiences. Again, the CFI seems to play a critical role in shaping students' perceptions of the safety culture and encouraging reporting behavior. Consider the following quotes from CFIs and students reflecting on their initial exposure to the reporting system:

Flight Instructor A: "As a student, having an instructor submit an ASAP report was pretty significant to seeing them do it for you, you know, use the program when a mistake has been made."

Student A:

> Actually, seeing how it remained anonymous and that it wasn't just you guys saying it. You know, this is how we do it. But actually, going through the process once and realizing that. Because, you know, sometimes you don't trust the system until you're actually going through the system, and that's probably what really made me open my eyes, and I guess really trusting the whole procedure and process.

Safety reporting feedback and safety behavior. Providing feedback for submitted safety reports was noted as a perceived critical influence on the institutions' safety culture by those in safety leadership positions. In addition, when students and CFIs participate in the reporting system, it is viewed that those who take that time to report deserve feedback for their effort. This, in turn, is believed to encourage future reporting.

Students and CFIs also addressed the importance of feedback. Feedback provided by the safety office for reports filed by students and CFIs creates a positive indicator that top leadership takes their concerns seriously. When discussing the role of feedback, one student said, "It's probably just going to go sit on the desk and build dust," when commenting on the lack of feedback. When students and CFIs do not receive feedback for their efforts to file a safety report, the adverse perception that nothing will happen with that report is further enhanced. Providing a form of feedback could mitigate this perception. One student said, "That helps me know whether it's going to be continually pursued or not," when discussing the effects of receiving feedback after a safety report.

SMS Implementation

Given that many collegiate aviation programs are beginning to pursue formal SMS programs (i.e., FAA SMSVP or IS-BAO), the following SMS implementation questions were designed to gauge perceptions related directly to SMS.

SMS type. Of all the students and CFIs interviewed between three different collegiate aviation programs with varying levels and types of SMS programs, no student or CFI accurately identified what kind of SMS they had in place or was pursuing. Moreover, when students and CFIs were asked what kind of SMS they had, they would reply with a description of the safety reporting system (e.g., non-punitive, voluntary). As previously mentioned, when discussing the role of safety policy on student and CFI perceptions of safety culture, students and CFIs view the SMS through the lens of their role (i.e., reporting). Students and CFIs perceive that their role within the SMS is to contribute safety reports, which seems to be how they relate to the SMS.

Those in safety leadership positions discussed the type and level of implementation of their respective SMS programs. When asked what role their SMS played with their students and CFIs, none believed it was critical for students. The formal elements of the SMS were viewed as more critical for those responsible for safety processes. The SMS was thought of as a guide, and the people were responsible for executing it.

One response that highlighted this perspective was, "So our SMS is literally just a document. It doesn't define who… We could have the best document in the world, and it does nothing for you if leadership doesn't follow it. If the students don't follow the responsibilities within that. So it's a guide, but I don't think the document itself makes the organization, how the organization uses the document that makes the culture actually thrive and exists." Another quote echoing this sentiment was, "It does more for those of us to say [SMS]. It means a lot more to those of us in this office in our, in our management flight department management. To the student, I don't think it means anything, or the instructor even."

SMS knowledge and understanding. Based on responses received from students and instructors, it was clear that their knowledge and understanding of what SMS is and how it works is lacking. This is highlighted by student and CFI responses, indicating that their SMS is "voluntary" or "non-punitive." While these are attributes of a safety reporting system, these do not represent the SMS. Safety reporting is one element, albeit a critical one of an SMS.

It should be noted that students and CFIs participating in the interviews were sent a copy of the interview questions ahead of time to review and begin thinking through their responses. In this case, students and CFIs were aware that they would be asked what kind of SMS their institution had in place or was implementing. Despite being aware of this question, no respondents were able to answer the question correctly. Some admitted they did not know, and others answered by offering answers describing the non-punitive or voluntary nature of the safety reporting system.

This finding shows a gap between the organization's SMS status and frontline stakeholders' understanding of this status. Determining the effect of this gap was not the scope of this research. Although, the prospect of improving SMS knowledge and understanding was discussed with students and CFIs during interviews to gain their perspective if they believed it would have an impact or not. For instance, one student responded to the question of what effect a deeper understanding of SMS would have, and replied, "Yeah, probably. I think the more you learn about anything is gonna tie into your performance."

Those in safety leadership positions agreed that there is potential to address the gap between students and CFI SMS knowledge and understanding. Those in safety leadership positions acknowledged that their students and CFIs do not fully understand everything that goes into their organization's SMS. Moreover, all acknowledged that students and CFIs having a more profound understanding could impact their behavior or perception of safety.

SMS impact on safety culture. Despite respondents being unable to explicitly state the type of SMS implemented or being pursued at their institution, students and CFIs were aware of SMS as an entity. Students and CFIs were aware of their organization's safety policies and procedures. According to respondents, they were aware of these policies and procedures' robust nature, which influenced their perception of safety culture—having these policies in place positively impacted their perception of safety and safety culture.

When students and CFIs were asked to describe this impact, responses often alluded to a foundational influence. Moreover, the presence of the SMS was said to be an initial primary influence early on in their flight training. To illustrate this point, one respondent had the following response when asked what impact the presence of SMS had on their perception of safety culture, "Now I will say that that has very foundational. I mean, when you go into, you know, you're learning straight away from private pilot you learn about SMS."

Students and CFIs would occasionally allude to the high volume of policies and procedures present at their institutions. However, they did not indicate that this had a negative impact on their perception of the safety culture. Instead, they acknowledged the presence of those policies and how it relates to SMS as being there for a reason. For example, one respondent highlighted the role of these policies by stating, "And I feel like that, that alone, knowing that if I'm a student, knowing that or just me knowing that that lets me know that we're trying to set ourselves apart even more and doing more so that perception definitely in a positive way would increase, I guess."

Safety Promotion and Communication

This final area addressed in the semi-structured interviews was directed at determining how SMS is taught and how effective it promotes SMS. Themes arose surrounding SMS training, formal versus informal SMS training, and the role of the Accountable Executive.

SMS training. When discussing the extent of SMS training offered at different institutions, those in Safety Leadership discussed classes that are offered that cover SMS. There is typically some formal class or similar delivery method to provide SMS training to students. Additionally, different collegiate programs embed SMS training in dedicated safety classes as part of the curriculum and ensure it is addressed on the flight training side.

The role of this initial safety training is not necessary to provide a robust understanding of SMS to students as viewed by those in Safety Leadership positions. Instead, this training is viewed to provide students with the necessary knowledge to function within the SMS. This is the way to articulate the role of students in SMS. For instance, one respondent stated, "That is literally it. They are. They are the eyes and ears of what we do. Day in and day out, because I am not sitting in a cockpit for 50 hours in a week, the CFIs and the students are, and they are the ones that see it."

The student responses would refer to these classes offered. However, when asked if these classes played a vital role in developing their perception of safety culture, they did not believe it was as important as other elements such as day-to-day interactions with their CFI. Instead, the influence of CFIs, peers, and stories was typically cited as playing a more important role in functioning with the SMS.

Formal versus informal training. The discussion of the role of SMS training with students and CFIs developed a theme around how these students and CFIs learn SMS. All students and CFIs referenced formal classes, but these were not viewed as having the most profound impact on how they learned SMS and their role in the SMS. This distinction can be viewed as a difference between a theoretical versus practical approach to learning SMS. Thus, the theme of formal versus informal training.

Given the CFI's role in developing students' understanding of SMS and their role in SMS, this was thought of as the practical application of the concepts. Students and CFIs would reference their interactions with their CFIs and how that shaped their understanding of how the SMS worked. The students often refer to their CFIs as being more like a peer. Learning from the example of CFIs and the stories CFIs tell influenced how students developed their SMS understanding. This point was articulated by one student when saying, "I think the theoretical side definitely comes from the professors, but the practical side of seeing where the theoretical side needs to the practical side is done by the flight instructors."

The Accountable Executive's role. SMS touts the importance of support from the Accountable Executive as a critical element (FAA, 2015a; ICAO, 2018). Students and CFIs were asked how well the relationships between top-level individuals and frontline personnel are managed and what impact their relationships have on safety culture perceptions. Students and CFIs would typically address salient individuals within their institution that represent safety. This was usually the Director of Safety. Comments would address how approachable these individuals are and the importance of an open-door policy.

When students and CFIs were asked what role the Accountable Executive would play in their perception of safety, they did agree that it was crucial. The support from these top-level individuals was necessary for the functionality of the SMS. It is believed that this support has a "trick down" function, which is in line with the traditional top-down implementation of SMS (FAA, 2015a; ICAO, 2018). One quote that addressed this concept stated:

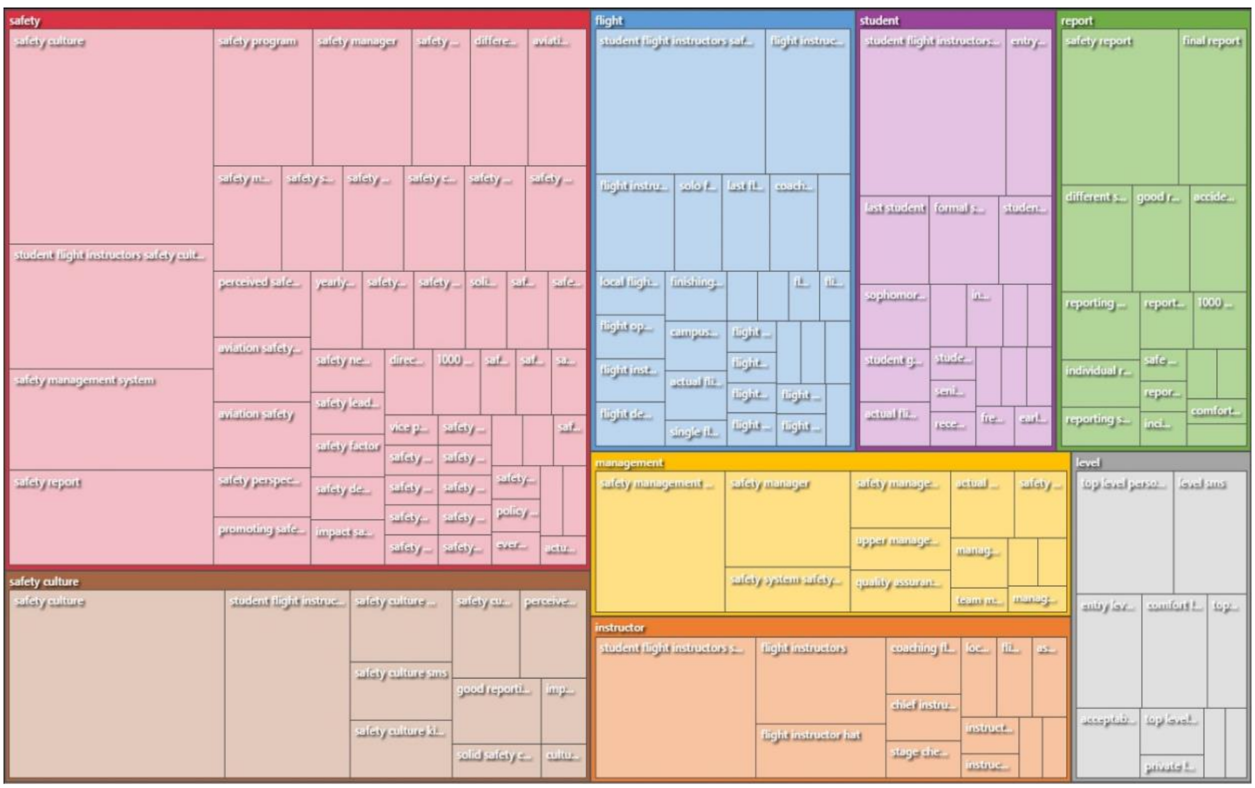
> I think [the Account Executive] definitely plays a major role because if he didn't care about safety. It wouldn't trickle down: When you know I think we [the CFIs] have the most influence directly but I don't think we would care about it as much if we didn't have that the top leaders who were constantly talking about safety how important safety is.

This concept seems to tie together the role of the Accountable Executive and the CFI. While the CFIs seem to have a substantial influence on students and students' development of SMS knowledge and safety culture, this is only possible with the support of higher-level individuals—namely, the Accountable Executive. One student participant highlighted this relationship well:

> So there's definitely a closer generally a closer connection between students and flight instructors and because there's a close connection between them and you know say higher-ups, they're more willing to listen to the flight instructor.

Figure 1 shows an automated coding output of nodes and emergent themes from qualitative analysis using the Nvivo® tool, and specific themes outputs can be found in Appendix C.

Figure 1.
Automated coding results from Nvivo®



Discussion

This discussion focuses on three primary areas: safety culture, SMS implementation, and safety promotion and communication.

Safety Culture

A resounding theme of the influential role the CFI plays in developing a safety culture and safety behavior was a critical finding. Students and CFIs interviewed from all institutions pointed to their current and past CFIs as playing a significant role in how they developed their sense of safety culture. The CFIs would set the example for proper behavior. This is not surprising given the number of contact hours CFIs have with students. Students and CFIs typically meet multiple times per week and engage in what is considered frontline operations. The influence of this high frequency of meetings is likely to contribute substantially to how students will perceive acceptable safety behavior in their organization.

This finding also corroborates some of the points made by those interviewed in safety leadership positions. Those in the safety leadership positions did not believe the presence of their SMS or their policies were powerful enough on their own to influence behavior. The people were responsible for carrying out those expectations. While the policy statements were a guide for describing desired behavior and outcomes, people (i.e., students, CFIs, Chiefs, managers) were responsible for carrying out the policies outlined in that document. While the document can serve as a top-down influence in guiding desired behavior, the document alone is not sufficient. The CFI can, directly and indirectly, influence students' safety behavior and may enhance strict adherence to these safety policies or negatively lead to non-compliance. The proximal effects of CFI on safety policy implementation within a collegiate aviation program cannot be underestimated.

The nature of how the CFI can explicitly exert a more considerable influence on the operational level implementation of higher-level policy guidance from leadership is not a novel finding. Research has shown that lateral or peer relationships can have a more significant impact than managerial influences (Brondino et al., 2012; Chiaburu & Harrison, 2008). Nonetheless, these findings suggest that attention should be given to CFIs to ensure they are setting proactive examples of safety behaviors worthy of emulation. Students and CFIs are considered the frontline of collegiate aviation. Therefore, their role in establishing and optimizing the desired safety behavioral traits among personnel and students is critical.

Another interesting finding on how students and CFIs develop their safety culture was their first exposure to the safety reporting system. Frequently stated during the interviews was how it took an initial exposure to the formal reporting system in the collegiate aviation program to build trust. This first exposure seemed like a critical barrier that needed to be overcome before students and CFIs were willing to contribute to the reporting system. Given the influential role of CFIs on student behavior, CFIs should prioritize exposing students to the reporting system early on in their training. This initiative could surmount the first exposure barrier and set an example for future behavior and participation.

In addition to the first exposure, the feedback was another component of safety reporting commonly cited by students, CFIs, and those in safety leadership positions. Furthermore, feedback has been shown to affect safety reporting behavior in previous quantitative studies (Adjekum et al., 2015, 2016; Jausan et al., 2017). These findings further validate those claims and suggest that collegiate aviation programs pursuing SMS should ensure they incorporate a feedback mechanism for their stakeholders.

SMS Implementation

A key finding from this research was the apparent knowledge gap students and CFIs have regarding the SMS implementation at their institutions. None of the students or CFIs interviewed correctly identified what kind of SMS their institution had in place or was pursuing. Interestingly, most respondents would reply by describing the reporting system. This response suggests an association of the safety reporting system with their perceived role in the SMS. A good understanding of the types of SMS and SMS implementation processes through structured academic coursework can be a primer for acceptability and engagement in SMS processes among students and instructors, as suggested by Adjekum (2017) and Velazquez and Bier (2015b).

It may be beneficial for the collegiate aviation program to promote these fundamentals of SMS and get stakeholders to know their role within the SMS implementation process. Active involvement of students and CFIs in the applied aspects of SMS processes, such as the fundamentals of safety risk assessment or developing safety policy and objectives, could provide a more profound understanding for these stakeholders.

Interestingly, all interviewees in safety leadership positions did not think it was practical for students and CFI to have a deeper technical understanding of SMS processes such as risk assessments and safety assurance due to the complexities and time required for training. It was viewed as being more important for students and CFIs to understand how SMS applies to their specific roles within collegiate aviation programs, such as identification of hazards during flight operations and reporting of such hazards for risk assessments.

Once it was determined that students and CFIs did not have an in-depth knowledge of SMS, they were asked if a more profound understanding would influence how they perceive SMS and their perception of safety culture. The students and CFIs indicated that it could have an effect, which corroborates previous studies on the need for an increased sense of ownership in SMS implementation (Adjekum, 2017; Patankar & Sabin, 2008).

The findings suggest some knowledge gap on SMS and its implementation complexities among respondents, which corroborates findings by Velazquez and Bier (2015), who suggested that there is not much standardization to the way SMS is taught in collegiate aviation and that many programs offer just a single class addressing SMS. Providing initial and recurrent training to address smaller SMS components may make it easier for students to retain and understand SMS.

The findings suggest that students and CFIs desire a pragmatic approach to teaching SMS. Recent research into teaching safety science has suggested using pragmatism which is "…centered on linking theory, research, ideas, actions to practical effects and focuses on aligning these with the student's experience and environment" to educate safety-orientated professionals (Klockner et al., 2020, p. 3). Structuring SMS training for students and CFIs around the "4P's of Pragmatism" (i.e., practical, pluralistic, provisional, and participatory) could benefit administrators. Utilizing a scenario-based approach has also been proposed as a method to allow students and CFIs to apply SMS skills in a practical manner (Adjekum, personal communication, 2020).

A respondent in safety leadership referred to their collegiate SMS as "a guide" and did not believe that the mere presence of SMS inherently played a role in the students' and CFIs' perception of safety culture in their collegiate aviation programs. The respondent, however, surmised that SMS implementation outputs, such as cogent safety policies and procedures, play a significant role in moderating desired safety behaviors in line with Grote and Weichbrodt (2017), who strongly advocate for strict reliance on policies and regulations to address cultural factors and Hollnagel (2014)assertions that people's role within the organization and cultural influences drive compliance with organization policies and procedures. This position seems at variance with Dekker (2017), who posits that organizations cannot regulate or proceduralize their way to safety.

Nonetheless, another respondent in a safety leadership position did view the implementation of SMS in collegiate aviation programs as a positive change. While the implementation and presence did not explicitly impact their perspective regarding safety culture, the improvements to processes, such as enhanced accountability and robust audits, provided better outcomes than their previous safety programs. They suggested that these audits could identify system weaknesses and guide the development of policies and procedures to address these deficiencies.

Promotion and Communication

The training provided to students in programs with and without fully implemented SMS programs does not seem to provide students and CFIs with an in-depth knowledge of SMS. While students and CFIs are well educated in their respective roles within the SMS, there is a gap in SMS's deeper understanding. Formal training on SMS and its components can be challenging and must be viewed within a collegiate aviation program's scope and complexity.

Based on these research findings, a suggested approach will be a step-wise building block approach in SMS training that is incorporated as part of the syllabus for the degree program in aviation. Fundamentals of SMS can be introduced as a required course in the first-year class, and subsequent intricate details on SMS are introduced at the upper-class levels. Subject-matter experts may be brought in occasionally to build the capacity of professors who teach SMS to enhance course delivery and ensure a cogent link between theory and practices.

Moreover, students and CFIs often mentioned a need for a practical SMS application. Involving students or CFIs in some of the higher-level SMS processes, such as safety risk assessments (SRAs), could be a way to address this issue. Additionally, these applied exercises would give students the experience they could use moving forward in their careers. For example, many aviation students aspire to be airline pilots, and part 121 carriers are required to have SMS (FAA, 2015b), and there is a demand for SMS in the part 135 environment (NTSB, n.d.).

Conclusion

This study qualitatively assessed the relationship between SMS implementation in multiple collegiate aviation programs and perceptions of safety culture. A literature review on SMS and safety culture provided an empirical framework for a semi-structured interview of a cross-section of students and safety leadership in three SMS implementation in most U.S collegiate aviation programs is still in its preliminary stages, with only one program attaining the FAA SMSVP status of active conformance.

However, findings from the semi-structured interviews suggest an apparent knowledge gap among respondents on the SMS implementation phases and some essential attributes of a fully-functional SMS program. Structuring or restructuring SMS training for students and CFIs could improve safety behaviors for stakeholders.

A significant finding was that CFI plays a critical role in developing the student's perception of safety culture by setting the example for desired safety behavior and exposing students to the safety processes institutions have in place. Initiatives to address the role of the CFI to empower them to be leaders for students and encourage active participation can influence the efficiency and effectiveness by which students develop a sense of safety culture.

The current research added to extant literature supporting the benefits of feedback and robust reporting systems (Adjekum et al., 2015, 2016; Dillman et al., 2010; Freiwald et al., 2013). Ensuring these systems are in place and being utilized is recommended. Much of the research done on SMS in collegiate aviation has not qualitatively probed the understanding of SMS implementation processes by its stakeholders, such as students and CFIs.

Given the findings from this research, further research into factors that influence the understanding of SMS implementation and its effect on safety culture beyond the scope of collegiate aviation programs of these three universities will be very helpful. Such assessments of SMS implementation process understanding by all stakeholders in a collegiate aviation program could provide a deeper sense of process ownership, which can inure to the safety benefits of these programs (Adjekum, 2017; Patankar & Sabin, 2008).

Trust has been suggested to be a key component of a robust reporting culture (Robertson, 2016). The current research supports this position but adds that this needs to be established early. Moreover, findings related to the role of the CFI suggest that the CFI could play a critical role in exposing new students to the reporting system early on to establish trust. Based on the influence of the CFI, poor interactions early on during a student's training could impede their ability to develop trust in the reporting system and SMS as a whole.

Limitations and Biases

The findings from the current research are limited to collegiate aviation programs in universities with fully implemented FAA SMSVP and others that have formally initiated some form of the implementation process (FAA SMSVP or IS-BAO). Social desirability bias can influence some respondents to provide responses that are acceptable to enhance their reputation among peers in their social settings. The use of an individualized interview format, which provided some levels of privacy and the assurances of confidentiality, was used to minimize such biases.

The likelihood of confirmation bias in deductive or theory-driven coding and theming needs to be considered. All the data obtained were analyzed independently among the researchers and later compared and were also audited by three SMS experts who were on the research advisory committee. Finally, even though data saturation was attained, it would have been desirable to have more respondents from the various year groups, and safety management leadership teams take part to enhance more diverse viewpoints. As stated earlier, there were challenges with recruiting more respondents due to schedule during a pandemic period, and the relatively small sample from the three universities must be considered when interpreting the findings.

Recommendations for Future Research

There is still a need to perform longitudinal studies to investigate how SMS implementation impacts perceptions of safety culture in collegiate aviation programs in the U.S. Analyzing a cohort of students across the span of their tenure at an institution would provide a new perspective of how some of the variables are affected over time. In addition, given the knowledge gap found in the current research, a quasi-experimental approach before and after an SMS training initiative may determine any potential effects of enhanced SMS knowledge on safety behavior.

As more collegiate aviation programs pursue and implement SMS, there may be a need to further expand this current research scope of assessing the effects of SMS implementation on safety culture perceptions in collegiate aviation programs by including other stakeholders such as academic staff, administrative support personnel, maintenance personnel, and dispatch personnel. Finally, as more collegiate aviation programs successfully implement SMS, an investigation into effectiveness and impacts on safety performance in observed safety behaviors and attitudes (safety culture) may be necessary.

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APPENDIX A

Semi-Structured Interview Session Guide

Date:

Time:

Interview Code Number:

Location of Interview:

Parts of the Interview	Interview Questions
Introduction	Hi, I am [redacted], the principal investigator for this study. Thank you very much for agreeing to be participants in this semi-structured interview. As you were informed earlier in the invitational email, the purpose of this interview is to seek your views of safety culture within your institution and how Safety Management Systems (SMS) has affected that perspective. This interview session should last about an hour. Please be reminded that this session will be audio-recorded and contemporaneous notes will also be taken. After the interview, I will organize and transcribe your responses, which will be coded and themed for our study. Please be reminded that every effort will be made by the researchers to ensure that no personal identifying information about you such as name or employee number inadvertently divulged during the session will be used in our final report. All audio recordings of this session will be deleted once the transcription process is completed and you have had the opportunity to validate the contents of the transcript which will be sent to you for your comments. You can choose to stop this interview at any time or decline to answer any question you feel uncomfortable with. I once again remind you that this interview will be audio recorded for transcription purposes. You will also have to read and sign the informed consent statement sheet before we start the interview.

	Do you have any questions? Are you ready to begin?
Part A	**Biographic Data (Taken for each participant)**
	Age: Sex: Year group (if student) or position: Level of education: Number of years at institution:
Part B	**Safety Culture**
	1. In your own words, how would you describe the safety culture at your institution? 2. How has your perception of safety culture at your institution changed over time? 3. What has had most significant impact on your perception of safety culture? 4. Why? 5. Is there something that your institution could do to further promote safety culture that they are currently not doing?
Part C	**SMS Implementation**

	6. What kind and level of safety management systems (SMS) does your institution currently have in place? 7. Does this have a significant impact on how you perceive safety culture in your institution? 8. How? 9. Are there any negative impacts of SMS implementation at your institution? 10. If so, how could they be better addressed? 11. If not, were there ever and how did you remedy them?
Part D	**Safety Promotion and Communication**
	12. What kind of SMS training does your institution provide? 13. How does this training impact safety culture perception at your institution? 14. How frequently is SMS training offered and/or repeated? 15. How are the relationships between front-line personnel (students) and top-level (accountable executive) personnel managed at your institution? 16. Does this have an effect on safety culture perception? 17. How could this be improved? 18. How well do you understand the SMS process?

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	19. Do you feel you have a responsibility in your role to know and understand these processes? 20. Why?
Part E	**Close**
Close	21. Do you have anything else you'd like to share? 22. Do you have any questions for me? 23. Thank you for your time and we will get in touch with you later with the transcript for your validation before the data analysis. Goodbye.

APPENDIX B

Table 1

Demographic Details of Semi-structured Interview Participants

Participant	Sex	College	Position	# of Years in College	Time spent per interview
1	Male	A	First-year	1	36 minutes
2	Male	A	Sophomore	2	32 minutes
3	Female	A	Senior	3	45 minutes
4	Male	A	Senior	3	40 minutes
5	Male	A	CFI	3	46 minutes
6	Male	A	CFI	5.5	61 minutes
7	Female	B	CFI	3	24 minutes
8	Male	B	CFI	6	35 minutes
9	Male	B	Safety Leader	6.5	52 minutes
10	Male	C	Senior	2	35 minutes
11	Male	C	Senior	3	29 minutes
12	Male	C	Safety Leader	21	59 minutes

APPENDIX C

Table 3

An extract from the codebook showing nodes and emergent themes descriptors (NVivo®)

Semi-Structured Interviews

Nodes	
Safety Culture Development	
Role of CFI	This theme was developed surrounding the codes referring how the CFI played a role with safety culture
Role of Safety Leadership	The theme arose when participants discussed the role of those in leadership positions within their institutions. This could be Department Chairs or Directors of Safety.
Role of Safety Policy and First Exposure	Participants often referenced the presence of robust safety policies but would also state that it took some form of exposure to the safety reporting system to develop trust—it was more than a policy in place.
Safety Reporting Feedback and Safety Behaviour	Feedback on reporting was consistently mentioned and how it impacted the willingness to participate in reporting systems.
Safety Promotion and Communication	
Formal vs. Informal Training	All institutions had formal training in place, but this was consistently mentioned that practical approaches through applied use of the concepts during flight lessons and similar methods were preferred
Role of the Accountable Executive	Participants believed the Accountable Executive played a key role in ensuring a top-down effect. However, their influence was limited given the hierarchal distance perceived by students and CFIs.
SMS Training	All institutions offered SMS training, but the impact on safety culture and development was not viewed as impactful. This training was primarily viewed as a means to establish expectations for stakeholders functioning within the SMS.
SMS Implementation	
SMS Impact on Safety Culture	Stakeholder perceptions of the impact that the presence of SMS had at their institutions was developed around responses when discussing the impact of their institution's SMS
SMS Knowledge and Understanding	Those not in leaderships positions had limited knowledge and understanding as to the intricacies of SMS and was developed surrounding the concept that students and CFIs would describe their SMS through the means by which they interacted with it (i.e., reporting system).
SMS Type	This theme was developed around participant responses describing their understanding of their institutions SMS (i.e., FAA SMSVP or IS-BAO)

Figure 2C
Automated output of themes - Safety

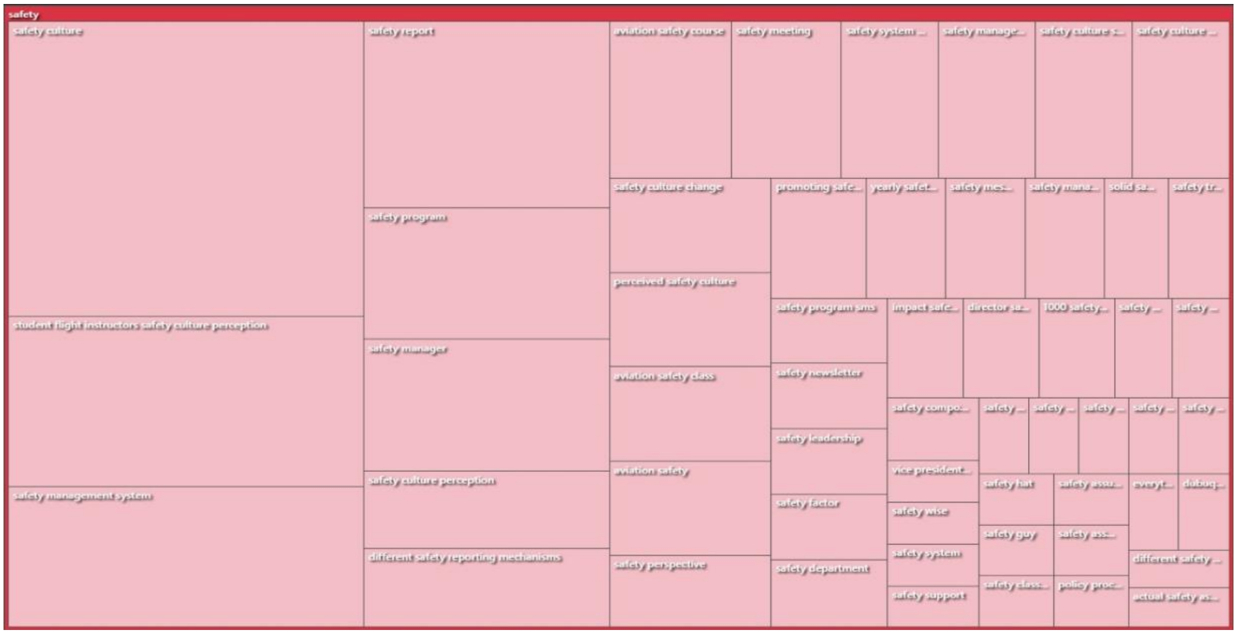
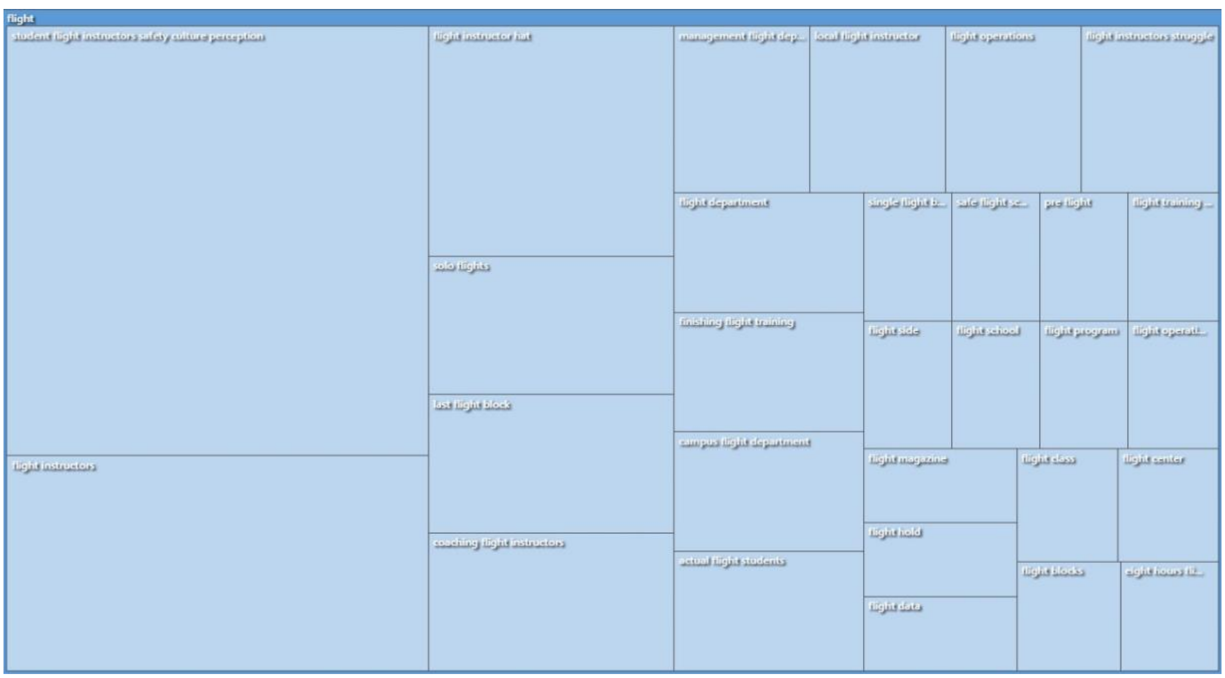


Figure 3C
Automated output of themes – Flight



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Examining Differences in Aviation Student Motivation During Blended Versus Online Asynchronous Courses

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This study evaluated responses to an adapted version of the Academic Motivation Scale (AMS; Vallerand et al., 1992) to collegiate aviation students at a midwestern university in the United States. The study is informed by Self-Determination Theory (SDT; Deci & Ryan, 1985; Ryan & Deci, 2000a) and sought to investigate the motivational differences of students according to their enrollment in one of two course delivery methods. The study compared two groups of senior-level undergraduate students enrolled in an undergraduate advanced aircraft systems course. Seven sections of face-to-face blended (n = 161) were compared with two sections of online, asynchronous (n = 43) to compare for potential differences in motivational attributes evaluated through the AMS. Despite differences in course delivery characteristics, such as the amount of peer-interaction and social-presence as well as the flexibility inherent to the online asynchronous course, results of independent samples t-test did not reveal any self-selection bias, or students with shared motivational characteristics to enroll in one delivery method or another. As other studies have shown differences in characteristics of students enrolled in online courses (Deming et al., 2012; Money & Dean, 2019; Nguyen, 2015), this result is an important addition to the research literature available to administrators, faculty and curriculum designers within the collegiate environment. To ensure effective course design, further study is warranted with instruments outside of the AMS to determine the presence of other potential student differences of those enrolled in online courses.

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Introduction

Online education is a growing presence in higher education (Seaman et al., 2018). Its origins can be dated back to the mid-1970s with the advent of email and similar electronic conferencing (Harasim et al., 1996). As technology, computing, learning management systems, and the myriad of visual presentation methods have become available, interest in online education seems to have followed (Seaman et al., 2018). Many studies have evaluated the effectiveness of online education (Nguyen, 2015), and within different disciplines (Means et al., 2009). Additionally, practitioners have evaluated and offered best practices of online education in selected learning environments (Johnson et al., 2014).

There are also documented differences in which student populations tend to enroll in online versus traditional face-to-face courses (Deming et al., 2012; Money & Dean, 2019; Nguyen, 2015). Typically, online courses have the benefit of being more flexible for the student and may tend to attract non-traditional learners at a greater rate than brick-and-mortar alternatives (Deming et al., 2012; Lei & Lei, n.d.). Research is expanding into understanding the motivation and academic outcomes of populations who enroll in online versus traditional forms of education (Artino & Stephens, 2009; Francis et al., 2019; Stewart et al., 2010). The present study seeks to expand this developing area of research into the collegiate aviation population. The purpose of this study was to test if students who enroll in blended face-to-face or online-asynchronous courses share common motivational attributes as observed through the Academic Motivation Scale (Vallerand et al., 1992). The article will start with a review of Self-Determination Theory (SDT; Deci & Ryan, 1985; Ryan & Deci, 2000a) and then a review of the current state of research on motivation in online education.

Review of Literature

Self-Determination Theory (SDT)

SDT is one mechanism by which educators, personnel managers and social psychologists understand human behavior within a particular contextual environment (Deci & Ryan, 1985; Ryan & Deci, 2000a). In the case of this study, SDT may inform our understanding of collegiate aviation student motivation within asynchronous online and blended learning environments. The three basic psychological needs (BPN) of SDT include an individual's need to demonstrate competence, their need for autonomy over actions and choice, and a desire to relate to others with whom they interact and who care for their well-being. An individual's attainment of the BPNs act as antecedents and are theorized to manifest into varying types and degrees of motivation (Ryan & Deci, 2000b). The perspective of the present study and the original use of the Academic Motivation Scale (AMS) (Vallerand et al., 1992) are founded in SDT.

Furthering the research into SDT, Ryan et al. (2009) refined the types of extrinsic motivation along a continuum from less autonomous to more autonomous. Starting with motivation from less autonomous (i.e., controlled) sources, Ryan et al. (2009) described *external regulation* where the individual performs behaviors simply to seek an outside reward or avoid a punishment. *Introjected regulation* describes an individual's task performance to feel better about him/herself or to avoid a negative impact to self-esteem. Moving towards more autonomous motivation, an individual may be driven to perform actions that they personally identify with, referred to as *identified regulation. Intrinsic motivation* is the inherent joy or pleasure witnessed through performing a particular activity. On the other end of the motivation spectrum *amotivation* describes a fundamental lack of intention to perform a particular task or activity (Ryan et al., 2009; Vallerand et al., 1992).

To fully apply SDT, it is important to understand the context in which the study occurs. A short summary of distance and online education follows along with growing research into online education in aviation as well as research into motivation and online education.

Distance and Online Education

Distance education has documented origins as early as the mid-1800s (Kentnor, 2015; Lee, 2017; Verduin & Clark, 1991). One example of this model included efforts at the University of London which identified students who were previously excluded from participation in higher education, such as women and minorities (Lee, 2017). In approximately the late 1960s, a model called the Open University of the United Kingdom, further expanded access to distance education, continued in the form of correspondence study witnessed in earlier examples (Lee, 2017). "This approach served the long-standing goal of distance education to increase access, especially for the educationally disadvantaged" (Garrison & Cleveland-Innes, 2010, p.16). As infrastructure and technology continued to expand, so did access to distance education.

Online education, a form of distance education, arrived with the advent of internet-enabled devices and represents, "a range of practices based on the Internet that provides synchronous and asynchronous communication in a personal and group environment" (Garrison & Cleveland-Innes, 2010, p.22). Stated differently, online education allows teachers and learners to interact at a distance using web technologies to close that gap (Lee, 2017). As instructors and students realized how technology could facilitate learning and exchange of knowledge, the available course offerings and facilitating technologies expanded rapidly.

Fast forward to present-day learning environments, students and instructors interact in a variety of technology-facilitated manners. Examples include live video-conferencing in the classrooms, which includes both face-to-face students and students working in disparate locations across the state, country or globe. Other examples of how technology facilitates online education includes remotely-proctored exams, such as via companies like ProctorU, that allow a student to take a computer-based exam while being video-monitored by a third party. Tools such as ProctorU allow significant flexibility to be enjoyed by the learner as well as the instructor of the course.

The structure and delivery of online courses may vary in one of several general structures. Online courses may be *synchronous*, whereby the instructor and students meet during a specified time for discussion and activity (Merriam & Bierema, 2014). During a synchronous online course, the experience of observing each other's non-verbal cues and hearing voices and concurrent feedback from instructors and peers may not be notably different than a brick and mortar learning environment. Online education may also be *asynchronous*. In this arrangement, students are not meeting the faculty member during a specified time and place to accomplish academic objectives. Although the structure of asynchronous only courses may differ in the quantity and method of educational technology or peer-interaction employed, at minimum, there are typically readings, peer discussion boards, videos, lesson homework or individual or group projects which the students must complete. Student deliverables may come with a structured milestone schedule or they may simply all be due prior to the end of the term. Decisions on course design are typically the volition of the instructor, and therefore will vary just as traditional face-to-face courses have today. Courses may also be delivered with *blended* instruction, which includes a combination of face-to-face and online (Merriam & Bierema, 2014). There are a variety of characterizations of hybrid or blended courses. However, the terms generally refer to the use of information delivery in an online environment (outside of the classroom) paired with some element of face-to-face or "seat time" with an instructor and classmates (Lei & Lei, n.d.; University of Wisconsin, 2020). Typically, lectures or other course material are covered outside the classroom, where peer interactions and material application with course material occur in a formal setting (e.g. labs or problem-based learning) (Lei & Lei, n.d.).

Student Motivation and Performance between Online and Traditional Education Formats

A growing body of research continues to evaluate differences in student motivation and performance between course delivery methodologies. Francis et al. (2019) studied the motivation and performance of over 2,400 community college students enrolled in either online or face-to-face developmental math courses. The authors found student motivation did not differ significantly across course delivery methods, yet online students received lower grades and were more likely to drop out. Additionally, the results suggested that status as an adult learner predicted lower academic outcome and higher dropout in online environments. Artino and Stephens (2009) reviewed the academic motivation and self-regulation of undergraduates and graduates learning online. The research suggested no difference between graduate and undergraduate students within task value or self-efficacy, but a statistically significant difference regarding continuing motivation, the undergraduate group reporting higher intention to enroll in future courses offered online. Research by Stewart et al. (2010) suggested, "students had clear preferences with regard to the delivery mode and the factors that motivated students to complete traditional degrees were the same factors that motivated students to complete online degrees" (p. 375). Yet, Stewart et al. continue to suggest differences in extrinsic motivators, such as time constraints and home responsibilities between online and traditional students. On the topic of student success, Johnson and Mejia (2014) cite that students enrolled in online courses in California's community colleges are less successful than in traditional courses. Research continues to expand into online and traditional education more broadly, yet this area of research remains limited within aviation education. A summary of relevant research of distance and online education within collegiate and professional aviation is included below.

Distance and Online Education in Aviation

There is a limited body of research on distance and online education within the collegiate aviation and airline domains. Kearns (2016) authored a text focusing on theory, effectiveness and topics related to instructional design for e-learning within aviation. Prather's (2018) research used survey data to gather opinions on awareness, effectiveness, and interest in distance learning versus face-to-face options for individuals interested in careers in airport operations. Prather's research suggested individuals may have concerns over the quality of distance degree programs, but also viewed them as more flexible. Scarpellini and Bowen (2018) conducted a phone-based qualitative survey to gather information on the assessment of distance degree programs within collegiate aviation institutions. Raisinghani et al. (2005) conducted a survey of business aviation professionals and their attitudes towards online training. Their research suggested such factors as efficacy, compatibility, and perceived usefulness as being important to the business aviation pilot. The research by Raisinghani et al. suggests stakeholders were aware of and planning for the arrival of distance and online education within aviation almost two decades prior to the current study. As limited research exists on this topic within the collegiate aviation environment, the present study seeks to add to the body of knowledge of student motivation and performance as these students choose between enrollment in blended and online, asynchronous course delivery.

Learning and Motivation with Generation Z

Generation Z is identified as those born between the years of 1995 and 2010 (Seemiller & Grace, 2017; Mohr & Mohr, 2017). As it relates to this study, most of the student participants would be considered members of Generation Z during the years 2018 and 2019. Generation Z shares many similarities to their well-researched predecessors, the Millennials, however, have been identified as having a distinct set of traits from the prior generation. Generation Z, also referred to as the *Digital Natives*, are documented to have more access to information than any prior generation at their age (Seemiller & Grace, 2017). Additionally, Generation Z has more economic well-being, is more highly educated and is more diverse (Schroth, 2019; Mohr & Mohr, 2017). Schroth also cites that the Digital Natives are less likely to have worked when they were young and are more likely to experience or be diagnosed with anxiety and depression. Potentially related to these latter points, the author also suggests that overprotective parenting impacted their ability to learn life skills and has made it "difficult for them to become autonomous adults" (Schroth, 2019, p.10). Generation Z's relationship with technology, also resulting in their descriptive secondary moniker, has negatively impacted traditional means of face-to-face communication. Schroth (2019) states in reference to over-reliance on technology, "this can impair their ability to effectively communicate and interact with others" (p.13). As evidence of their comfort with technology and education, it has been cited that Generation Z students prefer flipped courses and rely on sites such as YouTube for instruction (Seemiller & Grace, 2016; Mohr & Mohr, 2017). Yet, for this cohort, preference for and comfort with technology may not translate well into skills needed in the workplace. It is within this context that additional study of generational motivation towards traditional, blended and online, asynchronous learning should occur and be evaluated against performance of employee cohorts post "onboarding". This study represents one such data point.

Selection Bias

Sample (selection) bias may occur when members of a sample differ from the larger population in a systematic fashion (Blair et al., 2014). Selection bias can occur with quasi-experimental (non-random) samples when unobserved characteristics of participants differ meaningfully between groups and membership in one group or another is correlated with the unobserved characteristic (Deschacht & Goeman, 2015). In the case of online education more broadly, there have been assessments of such selection bias; focusing primarily, although not exclusively on issues such as socioeconomic status, race, gender and age. Deming et al. (2012) evaluated for-profit providers of online education and found, "the for-profit sector disproportionately serves older students, women, African-Americans, Hispanics, and those with low-incomes" (p.146). Money and Dean offered a much more comprehensive approach to the analysis of online student differences, they also reiterate that participants in online education tend to be older as well as more economically and socially disadvantaged (2019). What remains is to expand our understanding of selection bias outside of socioeconomic, gender, race or class and evaluate more subtle differences, such as motivation, in student populations. No difference between groups in student motivation would suggest that a student with a degree in Commercial Aviation is a student with a degree in Commercial Aviation. How they received the degree would matter little. A statistically significant result would suggest more advantageous or problematic outcomes for the career pathway as it would suggest that students may self-select into certain academic/course options due to personal or motivational differences. These individual differences are not likely to be accommodated in a highly standardized, highly regulated aviation industry.

The purpose of the current study is to evaluate for differences in motivation between students who enrolled in either a blended section or online, asynchronous section of a senior-level advanced aircraft systems course. The Academic Motivation Scale (AMS; Vallerand et al., 1992) will be used to evaluate for differences on five subscales, including *Intrinsic Motivation, Identified Motivation, Introjected Motivation, External Regulation,* and *Amotivation.* As a secondary analysis, the dataset also is analyzed for any predictive relationship between the AMS subscales and academic outcome, as well as potential differences in responses to the AMS by gender. Informed by SDT (Deci & Ryan, 1985; Ryan & Deci, 2000a), this is expected to inform our understanding of the relationship of collegiate aviation student motivation and course delivery.

Research Questions

Q1. As measured by the Academic Motivation Scale (AMS; Vallerand et al., 1992), do aviation students who choose online, asynchronous courses differ in motivation compared to aviation students who enroll in blended, face-to-face methods of course delivery?

Q2. Do gender differences exist for aviation students as measured by AMS subscales?

Q3. Do any subscales of the Academic Motivation Scale (AMS; Vallerand et al., 1992) show a predictive correlation relationship to academic outcome in the courses?

Methods

Procedure

Students enrolled in a senior-level advanced aircraft systems course at a Midwestern United States research university were recruited to complete a Qualtrics online survey. The survey and data collection were approved by the Institutional Review Board (IRB) of the collegiate location and all participants in the study provided consent using common methods approved by the IRB. Aviation undergraduate students who were enrolled in this advanced transport category aircraft systems course were recruited to participate through an in-class announcement followed by an email link to the survey from the course instructor.

The sampling frame included seven course sections utilizing a blended, face-to-face design and two sections using an online, asynchronous design. To ensure consistency of course content and assessments, all sections except for one blended face-to-face section were taught by the same instructor. The single section taught by a different instructor was standardized, using the same courseware, exams, and teaching methods. A total of 243 participants were invited to participate of which (N = 204) responded, yielding an 83.9% response rate. The students in the study included (n = 161) blended, face-to-face environment or entirely (n = 43) online, asynchronous methods. Students were provided the survey online via the Qualtrics survey tool after completion of approximately 75% of the academic term.

Participants

All participants in the study were collegiate aviation students enrolled in a four-year aviation baccalaureate program. By virtue of enrollment in the course in which the study was conducted, all students had previously completed coursework and Federal Aviation Administration (FAA) requirements to possess a commercial pilot certificate with single-engine, multi-engine, and instrument ratings. Additional demographic detail of study participants, including comparison by course delivery method, are included in Table 1.

Table 1
Sociodemographic Characteristics

	Combined Dataset	Blended	Asynchronous
	N = 204	*n* = 161	*n* = 43
Mean Age (SD)	22.1 (3.07)	22.1 (2.90)	22.2 (3.68)
Gender			
Male *n* (%)	176 (86.8)	141 (87.6)	35 (81.4)
Female *n* (%)	27 (13.2)	19 (11.8)	8 (18.6)
Gender Not Reported *n* (%)	1 (0.5)	1 (0.5)	-
Academic Preparation			
GPA (*n*)	3.47 (202)	3.45 (159)	3.51 (43)
ACT Score (*n*)	25.7 (129)	25.7 (102)	25.8 (27)
Racial Identity			
White *n (%)*	172 (84.3)		
Asian *n* (%)	14 (6.9)		
Not Reported *n* (%)	10 (4.9)		
More Than One Race *n* (%)	6 (2.9)		
Black or African American *n* (%)	1 (0.5)		
Native Hawaiian or Pacific Islander *n* (%)	1 (0.5)		
Academic Year			
Senior-Status (%)	169 (82.8)		
Junior-Status (%)	34 (16.7)		
Sophomore Status (%)	1 (0.5)		
Enrolled in or intended to enroll in defined career pathway (%)		114 (70.8)	33 (76.7)

Note: Due to small numbers of respondents in certain racial identity groups, quantities not reported between delivery methods to retain participant anonymity.

Measures

Motivation was measured using the Academic Motivation Scale (AMS) developed by Vallerand et al. (1992) and adapted to the collegiate aviation environment. The survey instrument was comprised of five constructs each containing four manifest variables assessing types of motivation: Intrinsic Motivation, Identified Motivation, Introjected Motivation, External Regulation, and Amotivation. See Table 2 for example statements for each motivation subscale.

The survey response options were provided on a five-point Likert-type scale. Responses range from: 1 = *Does not correspond at all*, to 5 = *Corresponds exactly*.

Table 2
Example Statements Represented by Motivational Subscales

Motivation Sub-Type	Exemplar Statement
Intrinsic	"Because I experience pleasure and satisfaction while learning new things."
Identified	"Because eventually it will allow me to enter the job market in a field that I like."
Introjected	"To prove to myself that I can do better than just a high-school degree"
External Regulation	"In order to get a more prestigious job later on."
Amotivation	"Honestly, I don't know. I really feel that I'm wasting my time in college.

Note. (Vallerand et al., 1992, p. 1008). Subscales arranged from most self-determined (intrinsic) to least self-determined (amotivation).

Results

Survey data was downloaded to SPSS and three cases of non-response to the AMS were excluded and similar response pattern matching (SRPM; Byrne, 2016) was applied to isolated datapoints within six cases to complete datapoints missing at random yielding (N = 204) responses. Participants were coded as belonging to one of two groups: (1) blended/face-to-face section (n = 161), or online-asynchronous course (n = 43). To assess internal consistency of the AMS within a new discipline, reliability analysis was performed in SPSS for each of the defined motivational subscales. Cronbach's alpha ranged from .74 to .87 (Table 2). Each of the four individual sub-scale items were averaged into new variables representing their pre-established motivational subscale (amotivation, intrinsic, etc.) adapted from the AMS (Vallerand et al., 1992). A correlational analysis was completed in SPSS and results are shown in Table 2. A exploratory factor analysis (EFA) was performed on the 20 individual survey items. Using principal axis factoring, a five-factor fixed solution was defined based on the original AMS using oblimin rotation. The results are consistent with the original AMS except for one survey (Ext_ID4) which showed stronger loadings on the *intrinsic* motivation sub-scale. Results of the EFA factor loadings are shown in the Appendix.

Table 3
Reliability and Correlation of Composite Exam Score to AMS (N = 204)

	Intrinsic	Identified	Introjected	Externally Regulated	Amotivation	Cronbach's α
Exam Score	.02	.05	-.04	.02	-.11	
Intrinsic	1					0.84
Identified	.64*	1				0.77
Introjected	.51*	.52*	1			0.87
Externally Regulated	.35*	.44*	.51	1		0.74
Amotivation	-.36*	-.49*	-.15	-.12*	1	0.83

Note. *p <.05. Correlational analysis includes observations recorded during last quarter of offered term of blended face to face and online, asynchronous course.

Next, a confirmatory factor analysis (CFA) was performed using the Analysis of Moment Structures version 27 (AMOS; Arbuckle, 2017). Individual factor loadings and fit indices of the measurement model suggested acceptable fit with some opportunity for improvement (Chi-square = 322.91, RMSEA = 0.07, CFI = 0.92, TLI = 0.90, SRMR = 0.07). Model fit was improved after review of modification indices (MIs) suggested addition of two covariance paths between two separate sets of error terms on separate latent constructs. Final model fit was deemed acceptable for further analysis (Chi-square = 281.73, RMSEA =0.062, CFI =0.938, TLI =0.926, SRMR =0.064). Analysis of convergent validity was performed by calculating average variance extracted (AVE) for individual subscales. Evidence of convergent validity was shown on the intrinsic, introjected, and amotivation subscales. Moderately low factor loadings on external regulation and identified scales suggested inadequate convergent validity. Lastly, the adapted AMS was evaluated for discriminant validity through comparison of the average AVE between constructs to the squared bivariate correlation between the compared latent constructs. The instrument showed evidence of discriminant validity between all scales except for between the intrinsic and identified scales. Overall, the adapted AMS showed acceptable validity within this sample population.

To assess for potential differences in motivational attributes of students, independent samples *t*-tests were performed between the two groups of students enrolled in the blended face-to-face versus online/asynchronous sections. Manifest variables of each scale were summed into new average variables representing the subscale and the *t*-tests were performed on each of the five motivational subscales included in the AMS. Results suggests no difference in motivational attributes on individual subscales of the adapted AMS between students enrolled in the two different course delivery methods.

As the original AMS study by Vallerand et al.(1992) noted differences in certain motivational subscales by a participant's gender, independent samples *t*-tests were also performed on the five motivational sub-scales by gender for the combined courses (N = 204). Although data approaches significance for Intrinsic Motivation and Amotivation, statistical tests suggest no difference in academic motivation by a participant's gender when combining responses between both delivery methods.

The data suggests no difference in the students within the two delivery methods as well as no difference in reported motivation on any subscale when evaluated by a students' gender. The researcher was then interested to see if any of the subscales appeared to be predictive of academic performance. To accomplish this test, the researcher included all five of the subscales into a simple linear regression model as the independent variables and the students' averaged exam score as the dependent variable. No individual subscale appeared predictive of the academic outcome and the overall model was not significant, $F(5,198) = 0.679$, $p>0.05$.

Discussion

Self-Determination Theory (Deci & Ryan, 1985) suggests that individuals have a need for autonomy, competence and an ability to relate to others. As we change our course design to embrace technology and increase flexibility for the learner, one could postulate potential changes to levels of autonomy and relatedness available to the learner between the course delivery methods. It was within this domain that the researcher sought to re-evaluate the AMS (Vallerand et al., 1992) to assess for potential differences in student motivation as they progress along their learning path within the aviation discipline.

Results of the present study show similar internal reliability compared to the original assessment of the AMS, with no notable differences in Cronbach's alpha between the two. This result suggests that modification of the AMS to the aviation discipline does not negatively impact scale-reliability. Correlation between the motivation subscales also appear to have expected outcomes with all forms of external motivation (e.g. identified, introjected and externally regulated) showing positive correlation with each other, as well as intrinsic motivation showing moderately strong, positive correlation to the three other measures of external motivation. As expected, the amotivation subscale shows negative correlation to all other motivation subscales ranging from weak to moderately strong negative correlation, particularly with identified motivation. It would be expected for a pilot to show amotivation (lack of amotivation) if she/he is not able to recognize who their present actions affect their ability to achieve a career goal in the future.

Given the difference in course delivery method and the potential for students to self-select into a method where there are substantially lower amounts of peer interaction (relatedness) yet higher amounts of flexibility (required autonomy), the non-significant results of the independent samples t-tests were less expected. Although the prior academic preparation (GPA, ACT score) and age were not statistically different between the two delivery methods, the researcher expected to observe some student differences in the motivational scales between the blended/face-to-face group and the online/asynchronous group. Similarly, as there were previously gender differences noted in the first publication of the AMS, the researcher also expected to see potential for statistically significant differences between gender. Although there were differences in the mean responses for intrinsic ($p = 0.059$) and amotivation ($p = 0.062$) between genders, the results did not reach the level of significance. As additional data is collected, re-assessment of these two subscales for gender differences may be warranted.

The non-significant results between course delivery methods are a favorable outcome when considering the rising prevalence of online courses and programs in many fields (Seaman et al., 2018). Through use of the AMS, the results of the study suggest that senior-level collegiate aviation students do not self-select into one course delivery method or another as a result of internal, personal factors associated with differing types of motivation, at least within the enrolled course. This result could suggest that the students' choice of enrolled course and the ultimate degree awarded may not be indicative of underlying motivational differences, when controlling for age and prior academic performance (GPA, ACT score). Airline and aviation recruitment may consider this as one piece of evidence to suggest that student enrolled in online education do not meaningfully differ across subsets of motivation.

Limitations

Data provided in this sample includes survey responses from collegiate aviation students within multiple consecutive sections of the same course, offered in two different course delivery methods. Due to the unique discipline of the sample population (aviation), the results of the study have limited generalizability to a broader population. On the topic of demographics, the sample population was predominantly white (84.3%) and male (86.8%). The study did not include enough representation across underrepresented populations to make meaningful statistical inferences. Expanding the study to include more students from underrepresented groups may yield differences across motivation. Finally, this study only included five subscales of motivation. Further research could be improved through inclusion of other psychometric scales useful to expanding our understanding of student differences in online and traditional education.

Implication for Practice

Despite changing enrollments across much of higher education, student enrollments in distance (online) education continues to rise (Seaman et al., 2018). Online courses offer a high degree of flexibility and offer the learner access to educational advancement without the limitations associated with attendance at a physical brick-and-mortar institution. Yet, there are many advantages and disadvantages of online courses compared to traditional face-to-face courses. Online, asynchronous courses require a higher degree of autonomy compared to traditional face-to-face or hybrid courses and also typically witness lower amounts of peer interaction (Lei & Lei, n.d.). Hybrid or blended courses, on the other hand, allow for continued peer interaction, instructor feedback and – presumably due to regular meetings – require the learner to require less autonomy than a comparable online asynchronous course.

Given the differences in course offering, the researcher sought to use this quasi-experimental design to assess for potential student self-selection into one of the two methods of course offerings; blended/face-to-face and online/asynchronous. To assess for such differences in motivation, the researcher adapted the AMS (Vallerand et al., 1992) to the collegiate aviation discipline. Reliability analysis of the adapted scale proved similar results to the AMS. Additionally, confirmatory factor analysis was performed on the data and showed acceptable construct validity for use within the sample population. Ultimately, independent samples *t*-test results did not suggest any difference in motivational attributes on the adapted AMS between the two groups of students by course delivery method or by gender. As Academia-at-large continues to offer more courses in online or distance formats, the results of this study offer another data point into our understandings of student motivation in various forms of traditional and online education.

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An Inductive Approach to Identify Aviation Maintenance Human Errors and Risk Controls

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Human errors can be present in any maintenance task and cause latent but dangerous situations to commercial aviation. By looking into past accidents and incidents caused by aviation maintenance errors, the importance of safety measures would be highlighted - including continuous education on maintenance human factors. Currently, the FAA Part 147 airframe and powerplant (A&P) training curriculum includes general, airframe, and powerplant modules. However, the curriculum does not mandate human factors education or aviation safety pedagogical content. The objectives of this study are to: 1. Find and analyze emerging themes of aviation maintenance-related accidents from existing documentation; 2. Apply risk assessment tools to conduct a risk assessment and identify causal and latent variables; 3. Use detailed qualitative case analysis on major accidents to identify contributing variables of human factors; and 4. Provide recommendations to advocate the importance of human factors education. This study uses a qualitative approach, employing meta-narrative analysis and the VOSviewer visualization tool to demonstrate inter-connected themes related to aviation maintenance problems. Detailed Fishbone (Ishikawa) diagrams showcasing the effectiveness of the selected tools for pedagogical purposes are followed by several case studies, together shedding light on the criticality of continuous education of maintenance human factors. The recommendations based on research findings are beneficial to maintenance training institutions for them to be more aware of potential shortcomings.

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Introduction

Aircraft maintenance is a critical success factor in the aviation sector, and incorrect maintenance actions themselves can be the cause of accidents (Illankoon & Tretten, 2019). Additionally, maintenance errors are a major cause of flight delays and cancellations, leading to financial penalties for airlines (O'Brien, 2012). In the United States, maintenance errors have contributed to 42% of fatal airline accidents from 1994 to 2004, excluding the terrorist attacks on September 11, 2001. In addition, the 2003 International Air Transport Association (IATA) Safety Report found that in 24 of 93 accidents (26%), a maintenance-caused event started the accident chain (Rankin, 2007). In 2005, Lu, Przetak, and Wetmore discovered non-flight errors and suggested emphasizing maintenance safety (Lu, Przetak & Wetmore, 2005). In 2011, Bowen, Sabin, and Patankar also discovered that emerging maintenance human factors had yielded a need for training (Bowen, Sabin & Patankar, 2011). The term "human factors" has grown increasingly important as the commercial aviation industry realizes that human error, rather than mechanical failure, underlies most aviation accidents and incidents (Federal Aviation Administration, 2018). Despite the United States' aviation industry's excellent safety record in the past few decades due to the advanced technologies installed in modern aircraft, aircraft maintenance tasks are ultimately completed by human beings. As a result, maintenance errors still pose a formidable threat to every commercial flight in the United States. While identifying potential human errors affecting maintenance safety is imperative on a daily basis, this paper embraces risk assessment methods to identify and manage human errors. Additionally, this paper discusses and recommends educational themes helping to shape safety attitude and culture.

Literature Reviews

A Quick Review of Human Factors

The Federal Aviation Administration (FAA) defines human factors as the "multidisciplinary field that generates and compiles information about human capabilities and limitations, and applies it to design, development, and evaluation of equipment, systems, facilities, procedures, jobs, environments, staffing, organizations, and personnel management for safe, efficient, and effective human performance" (FAA, 2017, p.2). Understanding the influence of human factors on aviation safety is essential because human factors contribute to human errors and result in aircraft accidents or incidents (FAA, 2018; Kharoufah et al., 2018).

The knowledge of human factors has grown increasingly popular as the commercial aviation industry has realized that human error, rather than mechanical failure, underlies most aviation accidents and incidents since the 1960s (Federal Aviation Administration, 2018). Although human factors are typically associated with flight crew, human errors in aviation maintenance have become a major concern as well. The mistakes of an aviation maintenance technician (AMT) are oftentimes present but not visible and have the potential to remain latent, insidiously affecting the safe operation of aircraft for longer periods of time (Federal Aviation Administration, 2018).

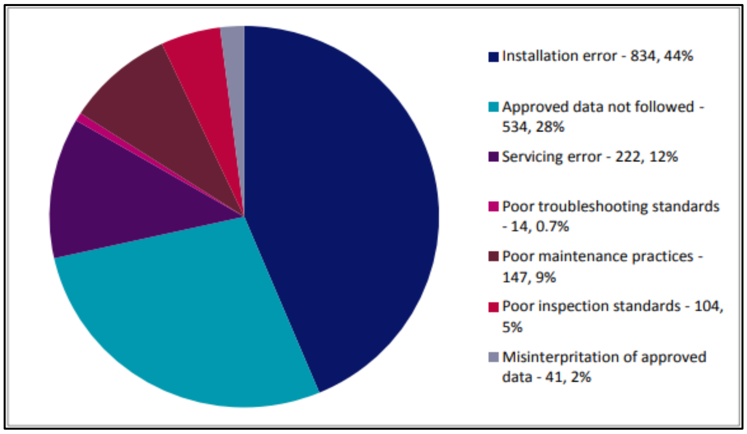
Regardless of the cognitive science, ergonomic/human-machine interface design, and psychological and behavioral variables, there is an extensive list of human factors that can affect AMTs and engineers, including boring and repetitive jobs, personal life problems, poorly designed testing for skill and knowledge, poor instructions, poor training, inadequate work conditions, incomplete or incorrect documentation, substance abuse, fatigue, poor communication, unrealistic deadlines, and lack of tools, equipment & parts. Some of these factors are more serious than others, but in most cases, when three or four of the factors are combined, they can create a problem that contributes to an accident or incident (Federal Aviation Administration, 2018). In the early 1990s, Transport Canada identified twelve human factors that degrade people's ability to perform effectively and safely, which could lead to maintenance errors (Federal Aviation Administration, 2018). These twelve human factors are known as the "dirty dozen", and include lack of communication, complacency, lack of knowledge, distraction, lack of teamwork, fatigue, lack of resources, pressure, lack of assertiveness, stress, lack of awareness, and norms. Maintenance errors, like other causal factors, are likely to be a combination of the above factors leading to an undesired event (Dupont, 2014). It is crucial for AMTs to be aware of the "dirty dozen" and its symptoms, but most importantly, AMTs must be able to understand, identify, and avoid human errors related to the "dirty dozen" (Federal Aviation Administration, 2018) in all stages of aircraft maintenance – from preventative inspections to heavy D checks.

Aircraft Maintenance Incident Analysis (United Kingdom's Civil Aviation Authority)

There have been significant improvements in aircraft system design and component reliability in recent years due to advanced aircraft design techniques, the use of new materials, and knowledge acquired from past incidents and accidents. However, despite these improvements, the maintenance schedule for a modern aircraft still demands the repeated disassembly, inspection, and replacement of millions of removable parts over the long working life of the system (Reason, 1997a). While human operators are error-prone, the process of performing maintenance tasks is involved with vulnerability (Civil Aviation Authority [CAA], 2015; Reason, 1997a). Following a number of high-profile maintenance error events in the early 1990s, considerable work was done looking at the issue of human factors and human performance within aircraft maintenance. It appeared that the growth of aircraft technologies, the prevalence of carrying out maintenance during the night, and the impact of increased pressure on the commercial needs of the operation all had the potential to create an environment where the potential for error could exist (Civil Aviation Authority, 2015).

Of the 2,733 maintenance occurrence reports from the United Kingdom's Civil Aviation Authority (CAA) Mandatory Occurrence Reporting (MOR) dataset between January 2005 to December 2011, 2,399 reports were related to maintenance human factors. According to the U.K. CAA Civil Aviation Publication (CAP) 1367 report, "installation error" was the greatest threat at 44% (see Figure 1). For example, door slides being incorrectly installed resulting from incorrect operating procedures had led to the failure of an emergency evacuation (Civil Aviation Authority, 2015).

Figure 1
MOR Maintenance Error Types from 2005-2011



Source: U.K. Civil Aviation Authority (2015).

AMTs must be fully aware of their responsibilities in the four following areas (Civil Aviation Authority, 2015):

1. Correctly recording and signing off work,
2. Identifying and carrying out safety-critical tasks or independent/duplicate inspections,
3. The importance of following procedures, maintenance instructions, reporting and investigating errors, and
4. Improving tool and debris control.

It is worthwhile to mention that the U.K. CAA has mandated aviation maintenance human factors training per Chapter 11 - *Human Factors Training for Personnel involved in Maintenance* (2009), whereas in the U.S., there are "no FAA regulations that mandate specific content requirement" for maintenance human factors (MxHF) (FAA, 2017, p.4).

Mitigating Human Factors in Aviation Maintenance

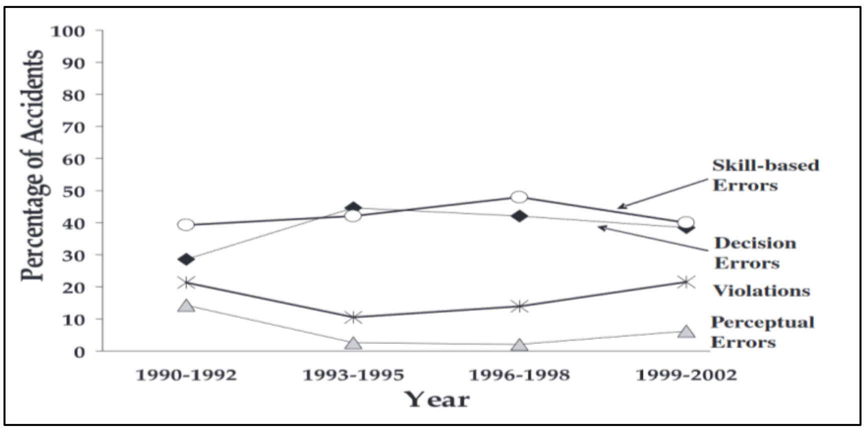
The mitigation of human factors in maintenance is important because the consequences of maintenance-related accidents are often serious. When it comes to aviation fatalities, approximately 15% are caused by maintenance errors (Lu, Bos & Caldwell, 2005; Masson & Koning, 2001). The nature of aviation maintenance typically refers to the jobs done by either the aircraft inspector or other maintenance personnel (Latorella & Prabhu, 2000). In 1995, the FAA published an aviation safety plan providing protocols and advanced maintenance concepts of human factors (Federal Aviation Administration [FAA], 1995) due to the increasing complexity of modern aircraft besides technologically advanced systems (Latorella & Prabhu, 2000). While modern aircraft must go through routine inspections and airworthiness reviews mostly per every 100-hour operation, the specified tasks could open up more opportunities for human error to occur such as the lack of training and qualification, corner-cutting, just to name a few (FAA, 2004).

Human Factor Management Program

When it comes to human factors, the aviation industry has come up with many different programs which could be enforced with the intent of decreasing the number of accidents caused by human error. In Figure 2, there is a decrease in the percentage of accidents caused by skill-based errors and decision errors (Reason, 1997b) from 1996-1998 and 1999-2002 (Shappell & Wiegmann, 2009). However, an increase is seen in perceptual and violation errors. This shows that the accidents were caused due to the lack of proper procedure, which correlates to what was found in many NTSB reports of accidents caused by maintenance. In the wake of the urgent need to improve maintenance safety, the FAA promulgated safety programs to help reduce problematic areas or maintenance human factors (Wiegmann, 2001).

Figure 2

Percentage of Accidents Associated with Unsafe Acts

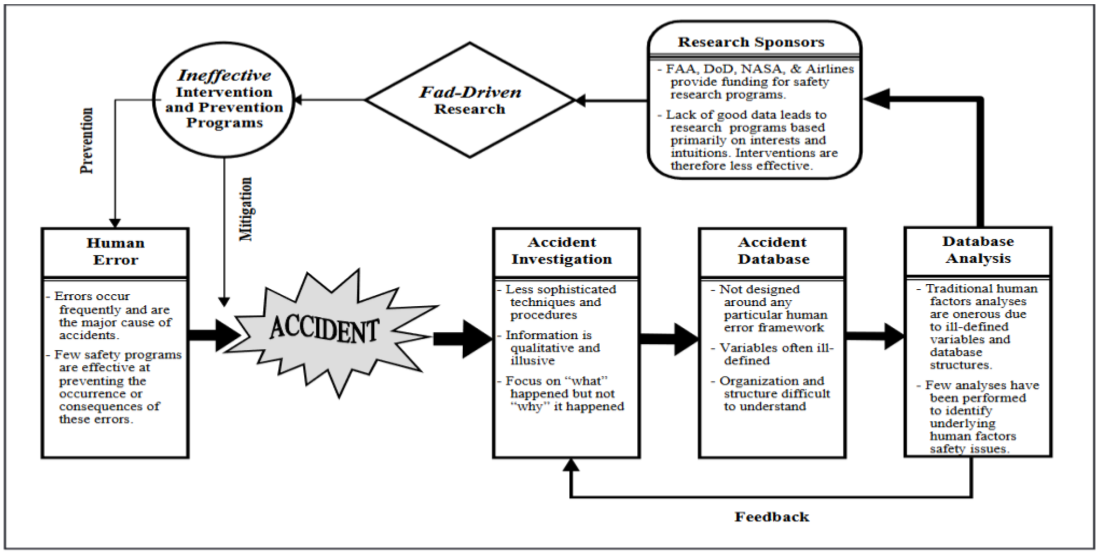


Source: Shappell, S. & Wiegmann, D. (2009, p. 254).

Figure 3 shows the FAA's systemic process to identify, analyze, and control human factors after an accident had occurred. However, there are many different sets of data that go into creating a program, including past intervention programs, which were proven to be ineffective for various reasons. An accident is one of the starting places that trigger the initiative to impulsively create a safety program. If an accident is due to human errors, the FAA forms a cohort task force to create a solution to preventing a similar accident from happening. This typically results in a drive to look for ineffective safety programs or desires to create or revise a safety program. The process is reactive in nature, and fad/intuition-driven research is normally ineffective or not inexpensive (Reason, 1997b).

Figure 3

FAA's Process for Human Factors Identification and Control



Source: Wiegmann, D. (2001, p. 3)

Research Questions

Any latent variables could lead to an undesired event if they are not properly controlled. Safety researchers and educators shall proactively identify and control possible contributing variables using lessons learned or existing cases. While the pedagogical content of human factors is not required by the FAA airframe & powerplant (A&P) curriculum, many researchers and safety practitioners have discovered the causality from human factors to operational errors and to aviation accidents. It is beneficial to retrospect those important research concerns and topics that had been covered to reflect on the merit of human factors. By doing so, not only can a holistic picture of the completed projects be realized, but it also presents readers with themes or areas for maintenance safety education. Furthermore, as most accidents are due to multiple variables, what are those salient ones that could affect aviation maintenance safety?

The research questions of this study are:

1. What are the emerging research themes of maintenance errors affecting the aviation industry?
2. What are the common contributing variables leading to aviation maintenance related accidents?

Research Methodology

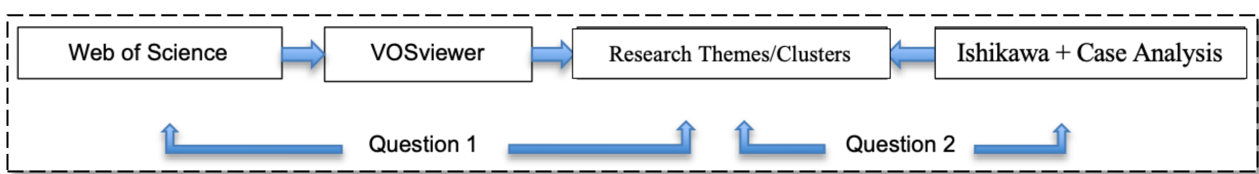
This study uses a series of research approaches to answer the proposed questions. Methods and tools include qualitative meta-narrative analysis, VOSviewer qualitative visualization tool, and detailed case study.

VOSviewer uses a smart, locally moving algorithm that efficiently identifies nodes and edges. This smart, locally moving algorithm constructs networks at different levels to break down the complexity and continually processes the sub-network. This algorithm reiterates itself until a maximum level of optimization has been achieved when processing a large number of iterations on larger-sized networks. The qualitative meta-materials use specific keywords to search the *Web of Science* for related downloadable documents (Waltman & van Eck, 2013; Waltman, van Eck, & Noyons, 2010; van Eck & Waltman, 2010). In this study, the authors use eight (8) keywords to retrieve articles. These combined keywords for article reviews are "aviation maintenance safety", "aircraft maintenance safety", "aviation maintenance error", "aircraft maintenance error", "aviation maintenance safety human factors", "aircraft maintenance safety human factors", "aviation maintenance error human factors", and "aircraft maintenance error human factors."

After all related articles are downloaded, all eight "txt" datasets are uploaded to VOSviewer for visualization and mapping. The purpose of theme mapping is to triangulate findings and generate important themes for selected research studies. The themes are then compared with the results of the Fishbone (Ishikawa) Analysis and Case Studies on selected aviation accidents to reflect on existing theories, such as the FAA's maintenance human errors, Transport Canada's "dirty dozen", James Reason's Swiss Cheese Model, and SHELL Model. The authors formed research reliability and validity using inter-rater reliability and construct validity (Salkind, 2012). The inter-rater reliability was coined by mapping all individual reports and thus yielded a collective agreement on findings.

Figure 4 below demonstrates the research approach of this study.

Figure 4
Research Approach of the Study



Findings & Discussion

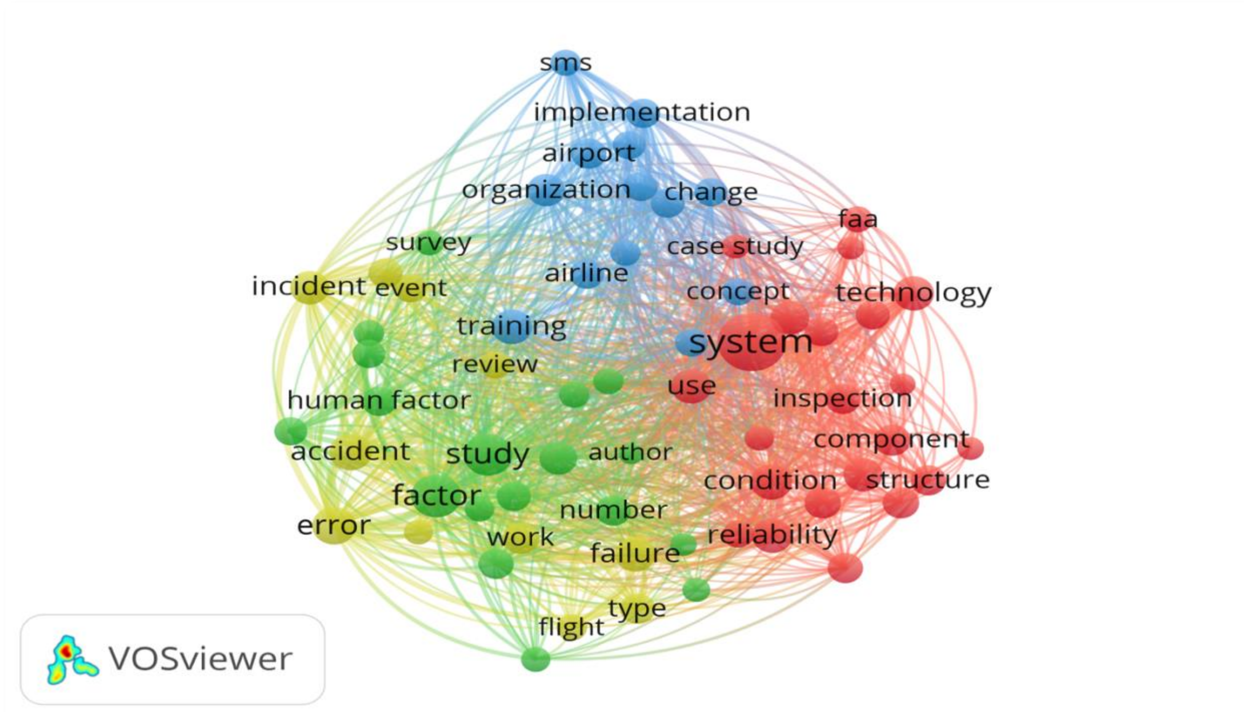
What Are the Emerging Themes of Maintenance Errors Affecting the Aviation Industry?

As described in the Methodology section, the authors used eight (8) keywords and VOSviewer to generate the following charts.

Based on 30 occurrences within 60 papers, Figure 5 below shows three major color-coded clusters under "aviation maintenance safety" including the study of human factors, safety systems, and organizational safety management. This chart indicates that existing research projects focused on aircraft system technology improvement, organizational management & safety program implementation, and human factors training to improve maintenance safety.

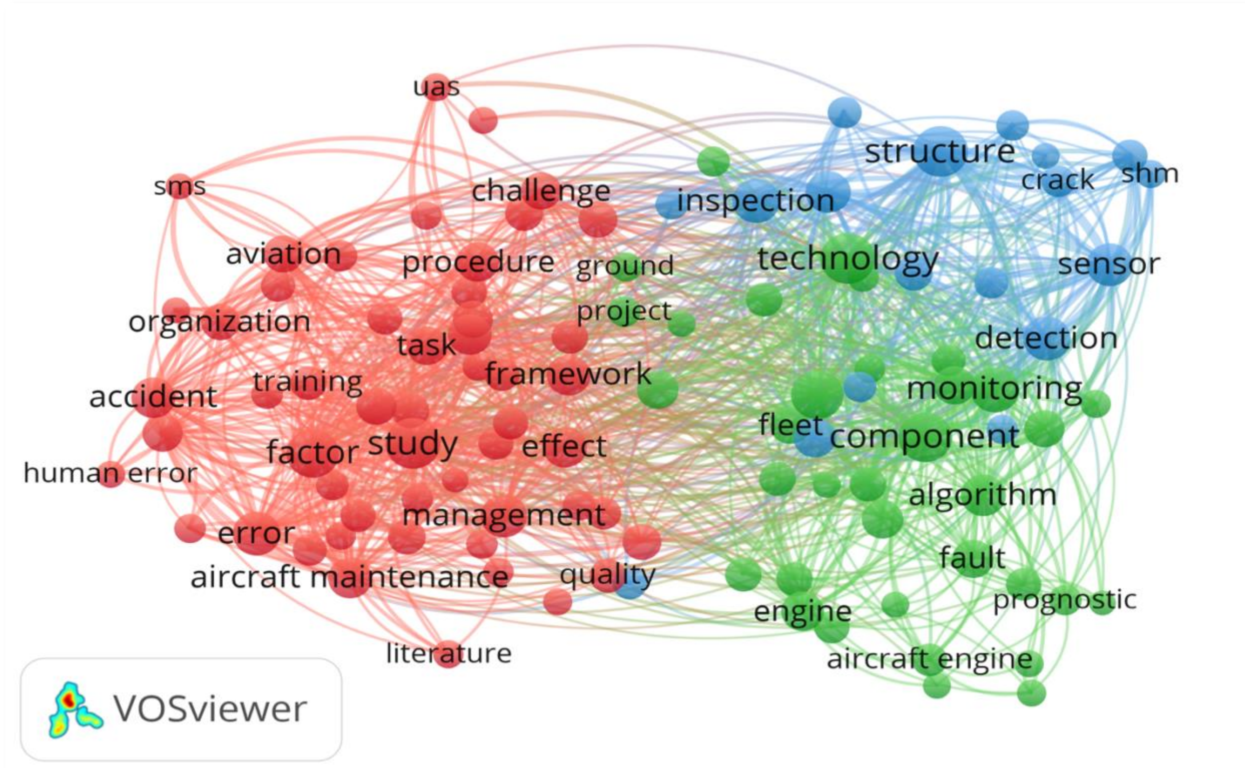
Using the keyword of "aircraft maintenance safety", the following three color-coded clusters were created. Figure 6 indicates that management cluster, inspection skills, and monitoring process are three (3) major color-coded clusters of the maintenance safety study using 30 occurrences as the benchmark within 1,077 research papers and projects.

Figure 5
Aviation Maintenance Safety



Source: VOSviewer software.

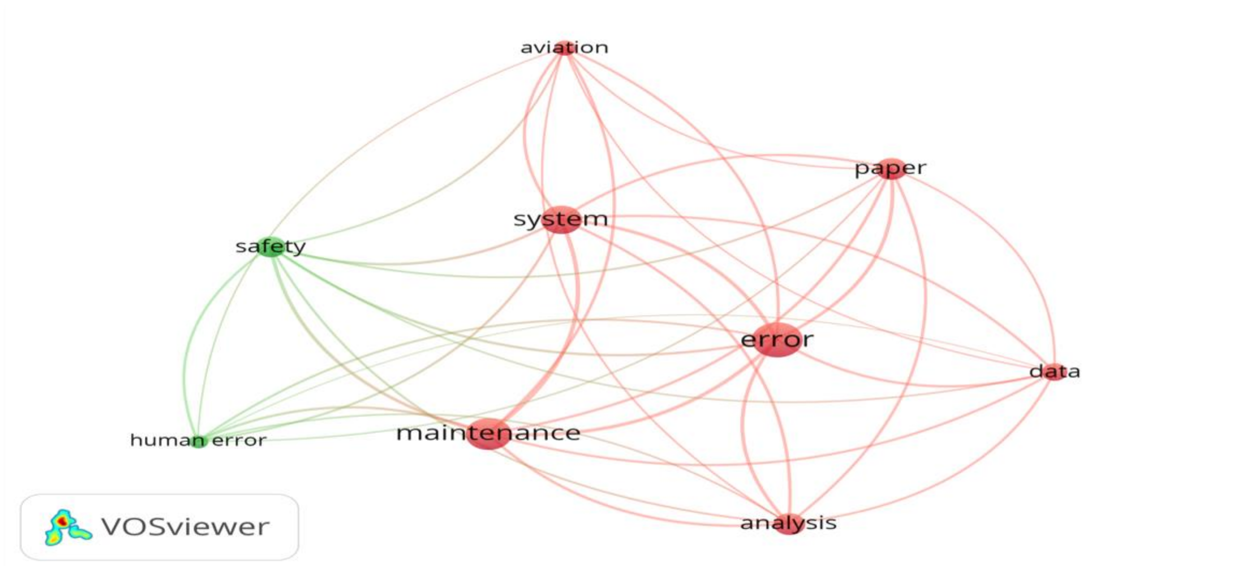
Figure 6
Aircraft Maintenance Safety



Source: VOSviewer software.

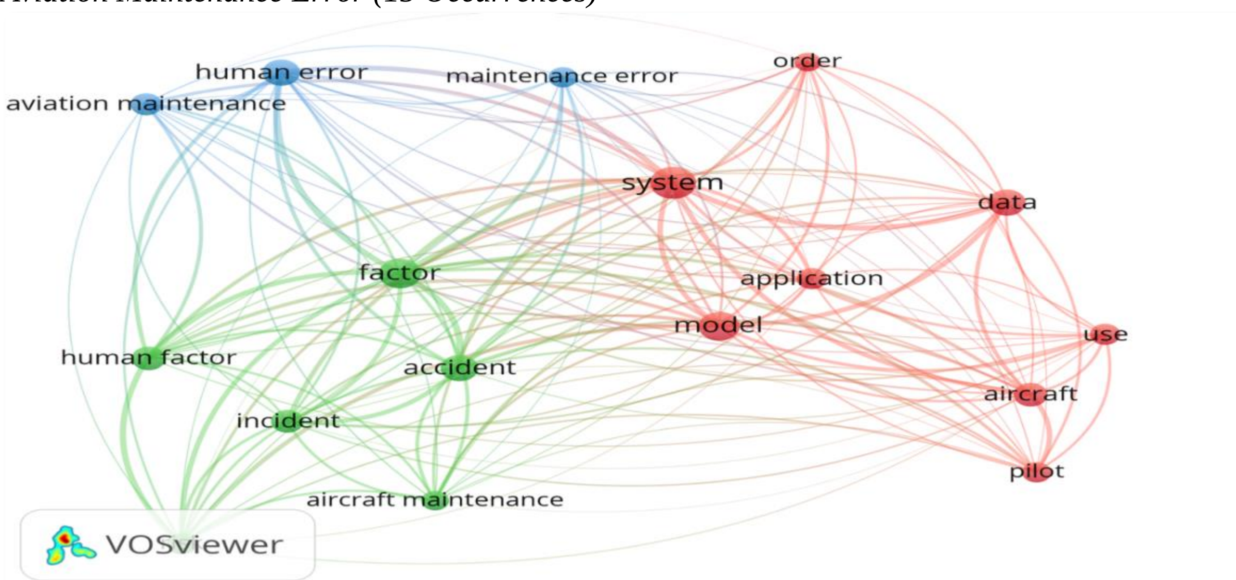
Using 30 occurrences as the benchmark within 212 papers, Figure 7 below shows two simple research clusters. To further identify research similarities and differences, the authors reduced the occurrence benchmark from 30 to 15 (Figure 8). When 15 occurrences are used as the benchmark (Figure 8), the chart indicates three meaningful clusters. The additional cluster is human error and error management.

Figure 7
Aviation Maintenance Error (30 Occurrences)



Source: VOSviewer software.

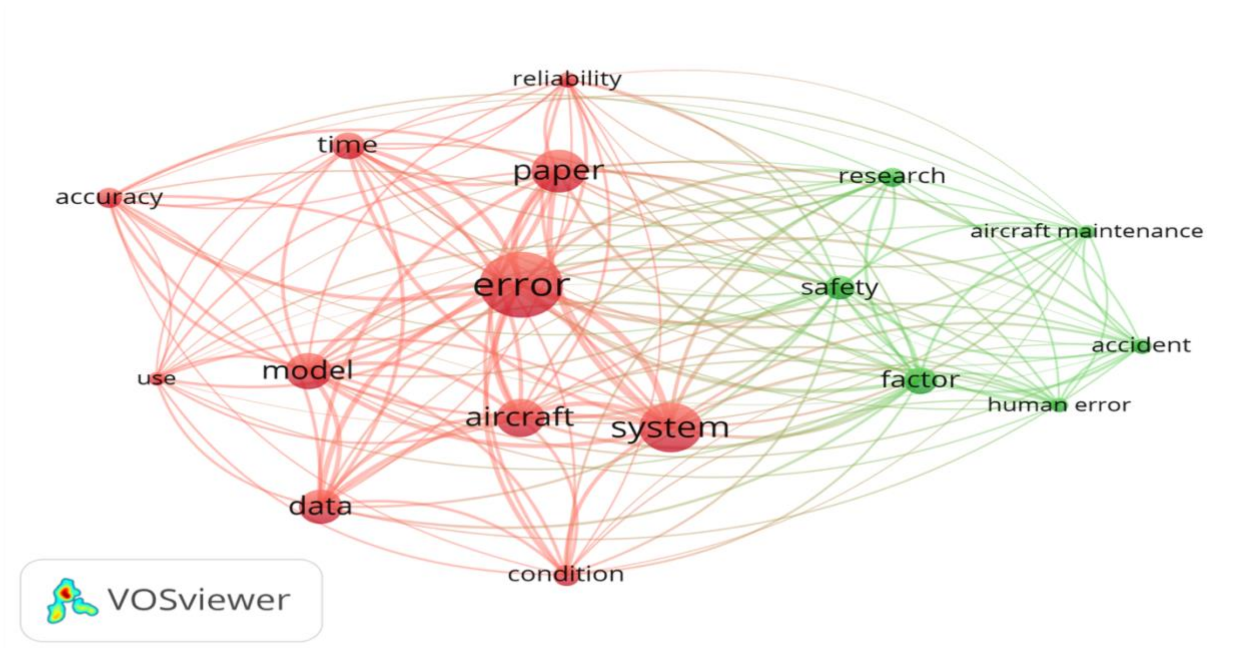
Figure 8
Aviation Maintenance Error (15 Occurrences)



Source: VOSviewer software.

Figure 9 shows two clusters – aircraft design reliability & maintenance human factors. The specific theme "human factors" surfaced when using "aircraft maintenance error" as the quired keyword, providing an informative finding. This analysis used 30 occurrences as the benchmark within 326 papers.

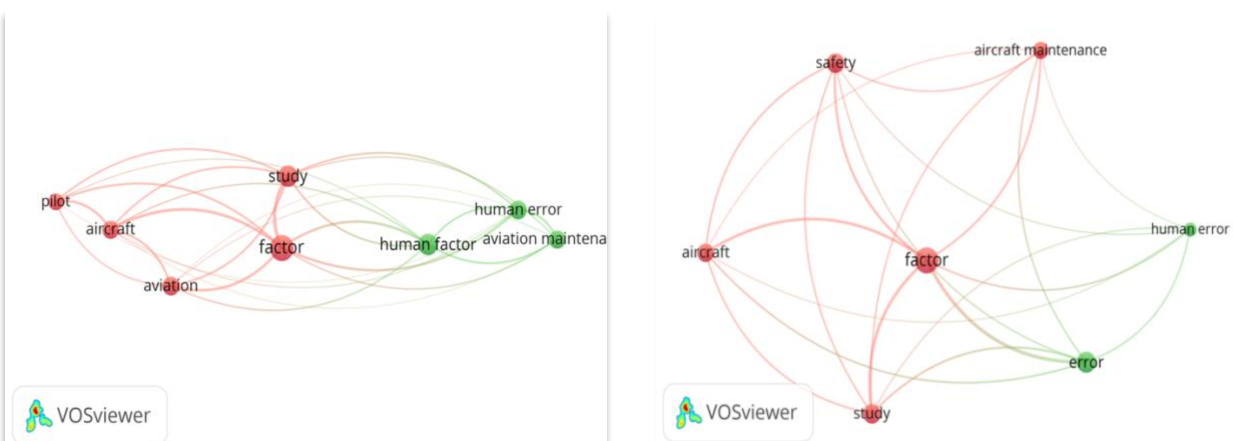
Figure 9
Aircraft Maintenance Error



Source: VOSviewer software.

In Figure 10, the author used 15 occurrences as the benchmark due to the number of downloadable papers. The keyword of human factors is inter-connected to human error and safety study. It also echoes that "aircraft" human factors are more related to pilot operation and engineering design, whereas "aviation" human factors are operator errors, safety study/non-engineering research, or the like.

Figure 10
Aviation Maintenance Safety Human Factors (122 Papers) & Aircraft Maintenance Safety Human Factors (104 Papers)



Source: VOSviewer software.

Using longer keywords in the search yields a smaller number of results. Figure 11 shows the interconnection among “maintenance”, “error”, “human factors”, and “accident”. Obviously, human factors could lead to human errors and thus accidents. In Figure 12, the combined inter-connection analysis shows the overlapping themes between aircraft maintenance and aviation maintenance – “analysis”, “error”, and “human factors”. “Error” was the major theme for a “paired” analysis based on the density visualization.

Figure 11

Aviation Maintenance Error Human Factors & Aircraft Maintenance Error Human Factors

Source: VOSviewer software.
https://www.vosviewer.com/

Figure 12

Combined Interconnection Analysis – Aviation/Aircraft Maintenance Error Human Factors

Source: VOSviewer software. https://www.vosviewer.com/

What are the Common Contributing Variables Leading to Aviation Maintenance Related Accidents?

Research question 2 is answered by case analysis using Fishbone (Ishikawa) Diagrams along with an in-depth qualitative narrative analysis of selected accident cases. The qualitative narrative analysis is obtained by thoroughly reviewing the original accident reports and conducting a comprehensive analysis using existing safety-related theories to find upper-level contributing variables that are beyond the original probable cause. Along with the identification and analysis of contributing variables, a synopsis of the accident is provided and includes the main points and highlights. Furthermore, the analysis includes the authors' findings on what led to the accident/incident chain.

1. Atlantic Southeast Airlines, Flight 529, Embraer EMB-120 Brasilia, N256AS

Synopsis. On August 21, 1995, Atlantic Southeast Airlines Flight 528 suffered from propeller separation that resulted in significant damage to the engine mounting frame and inadequate levels of lift from the left wing. The aircraft then crashed after a barely controllable descent into terrain (NTSB, 1996).

Causal Factors. *T*he major factor leading to the crash has been identified as the inflight fatigue fracture of one of the blades on the left-hand engine (NTSB, 1996).

Researchers' Additional Findings. Additional findings are based on Swiss Cheese and Fishbone Ishikawa analyses and are provided as follows:

Swiss Cheese Model – Latent Conditions. According to the well-known Swiss Cheese model for accident hazard identification, each accident sequence consists of both active failures and latent conditions, where latent conditions are mostly involved organizational risks (Reason, 1997b). These failures and conditions create "holes" in the layers of defense that a system has in order to prevent a hazard from leading to an accident. An active failure is an unsafe act that is likely to immediately impact the safety of the system at the moment. Latent conditions are decisions made within a system that go beyond the operator committing an unsafe act. Following James Reason's Swiss Cheese analysis, the authors list the following latent factors:

1. It was found that the decision by Hamilton Standard to stop the procedure of "shot peening" the internal area of the propeller made the blades more susceptible to early fatigue cracks than if the shot peening procedure had been continued (Armendariz et al., 2014).
2. Hamilton Standard and the FAA agreed on the usage of a chlorine-soaked cork inside the propeller, causing a situation where the inside of the blade could be corroded over time by the chlorine and creating an environment for fatigue cracks to form.
3. The accident blade had been ultrasonically scanned by Atlantic Southeast Airlines (ASA) maintenance personnel for imperfections following two incidents with propeller failures.
4. The technician that inspected the blade using a borescope was unable to detect any cracking inside the propeller due to unsatisfactory tools and the aircraft was returned for services.
5. The technician conducted a procedure in which he blended and resealed the interior of the blade to eliminate what he believed to be erroneous manufacturing imperfections. The technician ended up covering up the existing evidence of cracking that his borescope procedure had failed to detect.
6. Two fatigue cracks that had been missed by the inadequate inspection techniques eventually joined together to form one large crack.

7. The failure of Atlanta Center to expeditiously notify emergency services after the crash. Had the Carroll County Fire Department been notified when requested, they would have been able to respond to the crash site much quicker (NTSB, 1996).

Fishbone (Ishikawa) Analysis. The Fishbone (Ishikawa) Analysis is an effective tool for identifying and categorizing the various contributing factors that combined to result in the accident (Liang et al., 2019). This is referred to as a root cause analysis, which is a structured process for identifying the various underlying causes or factors that result in an accident. Figure 13 below is a Fishbone Ishikawa diagram incorporating the SHELL model.

Proposed Controls. Following Swiss Cheese and Fishbone Ishikawa analyses, safety controls for improvement include shaping a reporting culture, implementing SMS and

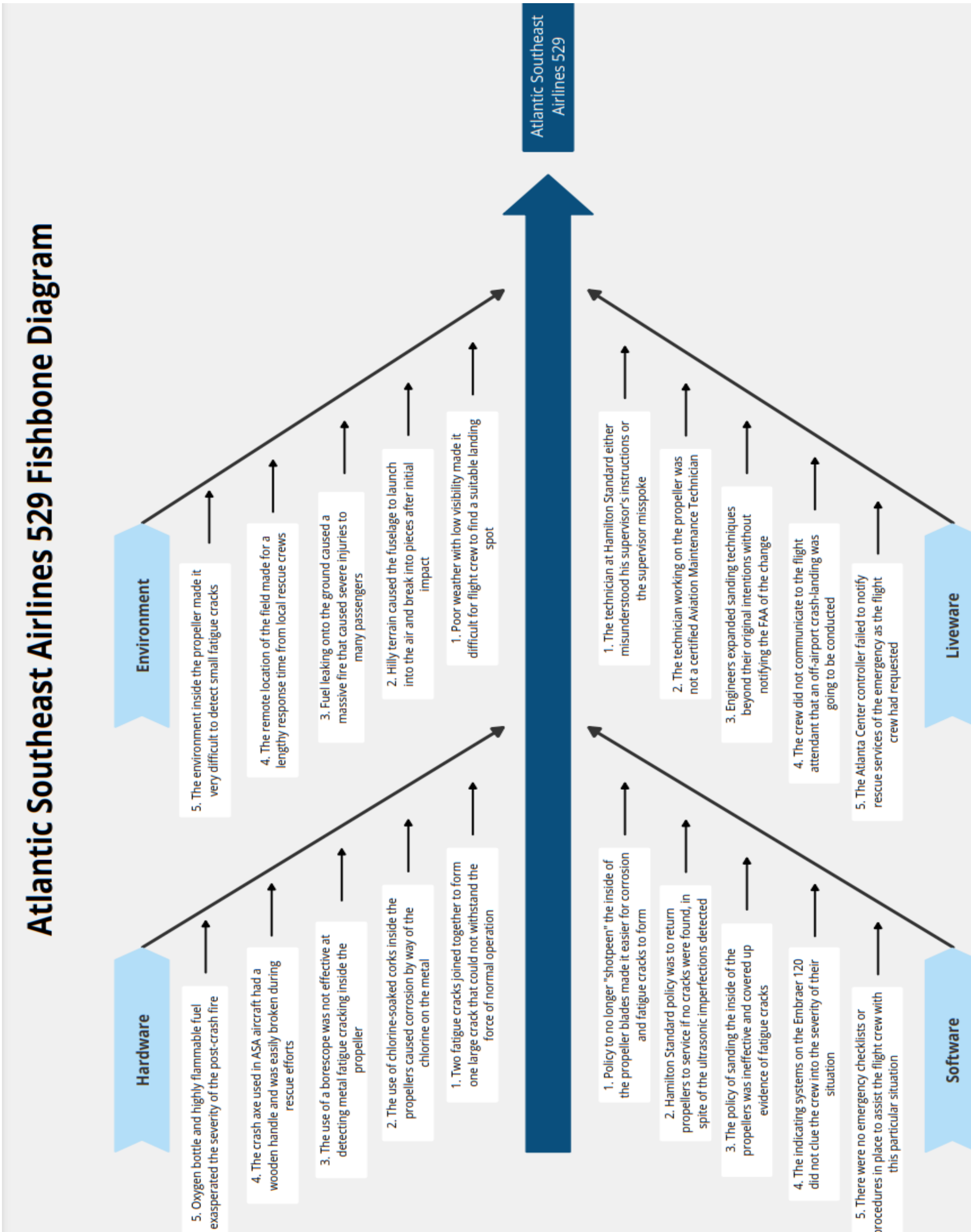
Reporting Culture. A tangible control is a change in culture regarding how potential human errors are identified and mitigated. To truly be successful in achieving safe design, manufacturers and maintenance organizations need to be proactive rather than reactive (Ballesteros, 2007). For the Atlantic Southeast Flight 529 accident, there had been previous accidents related to propeller design issues. In a reactive manner, the propeller manufacturer Hamilton Standard made some changes to increase inspections and change repair techniques. However, these measures had only put a bandage on the wound rather than preventing wounds from occurring in the first place. A high emphasis on identifying the latent factors of human errors could significantly reduce the risk of recurrent accidents.

Assertiveness. Some of the confusion on the part of the technician related to this accident had to do with miscommunication of policy, the uncertainty of correct usage of tools, and unclear work instructions. A quality documentation hierarchy places emphasis on clear policy, procedures, work instructions, and quality records (Stolzer & Goglia, 2015). The process of manufacturing and maintaining aircraft parts does not allow for ambiguity or confusion. Clear and concise documentation and procedures by the company would be beneficial for Hamilton Standard in reducing the chances of these types of errors from occurring.

Safety Awareness and Informed Culture. The technician that worked on the accident aircraft's propeller was not a certified aviation maintenance technician, nor was he required to be by law. It would be a plausible idea for them to place an increased emphasis on aviation safety education and training, such as maintenance resource management (MRM) and human factors (HFs). A strong educational and training program that goes above and beyond to teach employees how to conduct their duties in a safe and regimented manner creates an environment where employees are more likely to recognize potentials for hazards and ask questions if things don't make sense (Wood, 2003). These employees are more empowered and take ownership of the safety system within their organization. Furthermore, this would help enhance the organization's safety culture through the implementation of a better "informed culture". Informed culture requires that working personnel understand hazards and risks, ask questions, as well as have the relevant knowledge and skills pertaining to their job (CANSO, 2008). Better hazard identification kills and job knowledge through safety education and training allows technicians to be more informed and aware of potential hazards.

Figure 13

Fishbone (Ishikawa) Analysis – Atlantic Southeast Airlines Flight 529



2. Air Midwest, Flight 5481, Beechcraft 1900D, N233YV

Synopsis. On January 8, 2003, Air Midwest Flight 5481 suffered from a stall shortly after takeoff and crashed into a hangar after reaching 54 degrees of pitch. The NTSB concluded that the probable cause was the incorrect rigging of the elevator control system, which caused the pilots to have insufficient pitch control (NTSB, 2004).

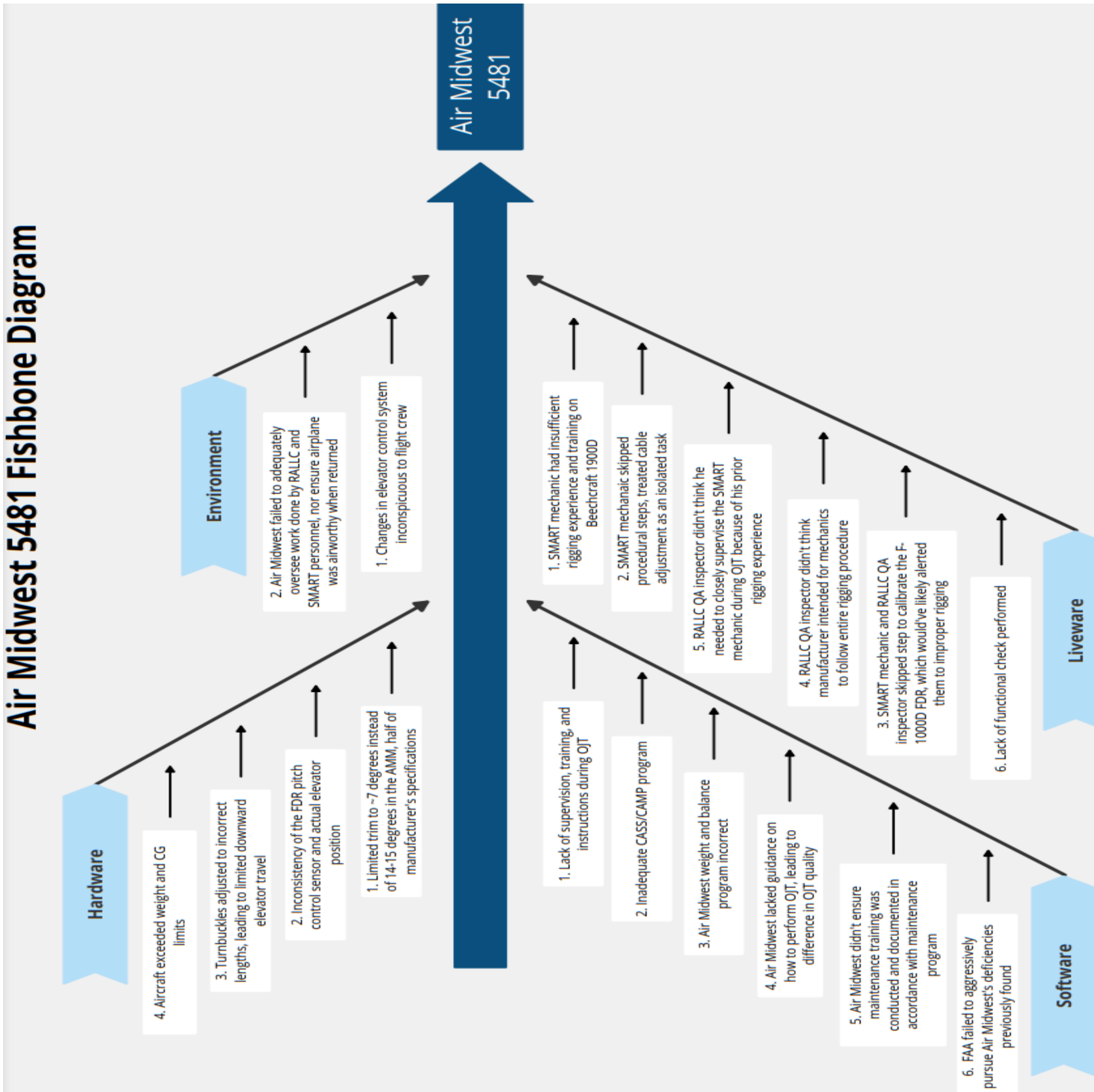
Causal Factors. The incorrect rigging restricted the elevator travel to about one-half of the downward travel specified by the manufacturer. This was caused by deficiencies in the rigging process, oversight, and training. Firstly, nine steps were skipped during the rigging procedure (NTSB, 2004). The mechanic violated the procedure and treated the cable adjustment as an isolated task. One of the skipped steps would've signaled the improper rigging, but this step was ignored. Skipping steps was in violation of 14 CFR 121.367 (U.S. Government Printing Office, 2011), the airline's procedures, and the manufacturer's manual.

Researchers' Additional Findings. Additional findings are extracted from another approach using the combined application of Fishbone Ishikawa Analysis and the SHELL model. Figure 14 below is a Fishbone (Ishikawa) diagram incorporating the SHELL model.

Based on the Fishbone (Ishikawa) analysis (Figure 14), the following are up-stream contributing factors:

- Software: 1. Lack of supervision, training, and instructions during OJT; 2. Inadequate Continuing Analysis and Surveillance System (CASS)/ Continuous Airworthiness Maintenance Program (CAMP); 3. Air Midwest weight and balance program incorrect; 4. Air Midwest lacked guidance on OJT procedures, leading to a difference in OJT quality; 5. Air Midwest failing to ensure maintenance training and proper documentation; and 6. FAA failing to aggressively pursue Air Midwest's deficiencies previously found.
- Hardware: 1. Limited trim to ~7 degrees instead of the 14-15 degrees specified in the AMM and manufacturer's specifications; 2. Inconsistency between the FDR pitch control sensor and actual elevator position; 3. Turnbuckles adjusted to incorrect lengths, limiting downward elevator travel; and 4. Aircraft exceeding weight and CG limits.
- Environment: 1. Changes in elevator control system inconspicuous to flight crew; and 2. Air Midwest failing to oversee work done by RALLC and SMART personnel, nor ensuring the aircraft was airworthy when returned.
- Liveware: 1. Mechanic having insufficient rigging experience and training on Beechcraft 1900D; 2. Mechanic skipping procedural steps, treating cable adjustment as an isolated task; 3. QA inspector failing to closely supervise mechanic during OJT because of his prior rigging experience; 4. QA inspector not thinking that manufacturers intended mechanics to follow entire rigging procedure; 5. Mechanic and QA inspector skipping the step to calibrate the F-1000D FDR, which would've likely alerted them to improper rigging; and 6. Lack of functional check performed.

Figure 14
Fishbone (Ishikawa) Analysis – Air Midwest Flight 5481



3. Alaska Airlines, Flight 261, McDonnell Douglas MD-83, N963AS

Synopsis. On January 31, 2000, Alaska Airlines Flight 261 crashed into the Pacific Ocean about 2.7 miles north of Anacapa Island, California. The NTSB determined that the probable cause of the accident was a loss of airplane pitch control resulting from the in-flight failure of the horizontal stabilizer trim system jackscrew assembly's acme nut threads. The thread failure was caused by excessive wear resulting from Alaska Airlines' insufficient lubrication of the jackscrew assembly. Furthermore, while not specifically mentioned in the

NTSB findings, the acme nut grease fitting passenger - which allows the grease to reach the jackscrew and acme nut threads, was found plugged with dry residue (Federal Aviation Administration, n.d.).

Causal Factors. The NTSB determined that the primary causal factors were the lack of emphasis on maintenance and safety. Numerous management positions, such as the Director of Maintenance, Director of Operations, and Director of Safety were vacant. Furthermore, the authority and responsibility of the roles were poorly defined (NTSB, 2002).

Researchers' Additional Findings. Safety culture was lacking at Alaska Airlines before and at the time of the accident. John Liotine, a mechanic working at Alaska prior to the accident, reported supervisors approving records of maintenance without authorization or when work was incomplete. Furthermore, he said that a supervisor had overruled his recommendation to replace the jackscrew and gimbal nut of the accident aircraft. The causal factors and the incident described here, along with the poor leadership propagated the lack of a safety culture, or if at best, a poor one throughout the airline from top to bottom. Another contributing factor was inadequate maintenance training. The general maintenance manual (GMM) didn't specify training curriculum or on-the-job (OJT) procedures and objectives (Software). The program was also informal and administered at discretion (Software). Alaska's lubrication practices were deficient, as the extension of service intervals decreased the chances of detecting inadequate/missed lubrication (Software). The mechanic performing the lubrication also lacked knowledge of the lubrication process, omitting the step to check for grease as specified in the procedures (Liveware), and did not use enough time to complete the procedure (Liveware). Finally, the FAA's oversight of Alaska's maintenance operations was deficient (Software).

4. Tuninter Airlines, Flight 1153, ATR 72-200, TS-LBB

Synopsis. On August 6, 2005, Tuninter Flight 1153 ditched into the Mediterranean Sea following the failure of both engines due to fuel exhaustion (Agenzia Nazionale per la Sicurezza del Volo, n.d.). On impact with the surface of the sea, the aircraft broke into three pieces. The Agenzia Nazionale per la Sicurezza del Volo (ANSV), an Italian government agency for aircraft accident investigation analyzed the accident using James Reason's Swiss Cheese model since the final ditching was caused by a series of interconnected events.

Causal Factors. The ANSV determined that the primary contributing factor was the incorrect replacement of the fuel quantity indicator (FQI) by Tuninter maintenance personnel (ANSV, n.d.).

Researchers' Additional Findings. Other contributing factors relating to human error in maintenance include errors made by ground mechanics when searching for and correctly identifying the fuel indicator (Liveware), such as not using the IPC as required to check parts compatibility, as well as unsatisfactory maintenance and organizational standards (Software). Furthermore, maintenance personnel lacked adequate training for the aircraft management and spares information system (AMASIS) being used (Software). Complicating the problem was that there was no responsible person appointed for managing the system itself (Software). Hardware similarities for the fuel quantity indicator on the ATR 42 and ATR 72 made it possible to install an ATR 42 type indicator in an ATR 72, and vice versa (Hardware). Finally, the fuel indicator replacement procedures lacked a step that called for a manual check using the dripsticks (Software) (ANSV, n.d.). Using James Reason's Swiss Cheese model, the accident barriers included established systems like the IPC and AMASIS. However, their effects are nullified by active and latent failures, like the omission of IPC usage and lacking a responsible person for managing AMASIS, respectively. Additional latent failures include unsatisfactory maintenance and organizational standards and lacking adequate training for the AMASIS system.

5. Colgan Airways, Flight 9446, Beechcraft 1900D, N240CJ

Synopsis. On August 26th, 2003, Colgan Airways Flight 9446 was destroyed after impacting water near Yarmouth, Massachusetts in a nose-dive. The NTSB concluded that the accident was due to the aircraft losing pitch control because of improper replacement of the forward elevator trim cable.

Causal Factors. Three days before the accident, the aircraft underwent a Detail Six phase check, which included checking the elevator trim actuators. The actuators failed the test and subsequent complications required the elevator trim tab cables to be replaced. However, the technicians skipped a step and did not follow the AMM to use a lead wire as instructed, instead of marking the top pulley with a "T" (NTSB, 2004). Subsequent investigations suggested that the cables would have to be crossed to reverse the system. However, because the technicians skipped the step to use a lead wire, they were likely not alerted. Furthermore, AMM depictions of the trim drum were backward. Despite being incorrect, the AMM instructions were ignored. This resulted in the discrepancy of the elevator trim system. These causal factors show that there were deficiencies both in the maintenance manual and training of technicians.

Researchers' Additional Findings. A series of upstream, latent and active procedural human errors constituted this accident. Aside from the maintenance technicians being ignorant of the procedures or having slips (latent), the captain of the flight crew had made active cockpit procedural errors. Prior to the flight, the captain did not address the cable change noted on the maintenance release, nor perform the preflight checklist that included the elevator trim check (NTSB, 2004). These steps would've likely alerted the captain to the error with the trim system. Skipping procedural steps is a major issue resulting in this accident, prevalent in both the technicians and flight crew. Furthermore, this suggests additional awareness is needed in encouraging personnel to follow all procedural steps and requirements.

6. China Airlines, Flight 611, Boeing 747-200, B-18255

Synopsis. On May 25th, 2002, China Airlines Flight 611 crashed into the Taiwan Strait after suffering from an inflight breakup. Authorities believe that this in-flight break-up was caused by structural failure of the aft lower lobe section of the fuselage due to an improperly repaired tailstrike 22 years prior (Aviation Safety Council, 2004).

Causal Factors. A major contributing factor to the accident was the 29 missed inspections and safety defects that the aircraft had been operating with, starting approximately 4.5 years prior in 1997. These missed inspections were in violation of Boeing's B747 Aging

Airplane Corrosion & Control Program Document and CAL's AMP. China Airlines had changed inspection intervals from letter checks to calendar-year requirements, and this caused some aircraft with a low flight time to be overdue (Aviation Safety Council, 2004). Miscommunication between CAL's Maintenance Operations Center and Maintenance Planning Sections was mainly to blame. Inefficient communication creates barriers towards the accomplishment of organizational goals (Schmidt et al., 2000). However, there is also a problem with the poor-quality assurance procedures, and lack of management oversight and coordination, perhaps even hinting to poor leadership.

Researchers' Additional Findings. The accident chain started with incorrectly accomplished repairs that remained latent for 22 years. In May 1980, a tailstrike was repaired using inappropriate methods in violation of the Boeing SRM. A doubler was installed over the scratched skin and failed to cover the entire damaged area (Aviation Safety Council, 2004). This repair method led to the accumulation of undetected fatigue cracks, weakening that area every time the aircraft was pressurized. CAA's report mentioned that eddy current and visual inspection non-destructive testing (NDT) methods couldn't be used to detect the hidden cracks. However, why did the technicians not use other methods for the inspection? If a method doesn't work in accomplishing a task, that doesn't mean the task does not need to be completed; another method should be used instead (ultrasonic testing, dye penetrant, etc). This, combined with the lack of coordination and leadership mentioned above points to a problem with negligence and safety culture at CAL. Maintenance personnel should care that a task is done fully and correctly, even if there are obstacles. Management, on the other hand, has the duty of ensuring that an order is clearly understood by all parties and provides oversight and direction. Furthermore, management should also provide resources to overcome difficulties maintenance personnel face, as well as ensure the correct accomplishment of a task. Finally, this accident also reveals a serious flaw in the training of maintenance personnel. The tailstrike was classified as a minor repair instead of a major repair, thus omitting the need to document the fix (Aviation Safety Council, 2004). This suggests that technicians have not been well trained in the difference between the types of repairs, as well as flaws in the documentation procedures. CAL's procedure is deficient in that it may make it hard for root cause analysis of future accidents, especially when analyzing variables that remain latent or seem insignificant at first.

7. British Airways, Flight 5390, BAC 1-11, G-BJRT

Synopsis. On June 10, 1990, British Airways Flight 5390 experienced an explosive decompression on the windscreen, partially sucking out the captain. The United Kingdom Civil Aviation Authority (CAA) concluded that incorrect diameter bolts were used when replacing the windshield (Deniz, 2000), as well as "a series of poor work practices, poor judgments, and perceptual errors…" (Department of Transport, 1992).

Causal Factors. This incident was largely due to the result of an accident chain started by the shift maintenance manager's complacency. His work lacked sufficient care and he used poor trade practices and ignored established procedures. These acts included - not using the IPC to identify required bolts' part numbers; not using the stores TIME system to identify the stock level and location of quired bolts; using physical matching of old and new bolts by touch and eye over comparing part numbers, leading to a mismatch; and over-torquing bolts which differed from the Maintenance Manual (Department of Transport, 1992). Furthermore, his complacency led him to ignore numerous cues, such as not questioning the choice to use A211-7D and A211-8C bolts one night and using the correct A211-8D bolts the next night for the same task. Furthermore, he did not use his glasses while performing the windscreen replacement despite requiring mild corrective lenses when reading small print.

Researchers' Other Findings. Complacency is one of the twelve common causes of human factors errors (FAA, n.d.). The causal factors listed above are representative that complacency is an underlying problem that has happened previously, as people become complacent after many repetitions of the same task (FAA, n.d.). The fact that similar errors were likely made in the past without being detected points to the fact that British Airways lacked quality controls. First, the product samples and quality audits department did not directly monitor working practices (Department of Transportation, 1992). Second, the shift maintenance manager's work being the only individual whose work wasn't subject to review created a single point of failure. Combined, these factors led to the detection failure of the inadequate standards used. Aside from complacency and the quality department, management is also a latent variable. Management allowed the maintenance manager's work to become a single point of failure and the complacency to continually repeat itself without being detected by the quality department. This raises an important question about the management's attitude – does management care if an error occurs but nothing happens? If the answer is no, this reveals a deeper flaw in the airline's safety and organizational culture. Using James Reason's Swiss Cheese Model to analyze the accident, the single point of failure combined with the latent variables (management, complacency, & quality department) allowed the hazard of using the incorrect bolts to pass through the barriers to failure (monitoring work practices & the quality department). If the work of the shift maintenance manager was monitored and management's attitude was to aggressively pursue all errors, his working practices would've been corrected, and the hazard would not result in the undesired incident. Further awareness in educating maintenance personnel about human factors susceptibility and complacency is needed.

Maintenance Related Accidents

For ease of review, tables below have been included that simplify the authors' findings into major contributing variables of maintenance related accidents, relevant cases, supporting details, and brief explanations. Contributing variables generally fall into four categories: 1. Poor training of maintenance personnel; 2. Deficient maintenance procedures, manuals, & tools; 3. Ignoring established procedures; and 4. Poor safety/organizational culture. Tables 1 to 4 below provide the inductive summary of each contributing variable.

Table 1
Poor Training of Maintenance Personnel

Poor Training of Maintenance Personnel	***Excerpt from Qualitative Narrative Analysis***
Atlantic Southeast Airlines 529	Technicians unintentionally covered up existing evidence of cracking on the blade after mistaking it for manufacturing imperfections.
Air Midwest 5481	Mechanic had insufficient rigging experience and training on Beechcraft 1900D; QA inspector not thinking that the entire rigging procedure was to be completed; lack of post-repair functional check.
Alaska Airlines 261	The mechanic performing the lubrication lacked knowledge of the lubrication procedure and relevant steps to check for grease.
Tuninter Airlines 1153	Maintenance personnel lacked adequate training for the AMASIS system.
China Airlines 611	Technicians incorrectly repaired tailstrike using inappropriate methods; tailstrike was incorrectly classified as a minor repair rather than a major repair.

Table 2
Deficient Maintenance Procedures, Manuals, & Tools

Deficient Maintenance Procedures/Manuals/Tools	**Excerpt from Qualitative Narrative Analysis**
Atlantic Southeast Airlines 529	The technician conducting borescope inspection on the blade was not able to detect cracking inside the propeller due to unsatisfactory tools; Hamilton Standard's decision to stop "shot peening" the internal area of the propeller made caused the blades to be more susceptible to early fatigue cracks; Hamilton Standard's usage of a chlorine-soaked cork inside the propeller allowed the blade to be corroded over time and fatigue cracks to form.
Alaska Airlines 261	Alaska's extension of service intervals decreased the chances of detecting inadequate or missed lubrication.
Tuninter Airlines 1153	Fuel indicator replacement procedures lacked a step that called for a manual check using the dripsticks.
Colgan Air 9446	The AMM depictions were incorrect, depicting the trim drum backward.

Deficient maintenance procedures, manuals, and tools pertaining to human factors education such that it may serve as a marker of reporting culture issues. It is presumed that it is not the first implementation of such and that prudent maintenance personnel would question the use of such tools or procedures. So, why did nobody raise a question or concern until it was too late? Could it be an effect of a lack of safety mentality among the technicians or perhaps that they didn't care to report because they didn't think it would be taken seriously? This may be a sign that more human factors education is needed to teach technicians to improve safety mentality and awareness.

Table 3
Ignoring Established Procedures

Ignoring Established Procedures	**Excerpt from Qualitative Narrative Analysis**
Air Midwest 5481	Mechanics skipped procedural steps, treating cable adjustment as an isolated task; mechanic and QA inspector skipping the step to calibrate the F-1000D FDR.
Tuninter Airlines 1153	Mechanics did not use the IPC as required to check parts compatibility.
Colgan Air 9446	Technicians did not follow the AMM and skipped a step to use a lead wire as instructed, instead marking the top pulley with a "T".
British Airways 5390	Shift maintenance manager engaged in a series of poor trade practices, including not using the IPC to identify required bolts' part numbers; not using the stores TIME system to identify the stock level and location of quired bolts; using physical matching of old and new bolts by touch and eye over comparing part numbers, leading to a mismatch; and over-torquing bolts which differed from the Maintenance Manual.

Table 4
Poor Safety & Organizational Culture

Poor Safety/Organizational Culture	***Excerpt from Qualitative Narrative Analysis***
Air Midwest 5481	Poor oversight and training from Air Midwest's responsibility to monitor RALLC and SMART personnel, as well as deficient OJT procedures point to management problems and poor safety culture. Furthermore, the airline lacked an adequate CASS/CAMP program and a proper weight and balance program. Management issues are seen on all levels and divisions within the company*.
Alaska Airlines 261	Management issues: Numerous management problems contributed to organizational accidents, such as the vacancy of the Director of Maintenance, Director of Operations, and Director of Safety positions; Leadership issues: Supervisors approving records of maintenance without authorization or when work was incomplete; Reporting culture issues: Supervisor overruled John Liotine's recommendation to replace jackscrew and gimbal nut and chose to ignore a safety concern**. A combination of these problems points to poor organizational culture on multiple levels of command and throughout the company.

Tuninter Airlines 1153	The vacancy of a responsible person for the AMASIS system and the unsatisfactory maintenance and organizational standards points to poor organizational culture***.
Colgan Air 9446	The technicians ignoring the procedures and more importantly, the captain not addressing the maintenance release or performing the preflight checklist possibly reveals poor safety and organizational culture. This type of attitude is persistent in more than one division, hinting to organizational and leadership issues.
China Airlines 611	Poor quality assurance procedures, lack of oversight and coordination, perhaps even poor leadership contributed to a problem of negligence and poor safety culture. Management failed to provide oversight and direction, as can be seen by the poor communication between maintenance divisions and the lack of sufficient instructions for NDT. In this case, management also does not care that the task is done fully and correctly, in turn contributing to poor safety and organizational culture.
British Airways 5390	Management allowed the shift maintenance manager's work to become a single point of failure and the complacency to continually repeat itself without being detected by the quality department. If management does not care if an error occurs but nothing happens, this reveals a deeper flaw about the airline's safety and organizational culture****.

Notes

*It can also be inferenced that Air Midwest suffered underlying organizational accidents and poor organizational culture.

**Safety culture is comprised of just culture, learning culture, reporting culture, and flexible culture. Reporting culture emphasizes that safety concerns will be taken seriously and acted upon.

***Organizational culture is formed by top level management, who in turn sets the standards for the company.

****Furthermore, either: 1. a leadership issue exists; or 2. a management issue exists, possibly resulting from deeper organizational accidents.

Discussion

Many of the maintenance-related accidents were caused by deficiencies in a combination of various human errors stemming from human factors. In a few of the cases investigated, the airlines had implemented quality control programs, such as CASS and CAMP. However, these programs could fail because they did not directly monitor onsite working practices, ensure compliance with established procedures, supervise maintenance personnel, and lacked knowledge and resources. Finally, the FAA, as a regulatory organization, sometimes failed to find and pursue deficiencies in airlines' maintenance and quality control programs. These factors lead to and exacerbated the negative effects of human errors, ultimately leading to catastrophes. This observation yields an opportunity to reconcile various opinions when considering the required education of maintenance human factors, despite of the potential cost that training institutes would incur.

Conclusion

Despite the United States' airline industry's excellent safety record in the past decade, maintenance errors still pose a formidable threat to the nearly 30,000 daily commercial flights in the country. Today, almost 80% of accidents are caused by human error from pilots, air traffic controllers, and mechanics. Human errors, especially among mechanics, can cause latent and dangerous situations to aviation. Therefore, it has become exponentially important to mitigate or prevent them as much as possible.

To achieve the research objectives (emerging themes of maintenance related accidents, risk analysis discovering latent variables, detailed accident analysis identifying human factors, and advocating the importance of human factors for aircraft maintenance training), this study used VOSviewer to discover themes and clusters reflecting on the focus of maintenance human errors. This study also revealed upstream contributing factors leading to accidents. Based on the case studies, incorrect procedures and inadequate training are major factors in aviation accidents caused by human errors. In addition, the authors found that other root causes and contributing factors include poor supervision, lack of knowledge, inspection, and quality control, negligence, and failure to follow protocol. Poor safety and organizational culture also generated human factors because the former can allow for the latter to be present, remain latent, and serve as a contributing variable to accidents. Human errors can be prevented through education and raising awareness on all levels of the company. If maintenance technicians and engineers were educated early in their career paths, they could be more knowledgeable on human errors and prevent unwanted events. When management understands the essentiality of maintenance human factors, they will be more willing to invest in maintenance safety. Hence, "training the trainers" is imperative.

In summary, aviation is the safest form of transportation (International Air Transport Association, 2018) simply because many measures are in place to make sure catastrophes don't occur. These measures range from personnel education, with the implementation of safety attitude and knowledge, to procedures and documentation, to airlines' safety culture, and includes the FAA and government regulations. Per James Reason's Swiss Cheese model, a catastrophe would occur if all defenses failed. These defenses include human operators' qualifications, skills, and knowledge. It is therefore important for all stakeholders, including aircraft maintenance professionals to be constantly vigilant.

Future Study

In this study, the authors focused on airline maintenance related problems between 1994 and 2004 due to the consequence of the accidents. While technologies have been developed and installed to help flight operations in the cockpit, they have simultaneously helped aircraft maintenance personnel avoid errors. It is suggested to continue this study and explore technology-induced benefits in diminishing maintenance errors.

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Impact of Lightning Strikes on Airport Facility and Ground Operations

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Lightning strikes may wreak havoc on airports, causing minor to substantial destruction worth millions of dollars. This study focuses on incidents that occurred at United States airports between 1996 and 2020, including death, injury, infrastructure damage, worker compensation claims, and airline delays. Even though the study showed a modest number of fatalities and injuries, any fatality is unacceptable. According to the study, infrastructure damage also included flight delays. During this analysis, two such costs to air traffic control towers at large airports were revealed.

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Long, T. & Miller, I. (2022). Impact of lightning strikes on airport facility and ground operations. *Collegiate Aviation Review International*, 40(1), 143-167. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/8533/7785

Airports are hazardous places to work, particularly in inclement weather. Lightning has the potential to disrupt airport operations. "Over the last 30 years, approximately 50 fatalities occurred by lightning strikes each year, with many more suffering permanent disabilities" (OSHA, 2016, p 1). Lightning can damage buildings, communications systems, electrical circuits, and powerlines, strike ground crew workers, and destroy airfield electrical systems, resulting in millions of dollars in losses (GHRC, 2021). Lightning struck the Baltimore Washington International (BWI) Air Traffic Control Tower in 2013, injuring one of the controllers (Gresko, 2014). After FAA Inspectors completed their inspection of the tower grounding system, investigators discovered "one cable designed to take electrical current from a lightning strike to the ground had been cut during construction" (Associated Press, 2014, p 1).

Lightning warning systems detect electrical activity in the atmosphere and send an alert based on the energy detected, a more accurate indicator of a lightning strike. The system notifies the public 20 minutes before a lightning strike within a two-mile radius, allowing them to seek shelter (Engle, 2015). There will be times when lightning can appear but no alarm sounds because the energy of the lightning strikes in the area is outside the measured range. However, there will be times when the alarm goes off, but no visible lightning strikes occur (Engle, 2015). Training the airport and tenants on the warning systems allows those on the ramp a warning to take cover when the alarm system goes off. False alarms delay airline operations unnecessarily.

Lightning is dangerous because it strikes any day or night, even in clear blue skies. The fact that lightning can hit more than 100 miles from the parent thunderstorm makes it dangerous (Robbins, 2017). For example, lightning from a sunny sky struck and killed a 7-year-old girl during softball practice, according to Lane Kelley (1998) of the South Florida Sun-Sentinel. Lightning strikes have occurred at airports with clear blue skies and fatally injuring aircraft mechanics.

Problem Statement

Weather alerts and lightning detection systems effectively warn individuals of severe weather and the threat of lightning strikes. Lightning detection systems are an integral part of a comprehensive lightning safety program to minimize threats to passengers and employees. Despite the advancements in technology, these systems are reactive because they issue alerts once lightning is detected. At this time, these systems cannot accurately predict when and where lightning strikes will occur. Lightning strikes have damaged buildings, communications equipment, airfield electrical systems, and struck passengers and employees. What is more, the threat of lightning strikes causes work stoppages, which result in delayed flights. Flight delays induced by lightning near airports are not only costly for airlines since all operations must be halted but also expensive for airports and the federal government to infrastructure damage, injuries, and deaths. Airports could invest in lightning warning systems to avoid potentially life-threatening circumstances, and each airport and tenant should develop policies and procedures for their organization to follow in the event of a lightning strike. Implementing the FAA's best practices may minimize the number of deaths or injuries. The primary purpose of this study was to evaluate the magnitude of the problem that lightning strikes pose to airports. With so many lightning strikes in the US, there was an unanticipated dearth of data on airport-specific lightning injuries and deaths, as well as the expenditures connected with infrastructure damage. The research team aimed to solve the following issues: 1) What effect did lightning strikes have on airport operations, and were there any fatalities or injuries to airport staff, tenants, or passengers because of such strikes? 2) To what degree are airport-specific lightning strikes causing infrastructure damage? 3) What regulations and procedures do airports, airlines, and tenants follow during severe weather events? 4) To what extent, if any, are airport personnel compensated for injuries directly caused by lightning? To answer these questions, extensive data were collected and analyzed to draw meaningful conclusions.

Literature Review

Ramp and airport personnel face many hazards daily when operating in the Airport Operations Area (AOA). Lightning is one of nature's most awe-inspiring phenomena. Lightning is harmful to the aviation industry because it jeopardizes outside ramp activities such as aircraft fueling, luggage handling, restaurant service, and tug operations (Mostajabi et al., 2019). Lightning strikes can cause infrastructure damage or affect airport operations in various ways (Steiner et al., 2014a). Lightning also causes severe electromagnetic interference, damaging electrical circuits, buildings, and other exposed built structures such as transmission lines, wind turbines, and photovoltaics (Mostajabi et al., 2019).

The initial thunderstorm lightning strikes may be the most dangerous, not because of their strength, but due to the element of surprise (Duclos et al., 1990). Because warning systems rely on detecting lightning strikes, ground personnel may not be alerted of a lightning strike because lightning must strike before a signal can be transmitted (Bloemink, 2013). That makes airport ramp workers the most vulnerable to lightning, as they must be relocated indoors until the lightning stops, effectively shutting down ramp operations (Heitkemper et al., 2008). Many lightning fatalities are caused by both the inability and reluctance to get to a safe area in a timely way. Many people wait much too long to begin their journey to safety, putting them in a perilous and perhaps fatal scenario (Jensenius, 2020). Operators would prefer to avoid the delay caused by ramp closures, but the process of closing and restoring a ramp is fraught with significant uncertainty (Steiner et al., 2014a).

Steiner et al. (2014b) stated delays are created by the distractedness of the person in charge of making judgments on-ramp closures. Other operational responsibilities (such as being on the phone or away from their workstation) might generate similar distractions, keeping them from concentrating on the lightning decision support tool (p. 7). According to the research of Steiner et al. (2014b), actual ramp closures frequently lagged the little time when a ramp closure should have begun based on the lightning information and safety rules used by a specific stakeholder. Delays may occur because airlines must adhere to schedules and ground turnaround times. Passengers board and disembark, refuel, cater, and load or unload cargo during these airline turnarounds. Accidents occur when ground crews work quickly. Working too quickly can endanger both aircrews and passengers. Employees may be an inducement to remain exposed, or people may be obliged to continue working. Workplace injury protection may necessitate regulations and guidelines that differ from those provided by the National Weather Service (Duclos et al., 1990).

Lightning-related ramp closures are unavoidable to guarantee the safety of outdoor employees, as false warning alarms or prolonged ramp closures create avoidable inefficiencies that operators would like to eliminate. Lightning monitoring and alerts about the start and duration of threats are among the safety procedures in place at major airports. The specifics vary significantly amongst operators, but one thing they all have in common is that they use lightning information to trigger work pauses and stop outdoor activities, albeit mostly in response to already occurring lightning (Steiner et al., 2014a). When airplanes that are currently occupying gates are unable to be prepped for departure and are delayed, there are eventually no more gates accessible for arriving planes. As a result, arriving taxiing aircraft must wait in a designated location until their allocated gate becomes available or divert to another airport (Steiner et al., 2013).

Even though some airports use lightning detection systems to safeguard personnel and tenants, without defined regulations, each tenant will select when they can begin moving aircraft from the gate for departures or allow passengers to disembark if they arrive without a gate allocated. Due to the lightning warning, planes parked at gates cannot be serviced, and arriving flights may not be able to locate a free entrance to discharge their passengers (Steiner et al., 2014a). Airport ramp closures, which cause ground operations to halt, are examples of lightning exposure (Holle et al., 2016). Observations and alerts are used as safety precautions when warning systems at an airport are unavailable; the decision to close the ramps is understood to depend on flash data. According to the National Weather Service, the sound of thunder travels a mile in roughly 5 seconds. One could determine the distance to the lightning in miles by calculating the seconds between the flash of lightning and the sound of thunder, then dividing that number by 5.

At the time of Bloemink's research (2013), no system could predict where lightning would strike within a specific timeframe (Bloemink, 2013). However, researchers at the Ecole Polytechnique Fédérale de Lausanne (EPFL) School of Engineering discovered they could predict when lightning would strike using artificial intelligence and standard meteorological data to the nearest 10 to 30 minutes within a radius of 18.61 miles (Mostajabi et al., 2019). This system can cover any remote region from radar and satellite range and unavailable communication networks (Ecole Polytechnique Fédérale de Lausanne, 2019).

Lightning data from Low Frequency (L.F.) networks is frequently used by airport and airline parties in their decision-making process about ramp closures. The meteorological factors of a site influence the use of lightning detection and warning systems at airports, as well as the geographic distribution of Cloud to Ground (C.G.) lightning strikes across the United States (Heitkemper et al., 2008). Major airports have safety protocols, including lightning monitoring and alerts concerning the beginning and duration of dangers (Steiner et al., 2014b).

Grabowski et al. (2005) published an article titled "Ground Crew Injuries and Fatalities in Commercial Aviation in the United States, 1983-2004." The purpose of the study was to "investigate airport ground crew injuries and fatalities involving aircraft of commuter air carriers and major airlines" (p. 1). This study found that 98 ground crewmembers were injured or killed in 80 accidents throughout the 22-year study. According to these researchers, 26 percent of these accidents resulted in ground crew fatalities. From the investigation findings, only one ground crew member died due to electrocution while wearing a headset connected to the aircraft when lightning struck the aircraft tail (Grabowski et al., 2005). The number of airplane ramp injuries and deaths is assumed to be low, according to Tarmier and Kisielewicz (2012), and no effort has been made to collect data into a systematic database because such instances are not needed to be reported to authorities.

The FAA may assist airports and airlines by implementing a ground stop until the airport is declared safe to operate. The FAA maintains the gates open due to flight delays and aircraft ramp waits until airlines use them safely. At the NAS level, traffic management initiatives like Ground Delay Program, Ground Stop Program, and Airspace Flow Program limitations attempt to reduce incoming traffic to an airport or geographical area (FAA, 2009).

The Federal Emergency Management Agency (FEMA) estimates that about 300 people are injured by lightning each year; about 10% of those struck by lightning die (Mader, 2020). Lightning strikes are not going away, as the planet warms, lightning strikes in the United States will increase by 50% by the end of the century (Brooks, 2014; Romps et al., 2014).

Lightning is an erratic natural force that can strike at any time and in any location, even when the skies are clear and blue. The initial strikes are the most lethal. Commercial flight delays are common when there is lightning in the area, and the ramps are cleared of support personnel. Major airports have lightning warning systems in place, occasionally giving false-positive results. As a result, airlines have experienced unnecessary delays. Even though no single approach could predict the time and location of a lightning strike during the research, researchers could narrow time and distance to a potential strike by using artificial intelligence and standard meteorological data. Lightning strikes are expected to rise due to global warming, placing airports, airlines, employees, and customers at risk.

Materials and Methods

One goal of this study was to determine the impact of lightning strikes on airport operations and if such strikes resulted in fatalities or injuries to airport staff, tenants, or passengers. To do this, in-depth research was conducted using two distinct sources of information, including official data and media sources.

Government Records

Data was acquired from several government agencies, including the National Oceanic and Atmospheric Administration (NOAA) and the Centers for Disease Control and Prevention (CDC). The National Centers for Environmental Information (NCEI) and the National Weather Service are both parts of NOAA (NWS).

National Centers for Environmental Information

The NCEI receives storm data information from the NWS (NCEI, 2021). Researchers analyzed this database by examining lightning injuries and fatalities from 1996 through 2020. On the website, a search for lightning strikes and the year was performed under the tab labeled "Narrative Text Search" by typing, for example, "lightning strikes 1996." A list of occurrences was downloaded into Microsoft Excel® for examination. After downloading each year, each event narrative was checked for mention of lightning strikes on airports and categorized. Data gathered included the event, state, report source, dates, deaths, injuries, property damage expenses, and narrative.

National Weather Services

For data, the researchers went to the National Weather Service database. This database contained additional information not available in the NCEI listing. Such as specific names of people killed, albeit this information lacks the story supplied by the NCEI database. When the year of lightning deaths was selected, the data provided the city, state, location, activity being done, and name of the individual who died.

By choosing the year under the information on US Lightning Deaths, the NWS database offered U.S. Lightning Deaths by year: A listing of events would include the place and activity, as well as the individual's name. These individual reports were reviewed for events that occurred at an airport. For example, in 2017, one fatality shows in the city of Jacksonville NC, the location is Tarmac, and the activity was working on aircraft, along with the victim's name. (NWS, 2021). This database site also includes a listing of U.S. lightning deaths since the 1940s titled: "80-year List of Severe Weather Fatalities" (NWS, 2021). This listing covers all lightning, tornado, flood, and hurricane fatalities from 1940 – 2020.

Additional information was downloaded from this same database site, by selecting "Storm Data Publication" under "Storm Events Database". From this location, each annual report was then downloaded from the select publication listing. Scrolling to the lightning fatalities for that year would provide all lightning fatalities that occurred that year per state These annual summaries also provided the total lightning injuries from 1996 to 2011 (NCDC, 2021). Since these annual reports only covered through 2011, another source was pursued. Under the NWS Weather Related Fatality and Injury Statistics, U.S. Summaries, each year from 1996 through 2020 were found to provide both the fatalities and injuries. Data from these two databases were compared for accuracy between the two sources.

Media Sources

Even though the NCEI gets information from the media, not every incident is recorded. Some recorded occurrences were discovered by a detailed search of numerous databases, including Newspaper Source Plus, Nexis Uni, Proquest, Newsbank Access World News Research Collection, and Google Scholar.

Newspaper Source Plus and Nexis Uni are news transcript databases that include news from newspapers, television, and radio. The criteria used within these sites were "lightning strikes" or "Airports", or "Airfields". The search produced articles (377,557 in total) that covered U.S. newspapers, newswires, radio, and television news transcripts.

To be consistent with the dates obtained through government records, the researchers of this study primarily analyzed these databases for articles from 1996 to 2020.

Each airport-related mishap was further studied by combing through newspaper stories regarding that specific incident. These databases contain information on the occurrence, the state, the county, direct and indirect deaths, injuries, property damage, and a narrative of the incident. Strikes involving airport staff, ramp workers, airline passengers, and visitors to the airport for a specific reason, such as an air show or an airport open house, were discovered throughout the search. Also, discovered during this search were articles that pertained to lightning strikes on airports where the injured individual filed worker compensation claims against the airport and airline.

The outcome of those worker compensation claims articles that contained the name of the individual, the date, and the place was then explored through that city or county court system.

All data was collected and downloaded into a Microsoft Excel® spreadsheet for further evaluation. Any occurrence that did not include lightning strikes at an airport was excluded from further investigation. Any reports that were duplicated were also deleted.

Results and Discussion

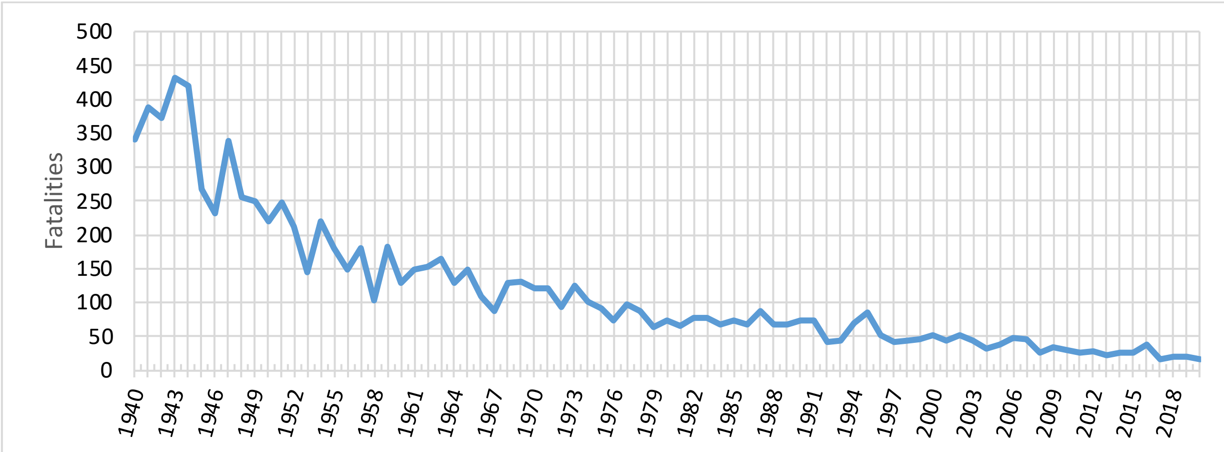
One goal of this study was to determine the impact of lightning strikes on airport operations and if such strikes resulted in fatalities or injuries to airport staff, tenants, or passengers.

It is noteworthy to observe that long-term lightning mortality in the United States has decreased from 432 fatalities in 1943 to 17 deaths in 2020. (Figure 1). This huge drop might be attributed to education, modern medical techniques, and people migrating from farmlands to rural regions (Borenstein, 2017; Robbins, 2016). More than one-third of all lightning-related deaths occur on farms (CDC, 2021). 16,925 lightning strikes were observed and assessed between 1996 and 2020. 867 persons were killed and 5,126 were wounded in the 16,925 lightning strikes (NWS, 2021).

With so many lightning strikes in the US, there was an unanticipated dearth of data on airport-specific lightning injuries and deaths, as well as the expenditures connected with infrastructure damage. The researchers were interested in the effects of lightning strikes on airport operations, as well as if such strikes resulted in fatalities or injuries to airport employees, tenants, or passengers.

This data was limited to records from 1996 to 2020 to examine based on data received from NOAA's National Centers for Environmental Information website. Each individual complaint was then evaluated to ensure that it was a lightning strike on an airport.

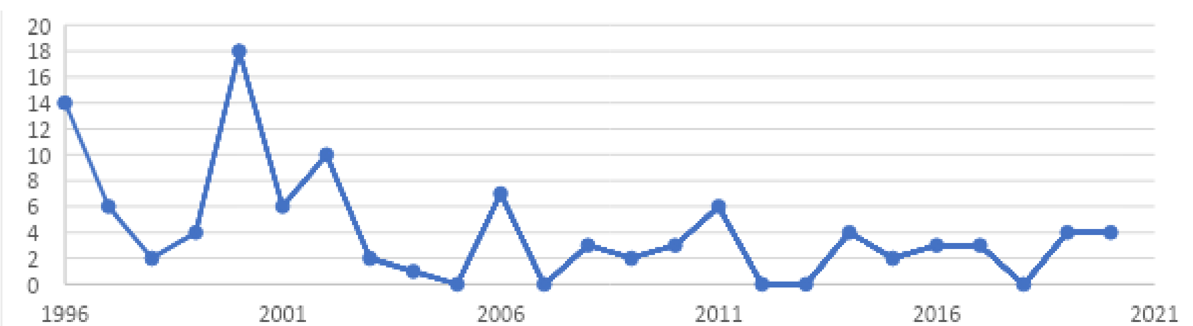
Figure 1
U.S. Lightning Strike Fatalities from 1943 to 2020



(Source: www.weather.gov/hazstat/)

During these 25 years, three fatalities were reported: one was an airline passenger released from the plane to walk to the terminal, another was an aircraft mechanic working on a plane in Florida, and the third was an aircraft mechanic working on an aircraft in North Carolina (Table 1). The researchers also discovered 93 airport worker injuries were caused by lightning strikes from 1996 to 2020 (Table 1). Some of these workers filed worker compensation claims. At the time of writing, the researchers discovered that two worker compensation claims were denied compensation due to "Acts of God," and one was approved in the court system.

Figure 2
Injuries caused by lightning strikes at airports between 1996 and 2020



The most significant number of airport injuries from lightning strikes occurred in 2000, out of all the resources used. Half of those 18 injuries occurred in a single incident on May 18, 2000, when lightning struck the steel superstructure of a new terminal under construction at Detroit Metro Airport, injuring nine (9) construction workers (Figure 2).

Table 1

Documented Lightning Fatalities and Injuries at Airports from 1996 -2020

State	Fatality	Injury	Total
Florida	1	33	34
Alabama		9	9
Michigan		9	9
Oklahoma		7	7
Georgia		5	5
Kentucky		4	4
Arkansas		3	3
Minnesota		3	3
Hawaii		3	3
North Carolina	1	1	2
Texas		2	2
Kansas		2	2
New Jersey		2	2
Tennessee		2	2
Illinois		1	1
South Carolina	1		1
Arizona		1	1
Iowa		1	1
Maryland		1	1
New Mexico		1	1
West Virginia		1	1
Maine		1	1
Wyoming		1	1
TOTALS	**3**	**93**	**96**

Of all the lightning strikes (16,935) there were three fatalities that occurred at airports (Table 1). Those three deaths are detailed in the case reports that follow. There were 28 individual lightning strikes reported in the NWS database that damaged infrastructure costing $1,151,310. None of the federal facilities, repair or replacement costs, or delay costs, were included in our total estimated costs (Table 2).

Case 1. When a lightning storm passed within 5 miles of the Marine Corps Air Station at New River in July 2017, workers working on the flight line were ordered to leave. Both mechanics were on their way out of the MV-22 Osprey when it was struck by lightning. Skyler Dean James, 23, was ruled brain dead five days after he and another Marine mechanic were hurt on July 11 at Marine Corps Air Station New River in Jacksonville (Smith, 2017).

Case 2. In June 2015, Passengers sat on the plane for 45 minutes in Columbia, waiting for the weather to clear before they were ordered off the plane, even though thunderstorms approached. Passenger Sonya Dockett was running from the aircraft to the concourse when she was struck by lightning in full view of her son. Dockett collapsed and was carried unconscious and suffering from burns into the terminal, only to be pronounced dead in August 2016 in her home in Connecticut. Social media reported a woman was struck by lightning as she deplaned onto the tarmac to walk into the terminal at Columbia Metropolitan Airport. Ms. Dockett eventually died from her injuries on August 5. Ms. Dockett's husband brought this to court in 2016 based on a Wrongful Death and Negligent Infliction of Emotional Distress against American Airlines, Inc, PSA Airlines Inc., and Piedmont Airlines, Inc. (Mills, 2015; Mills, 2016). A settlement for a confidential amount was awarded to the family in 2020.

Case 3. In April 1996, eleven military employees were working on an aircraft at Hurlburt Field when lightning struck the plane or nearby. One airman was killed, and ten more were injured. Because of thunderstorms in the vicinity earlier in the morning, the workers had been advised to stay indoors. At 8:29 a.m., the airmen were permitted back on the field, and lightning struck at 8:38 a.m. The strike that hit the airmen was most likely the initial strike from a developing thunderstorm (NWSD, 2021).

A second goal of this research was to determine to what extent are infrastructure damages due to airport-specific lightning strikes.

"Facility Damage" refers to lightning strikes that damaged airport beacons, runways, taxiways, ramps, electrical systems (including runway lighting), ATC equipment, and weather equipment but did not provide an estimated cost for repairs or replacements (Table 1). Lightning struck the Dallas Fort Worth (DFW) Airport, destroying "transmission equipment in the Terminal Radar Approach Control room causing delays to the traveling public. Until the equipment was repaired, DFW Airport resorted to backup transmitters. Approximately "600 aircraft were delayed and 425 were canceled at DFW Airport as well as 135 aircraft were delayed and 65 were canceled at Love Field" (Jimenez & Cardona, 2019).

Table 2
Lightning Estimated Damage to Airport Infrastructure and Total Events per year from 1996 – 2020

Year	Fatalities	Injuries	Airport Est. Costs	Facility Damage	Total Events
2020		4	$1,000		246
2019		2		4	343
2018				1	396
2017	1	4			365
2016		3	$70,110		409
2015	1	3	$10,000		403
2014		3	$70,200	1	498
2013			$131,500		471
2012			$153,000		591
2011		2	$53,000	1	765
2010		3	$455,000	2	864
2009		2		2	721
2008		3			795
2007			$16,000		722
2006		7		1	840
2005			$3,500	5	864
2004				2	715
2003		3	$56,000	2	741
2002		6			875
2001		3	$87,000	2	880
2000		18			909
1999		4		2	863
1998		2	$40,000		899
1997		6		2	838
1996	1	15	$5,000	1	918
Totals	**3**	**93**	**$1,151,310**	**28**	**16,931**

Cost of Delays

Federal Air Traffic Control Towers, transmission equipment, TRACONs, weather stations, and radar towers were among the installations damaged by lightning. Lightning struck multiple Air Traffic Control Towers, creating significant delays in air traffic. Among those reported during this study were Atlanta-Hartsfield, BWI, Fort Lauderdale, Southwest Florida International, Orlando, Miami, and Tampa International Airports.

When lightning struck the Baltimore Washington International (BWI) Air Traffic Control Tower in 2013, the total direct cost of lightning-induced delay and cancellation was $1,887,850 (Ding & Rakas, 2015).

On April 23, 2009, lightning struck the Hartsfield–Jackson Atlanta International Airport Air Traffic Control Tower. Following the strike, the tower was briefly evacuated, and heavy storms caused a power outage in the region. Due to storm and wind shear occurrences, all arrivals and departures at the world's busiest airport were halted (Canadian Press, 2009). The estimated total direct cost of this event's lightning-induced outage delay and cancellation was more than $2 million ($2,287,261) in delay costs and $168,948 in cancellation costs from eight weather-induced cancellations (Ding & Rakas, 2015).

Lightning struck a mobile lounge (transporter) at Dulles International in 2007 when it was traveling from Terminal B to the Main Terminal. While crossing taxiway bravo, lightning struck the lounge, causing the shuttle to come to a halt. After being restarted and on its way to the terminal, lightning struck again, knocking it out of commission. No one was hurt on the mobile lounge, but damage to the mobile lounge included two blown-out windows and tire damage (Angel et al., 2007). This damage was projected to cost $10,000 (Figure 3).

Figure 3
Mobile Lounge damaged by Lighting, Dulles International Airport, 2007.

Source: (Angel et al., 2007, p. 378)

Locating Lightning Systems

The foundation of the warning equipment employed at various airports is lightning detecting systems. These devices are programmed to respond to the first lightning strike that occurs within a certain distance of the sensor. There are risks that notices will not be sent if the first strike occurs on-site. The ideal situation would be to have a system to predict a lightning strike within a specific time frame. Unfortunately, such a system does not currently exist (Bloemink, 2013).

Policies and Procedures

A third objective of this research was to determine what, if any, policies, and procedures are used by airports, airlines, or tenants use during these weather events. A survey was presented by Randy Bass (2015) on Lightning Warning Procedures for Ramp Closures at US Airports during the 17th Conference on Aviation, Range, and Aerospace Meteorology. His findings indicated that larger airports have some form of policies to address lightning but vary from one airport to another. Of those airports that do have policies, some require the fueler to have such a policy and some leave it up to the airline. Those small and regional airports that responded to the survey reported they do not have such policies. Most airports surveyed reported they do not have a policy in place due to liability issues.

According to the National Fire Protection Association – 407 Standard for NFPA 407. Standard for Aircraft Fuel Servicing, section 4.2.10, Lightning: states that “written procedures shall be established to set the criteria for when and where fueling operations are to be suspended at each airport as approved by the fueling agent and the airport authority” (NFPA 407, 2022, p. 407-10).

Airports either do not have policies and procedures for lightning strikes for all airport tenants to follow, or state these policies and procedures are voluntary. Most general aviation airports do not have warning systems and must rely on telephone alerts to keep general aviation and fixed base operators informed or they receive no alerts at all. For those airports that lack policies or procedures, implementing the FAA's best practices may minimize the number of deaths or injuries would be a great option for some airports (Appendix A).

Alert System and Notification

One alert system reviewed was at Southwest Florida International Airport, which uses Thor Guard warning sensors (Figure 4). ThorTV was used to discover lightning strikes in the Florida areas surrounding airports such as Tampa International.

According to Heitkemper et al., (2008) research, there are many techniques by which airport staff and tenants were either notified of impending lightning strikes. Some airports do not alert tenants of a potential threat, while others tell airport workers through radio or telephone. Some airport operations centers at major commercial service airports collaborate with airline ramp tower employees to notify the air traffic control tower, aircraft fuelers, and aircraft servicing trucks of approaching dangers.

Figure 4.
Thor Guard (VOT) Sensor at RSW

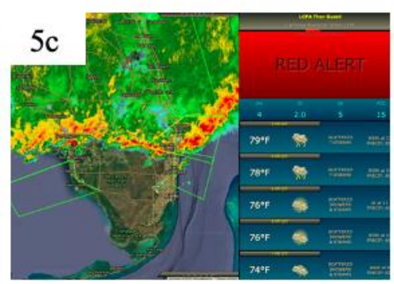
Note: Photo Courtesy of Thomas Long

The Thor Guard lightning warning systems, like other systems, have been progressing to be more predictable and accurate than past technology has provided. ThorMobile allows the public to access lightning warnings through their smartphones around those airports that have Thor Guard technology, such as the one shown in Figures 5a, b, and c, for Tampa International Airport, Florida provides anyone access to ThorTV or ThorMobile to provide up to date data using a computer system or Smartphone. The system has four alerts; All Clear, Warning, Caution, and Red Alert, three of which are shown below.

Figure 5a
ThorTV All Clear

Figure 5b
ThorTV Warning

Figure 5c
ThorTV Red Alert



All Clear signifies that the area is safe, while Caution suggests that the atmosphere may be in flux. Warning indicates that energy changes in the atmosphere, but it may pass by, and Red Alters implies that safety is jeopardized (Thor Guard, 2021).

Terminal Docking Stations

Southwest Florida International Airport has installed a docking system at three concourses to be used during inclement weather. These docking systems allow planes to land and taxi to a gate without the assistance of ramp personnel. The docking systems indicate whether the pilot should proceed to the left, to the right, or come to a complete halt. To locate aircraft, these systems employ infrared cameras and laser sensors. The first docking system was built at D10 gate (Figure 6). Concourses B and C quickly followed (Shaw, 2019).

Figure 6
Docking Station Gate D10 RSW Terminal.

Photo Courtesy of Jeremy Valcich, RSW Operations, 2020

Aircraft ground marshaling

According to the above-stated Grabowski et al. (2005) study, one tug driver was towing an aircraft with his headset attached to the aircraft when lightning struck the aircraft's tail. An electrical current was sent through the headset electrocuting the tug driver. In 2017, at Southwest Florida International Airport, an aircraft was being towed from the gate in preparation for taxing to takeoff when lightning struck the aircraft's tail. The only difference between this and the previous occurrence was that in the Southwest Florida accident, another lineman disconnected the headset when the lightning hit the aircraft's tail, resulting in the linemen being hospitalized. The tug driver escaped unscathed. A lightning warning system was activated during the lightning strike on the airplane in the latter instance.

These incidents necessitated changes to airport policies, terminal amenities, and training programs. Since most airports do not have written policies, the FAA has established "Suggestions for Lightning Safety Procedures and Capabilities at Airports" (Bass, 2019).

Another solution is to construct terminal docking stations at each gate, which would allow planes to approach without jeopardizing ground crew safety. This technique works well for arrivals; however, for pushbacks, additional procedures must be performed.

A solution for pushbacks would be to use E-Vehicles to transfer aircraft from terminal gates to taxiway openings as an approach to protecting line staff from lightning strikes. In 2018, Fraport AG and Lufthansa tested E-Vehicle tugs by pulling back jets like the B737 and A320 using remote-controlled aircraft tugs (Toczauer, 2018). When this tug is used in conjunction with the aircraft ground radio frequency to the cockpit, the aircraft may push back during inclement weather without risking lightning strikes to the lineman.

Figure 7
Lightning Safety Informational sign in Lee County Parks.

Courtesy of Lee County Parks

Finally, loading and unloading freight during storms is currently not a possibility. As reported by Youssef Rddad of the Arkansas Democrat-Gazette (2019), "A 52-year-old Arkansas man was recovering at home Wednesday after a bolt of lightning "came out of the blue" and struck him hours earlier as he was loading an airplane at the Clinton National Airport in Little Rock" (Rddad, 2019).

Notifying the Public

During inclement weather, commuters traveling from open-air parking lots to terminals are not shielded from lightning strikes, nor are those passengers deplaning aircraft to walk across the ramp to the terminal. When a lightning warning system is activated at an airport, travelers are completely unaware of what danger the siren indicates. One cause of concern is the general public's lack of understanding of the processes that may be followed when an airport warning system is activated.

Flight crews and operations personnel are briefed on the warnings and procedures to follow to seek refuge. Airports can learn how other organizations communicate the importance of public notices. The Lee County, Florida - Parks Administration has installed lightning detection warning systems in its county parks, which has been a valuable technique for the public to learn from this type of sign. The County installed instructional signage throughout the parks to inform visitors what to do if the siren and lights go off (Figure 7). A warning system like this one at Jackson Hole Wyoming Airport could have prevented the medical doctor / CEO of the hospital from being struck by lightning as he walked from the airport to the parking lot (Hallberg, 2019).

Injured Workers Claims

According to the study's results, a total of 93 individuals (airport employees, tenants, and passengers) were harmed. The researchers' final goal for this study was to discover if airport workers were compensated for injuries directly caused by lightning. From 1996 until 2020, three worker compensation applications were filed, and three court judgments were issued. The researchers' ability to discover all those who applied for workers' compensation was limited by knowing the individual's name, date of occurrence, and location.

Workers Compensation & The Law

The workers' compensation procedure and the rules that regulate it are intricate and differ from state to state. Employers are required by law to acquire workers' compensation insurance. Although workers' compensation insurance might be expensive, it is required to safeguard companies and employees against job injuries (Insureon n.d.). In 2019, private companies in the U.S. reported 2.8 million nonfatal workplace injuries (*Insureon* n.d.). Moreover, these same companies in 2019 lost almost $62 billion related to lost time due to workplace injuries (*Insureon* n.d.). Workers' compensation insurance is based upon no-fault coverage which protects the employer from employee lawsuits resulting from workplace injuries; however, it also protects employees injured in the workplace (*Insureon* n.d.). It does not matter who is to blame for the employee's injury because an employee can be compensated if they made the mistake that resulted in their injury. Also, an employee does not have to prove the employer was at fault as well (Hoffmann, 2020). Workers' compensation insurance may cover employee costs such as medical bills, lost wages, and disability benefits.

Lightning strikes are referred to as an "Act of God," but this does not eliminate the employees' right to seek workers' compensation benefits (Hoffmann, 2020; Roffis et al., 2019). It is important to note that an "Act of God" does not guarantee the employee's workers' compensation claim will be approved. There are several criteria that need to be satisfied to seek workers' compensation benefits.

1. Did the employee need to be at the workplace at the time of the incident? Was the employee on the clock?
2. Was the employee traveling to or from work at the time of the incident?
3. Was the employee assigned to that specific job location where the incident occurred (Hoffmann, 2020)?
4. Did the employee work in conditions that increased the likelihood of being injured by lightning as compared to the public (Standler, 2004)? Indeed, an employee being asked to work on the airport ramp, during local thunderstorm activity, places the employee at an increased risk of injury from a lightning strike as compared to the public.
5. What if the employer could not reasonably foresee the risk of lightning strikes? Is the employer still liable for any injuries sustained by the employee due to a lightning strike?

Airports and airport tenants have a legal obligation to protect their employees. Airports have a legal obligation to protect employees, passengers, and visitors from lightning strikes.

What is more, airports have an obligation to provide warnings to employees, passengers and visitors, urging them to seek shelter because of the imminent danger of lightning (Standler, 2004). If the airport fails to uphold this obligation, it may be liable for injuries or fatalities that result from lightning strikes. In other words, if an employee is injured, while working at the airport, the employee may be eligible to receive workers' compensation benefits. "The defendant's failure to provide shelters with lightning protection, or to use appropriate warning technology, is an act of Man that is the basis for plaintiff's litigation" (Standler, 2004, p. 19). However, the airport or an airport tenant normally cannot be found accountable to pay compensation for injuries caused by not issuing a lightning warning that the employer cannot reasonably anticipate and protect against, such as lightning strikes during clear blue sky (Standler, 2004).

The Workers Compensation Claim Process

It is the employer's responsibility to inform their employees of the workers' compensation claim process. If an employee is injured at the workplace, they need to report the incident to their employer as soon as possible. Employees located at airports have a specified period to notify their employer of any injury that occurs at the workplace. The law varies, depending upon the state, but typically employees have approximately 30 days to notify their employer of an injury sustained while at work (Insureon, n.d.). Once an employer is notified by an employee of an injury sustained at the workplace, the employer must provide the employee with a workers' compensation claim form. It is the employer's responsibility to provide the employee with information detailing the employee's rights and benefits provided by workers' compensation (Insureon, n.d.).

Next, the employer is responsible for submitting the workers' compensation claim form, along with the required documentation. It is essential for the employer to keep accurate and thorough records regarding workplace incident. Once the claim is submitted by the employer, the insurance company will approve or deny the claim. If the workers' compensation claim is approved by the insurance company, the employee can accept the offer or negotiate with the insurance company. However, if the claim is denied the employee can file an appeal with the state's workers' compensation board (Insureon, n.d.). There are many reasons why a workers' compensation claim may be denied. For example, a claim may be denied if it can be proven the injury was self-inflicted or caused by misbehavior. The employer may need to be asked to provide information during the claim process, so it is imperative that all documentation is thorough and accurate. The goal is for workers to recover from their injuries and return to work.

Court Cases

What happens when a workers' compensation claim is denied, or the employee cannot reach an agreeable settlement with the insurer? Sometimes it comes to this: court. Employees at airports that have sustained injuries due to lightning strikes, have been denied workers' compensation benefits, and have taken legal action against their employer. Robert Clark took such action against United Airlines when he was struck by lightning while working at National Airport as a line mechanic. On September 24, 1975, Mr. Clark was working a flight at National Airport and was struck by lightning (*Clark v. United Airlines, 1982).* Mr. Clark sustained injuries because of the lightning strike and was unable to work for eleven days. A workers' compensation claim was filed after the incident and United Airlines paid Mr. Clark his salary for eleven days and his medical expenses (*Clark v. United Airlines*, *1982*). Mr. Clark claimed that he continued to suffer from pain in his knee, due to the lightning strike incident, between September 24, 1975, and January 19, 1979. Mr. Clark's physician could not confirm that Mr. Clark's knee pain was from the lightning strike incident. Mr. Clark sought legal action against United Airlines when the company refused to continue paying his medical expenses. Mr. Clark lost his workers' compensation case because the statute of limitation was two years for workers' compensation claims in Virginia. Mr. Clark received his last workers' compensation benefits in December 1975, so his final opportunity to file an additional workers' compensation claim was December 1977 (*Clark v. United Airlines*, *1982*).

On August 11, 2017, Cary O'Donoghue was working at Dulles Airport while employed by United Airlines. That day there were thunderstorms in the area and the ramp had been temporarily closed earlier that day due to safety concerns resulting from the thunderstorms in the area and the associated lightning (*O'Donoghue v. United Cont'l Holdings,* 2019). Once the ramp reopened, O'Donoghue was preparing for the arrival of a United Boeing 787 aircraft at the airport gate where he was working. Once the aircraft arrived at the gate, O'Donoghue began his work on the ramp to service the aircraft. There are some important facts of the case that needs to be considered. First, the airport had experienced heavy rain that day and there were puddles of standing water on the ramp. Second, the Boeing 787 is a newer aircraft that is constructed of metal and composite material. Finally, the Boeing 787 does not need to be connected to a ground power unit while at the gate because the aircraft used its lithium batteries to power the aircraft while sitting at the gate. During the flight, aircraft can accumulate static electricity; however, the static electricity is dissipated once it is connected to the ground power unit (*O'Donoghue v. United Cont'l Holdings,* 2019).

On the evening of August 11, the Boeing 787 parked at the gate where Mr. O'Donoghue was working. As he approached the aircraft, he noted that it was still raining and there was lightning around the airport. Mr. O'Donoghue approached the aircraft with a metal ladder and placed the ladder in a puddle of water near the aircraft. He climbed the ladder and opened an access panel on the fuselage of the aircraft. The fuselage of this aircraft is constructed with composite material. He then touched a toggle switch that operated the cargo door of the aircraft. When he touched the toggle switch, he reported seeing a blue arc and felt electricity move through his body (*O'Donoghue v. United Cont'l Holdings,* 2019). Mr. O'Donoghue did not report seeing a blue flash on any other part of the aircraft. He reported to his supervisor that he was struck by lightning and immediately sought medical attention. The ramp at Dulles Airport was temporarily closed again after this incident.

It cannot be confirmed if Mr. O'Donoghue's injuries were the result of a lightning strike or the discharge of static electricity. The aircraft was not connected to a ground power unit so there was no opportunity to dissipate any static electricity that had accumulated during the flight. However, it would be determined an "Act of God" if Mr. O'Donoghue sustained the injury due to a lightning strike. Mr. O'Donoghue filed a workers' compensation claim but was denied. The Court of Appeals of Virginia ruled the evidence did not identify the aircraft or the employment activities as causes of his injuries. Subsequently, the court upheld the decision to deny him workers' compensation benefits. According to Virginia law, an employee sustaining an injury due to a lightning strike while at work does not entitle the employee to workers' compensation benefits. Mr. O'Donoghue had to prove that the tasks or location of the work being performed put them at a higher risk, than the general public, to sustain injuries due to a lightning strike. Furthermore, it could not be proven that the injury was the result of a discharge of static electricity from the aircraft or a lightning strike. Based upon these findings, Mr. O'Donoghue was denied workers' compensation benefits (*O'Donoghue v. United Cont'l Holdings*, 2019).

On July 22, 2017, Austin Dunn was working at Southwest Florida International Airport while employed by Navstar Aviation. The airport's lightning alarm system was activated on July 22 while Mr. Dunn was at work. The other Navstar Aviation employees went inside the terminal building when the lightning alarm system was activated, but Mr. Dunn and two coworkers remained on the ramp to continue pushing back a Sun Country flight for departure ("Airport Worker," 2018). After the aircraft was pushed back from the gate, Mr. Dunn reached into the aircraft access panel to disconnect his headset cord from the aircraft. As he did so, lightning struck the tail of the aircraft and traveled through the aircraft and into his body ("Airport Worker," 2018.). The lightning strike caused injuries to his arms, legs, torso, head, and internal organs ("Airport Worker," 2018.). Mr. Dunn hired an attorney to ensure he received adequate workers' compensation benefits due to his injuries. The attorney stated that Mr. Dunn, along with his two coworkers, was told by the pilot of the aircraft to remain on the ramp to push back the aircraft ("Airport Worker," 2018). Mr. Dunn reached a settlement agreement, with NavStar Aviation, in the amount of $150,000 (*Austin Dunn v. WGA NavStar Aviation USA*, 2019).

There are many more workers' compensation claims, such as these, that demonstrate the difficulty for employees at airports to receive workers' compensation benefits sustained by lightning strikes. The workers' compensation laws are complex and vary depending upon the state where the incident occurs. Employees at airports are at an increased risk of being injured by lightning strikes due to the airport environment. Due to this increased risk of injury, it is imperative that airports develop a comprehensive lightning safety program to minimize the threat to employees.

Conclusion

Most airports in the United States have been found to use visual counting of lightning strikes to avoid risk. Not all the major commercial airports have invested in warning system technology, and those that have can upgrade their systems when new technology improves tracking accuracy and reduces delays. Because not every incident has been documented, only those that have been discovered to have been reported have been counted. As new technology becomes accessible, public warning communication has improved considerably in terms of precision and location of the imminent hit. During this investigation, there were only a few fatalities among all the lightning strikes in the United States. Not to diminish a fatality, since one fatality is too many, but airport fatalities are incredibly minimal when compared to the total fatalities in the United States during this study period. Of those injuries at airports, only three worker compensation claims were identified. Those were only discovered by publications that revealed the identities of lightning victims.

Lightning strikes are anticipated to increase by 50% over the next decade due to Global warming. As a result, airports must improve their technology and policies to warn the public about this potentially lethal force. The expenses of these unavoidable strikes are rising.

Because of the lack of standardization in the aviation industry's lightning safety policies, numerous airlines may apply noticeably different restrictions even at the same airport. Airports and airlines should inform passengers and airport tenants about warning alerts issued by the airport or airline and follow the necessary procedures.

Recommendations for Future Research

As global warming increases, airports become increasingly vulnerable to lightning strikes. Certain types of public notices, according to the study's findings, must be handled not only by airports but also by airlines. Although airports cannot eradicate the disastrous effects of lightning strikes, further study into how airports might lessen these damages and reduce delays is required. Because airplanes are not grounded when operating, it would be useful to investigate which injuries and deaths happened after lightning strikes while the aircraft was physically grounded, and repair was being conducted.

Future studies will include a more in-depth examination of the language in airport policies and procedures relating to lightning strikes, as well as the construction of a Benefit-Cost Analysis based on loss of life and injuries vs the purchase and implementation of established warning systems and processes.

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A Systematic Literature Review Examining the Gender Gap in Collegiate Aviation and Aerospace Education

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Using a systematic literature review research methodology, researchers identified 22 scholarly journal articles published between January 2004 to May 2020, from five engineering, science, technology, and education databases. The objective of this study is to systematically explore the gender gap in collegiate aviation and aerospace education and highlight some of the factors that may be contributing to the gender gap in aviation and aerospace college programs. In addition, the researchers provide an in-depth analysis showing the research areas covered in the existing literature on the topic of gender imbalance and perceptions of female students in collegiate aviation education. Two research questions were developed, and a search strategy was developed. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was used to search, screen, and set inclusion and exclusion criteria for the scholarly journal articles. The 22 scholarly journals were analyzed thematically. Results show that lack of organized mentorship and challenges in recruitment and retention of female students are among the areas that need more attention to bridge the gender gap in collegiate aviation programs. Other themes include persisting gender stereotypes and masculine culture in traditionally male-dominated fields. Based on the findings of this study, the researchers recommend a follow-up study focusing on the analysis of the trends in the number of women enrolled in collegiate aviation and aerospace programs.

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Before the global COVID-19 pandemic that hit the world in early 2020, the aviation industry was one of the fastest-growing industries, with an estimated annual growth of 4.6 percent (Boeing, 2019). While the aviation industry has experienced steady growth over the last decades, women and minority groups are underrepresented in most aviation and aerospace professions. Ludtke (1994) reported that approximately six percent of all United States (U.S.) registered commercial pilots were women. Nearly three decades later, the number of female commercial pilots remains significantly slow. Data from the Federal Aviation Administration (FAA) airmen statistics, 2009 to 2018, showed that about 6.5 percent of all registered commercial pilots in the United States were female (FAA, 2019). In addition, other studies spanning decades have shown that women are underrepresented in undergraduate aviation and aerospace degree programs (Ison, 2009; Ludtke & Bowen, 1993; Sobieralski & Hubbard, 2019).

Furthermore, women are underrepresented in many STEM fields (Kanny et al., 2014; Saunders et al., 2020), under which aviation and aerospace degrees are classified. According to the National Center for Education Statistics [NCES] (2019), the percentage of women graduating with a bachelor's degree in any field is higher than that of men (58% to 42%). However, fewer women are graduating with a bachelor's degree in STEM (64% to 36%). Saunders et al. (2020) cited "implicit and explicit bias, sexual harassment, unequal access to funding and resources, pay inequity and higher teaching and advising load" (p. 2) among the factors that discourage women from pursuing careers in science, engineering, and medicine. Other studies showed that lack of role models and mentors, gender stereotyping, and less family flexibility in STEM careers contribute to low interest in STEM careers by women (Beede et al., 2011; Ludtke, 1994). Mentorship and role models play an important part in attracting youth to aviation and aerospace careers (Bishop et al., 2002; KORNFERRY, 2019; Opengart & Ison, 2016). With fewer women in aviation faculty positions, women in collegiate aviation and aerospace degree programs often lack mentorship, a key factor in increasing retention of women in traditionally male-dominated fields (Anderson & Pucel, 2003). There have been efforts to increase mentorship for youth who show interest in aviation aerospace careers at an early age. Organizations such as the *Ninety Nines* and Women in Aviation International (WAI) provide a platform for young girls to connect with professional women in aviation and aerospace careers through networking and mentorship. Nevertheless, a lot more proactive actions are needed to increase the participation of women in aviation and aerospace careers.

The entire aviation and aerospace industry stands to benefit from gender diversity and other forms of diversity. Studies of gender diversity in the workforce show that organizations with higher gender diversity reported positive market valuation and increased revenue (Fischer & Mullin, 2014; Zhang, 2020). Furthermore, the importance of gender diversity in the aviation and aerospace industry has been highlighted by various governments and international organization initiatives. In 2020 the FAA formed the Women in Aviation Advisory Board to provide recommendations "to explore opportunities for encouraging and supporting female students and aviators to pursue a career in aviation…" (FAA, 2020. Par 1). The International Civil Aviation

Organization (ICAO) in collaboration with the South African Civil Aviation Authority (SACAA) held the first ever Global Aviation Gender Summit in Cape Town, South Africa in 2018 "to mobilize the global aviation community to accelerate gender equality in aviation" (ICAO, 2018, par 4). The International Aviation Women Association (IAWA) in collaboration with industry stakeholders published the *Soaring Through the Glass Ceiling* report, a "comprehensive study focused on enhancing the attraction, retention, and advancement of women across all facets of the industry" (KORNFERRY, 2019, p.1).

Notably, although several studies have explored the underrepresentation of women in aviation and aerospace careers, few studies have focused on the gender gap in collegiate aviation and aerospace education. This study aims to bridge the gap by systematically exploring existing literature on the underrepresentation of women in aviation and aerospace degree programs and highlighting some of the factors that may be contributing to the gender gap in aviation and aerospace collegiate programs.

Study Objective and Research Questions

Women are underrepresented in aviation and aerospace collegiate education. The objective of this systematic literature review is to use a systematic literature review methodology to explore the gender gap in collegiate aviation and aerospace education. In addition, the study aims to highlight some of the factors that may be contributing to the gender gap in aviation and aerospace college programs. The researchers will provide an in-depth analysis showing the research areas covered in the existing literature on the topic of gender imbalance and the perception of female students in collegiate aviation education. The study will answer two research questions:

RQ1. Which aspects of gender imbalance and perceptions of female students in college aviation and aerospace programs are addressed in current literature?

RQ2. What factors have contributed to the current gender gap in aviation and aerospace collegiate education?

Methodology

This study uses a systematic literature review research methodology to examine the current gender gap in collegiate aviation and aerospace education. A systematic review is a review of literature that follows a set of scientific methods that clearly aim to limit systematic error (bias) by attempting to identify, appraise and synthesize all relevant studies (of whatever design) to answer a particular question (Bettany-Saltikov, 2010; Petticrew & Roberts, 2006).

Systematic literature reviews are commonly conducted in the fields of medicine, psychology, and education to critically appraise, summarize, and attempt to "reconcile the evidence in order to inform policy and practice" (Petticrew & Roberts, 2006, p. 15). These types of studies can be applied to other emerging fields of study to provide synthesized reviews on the ever-mounting scholarly work produced every year (Borrego, Foster & Froyd, 2014). Based on the literature review conducted for this study, no existing systematic literature reviews were found on the topic of gender imbalance in collegiate aviation and aerospace education.

Advantages of Conducting a Systematic Literature Review

1. Any individual research study may be fallible, either by chance or because of how it was designed and conducted or reported,
2. Any individual study may have limited relevance because of its scope and context,
3. A review provides a more comprehensive and stronger picture based on many studies and settings rather than a single study,
4. The task of keeping abreast of all previous and new research is usually too large for an individual,
5. Findings from a review provide a context for interpreting the results of a new primary study,
6. Undertaking new primary studies without being informed about previous research may result in unnecessary, inappropriate, irrelevant, or unethical research (Gough, Oliver & Thomas, 2017, p. 3).

Search Strategy

Five databases with publications in the fields of engineering and technology education, aviation and aerospace education, and STEM were selected for this study. Namely, ERIC, Compendex, Scopus, ProQuest Technology Collection, and Academic Premiers. Search strategies were applied to each database to identify candidate scholarly articles for the systematic analysis. A combination of the keywords was identified and entered in each of the five databases. Boolean terms 'AND' and 'OR' were applied. Table 1 shows the summary of the search strategy used in each of the five databases. Filters: 'Language = English,' 'Year of publication = Jan 2004 – May 2020', "Publication type = peer-reviewed or scholarly article', were used to narrow down results in each database. Keywords entered in the databases search were Aviation, aerospace, education, postsecondary, undergraduate, college and university.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria are the processes of identifying the types of study to be included or excluded from the analysis (Petticrew & Roberts, 2006). Table 2 shows the inclusion and exclusion criteria used.

Table 1
Summary of the search strategy

Database	Search Strategy
Compendex	Search Field 1 Search constructed using the "Quick Search" option: Search Field 1: (gender or female or wom*n); selected "Subject/Title/Abstract" AND Search Field 2: (aviation or aerospace); selected "Subject/Title/Abstract" AND Search Field 3: (college or university or undergraduate OR postsecondary); selected "Subject/Title/Abstract"
Scopus	Search constructed using the "Advanced option: Search Field 1: (gender or female or wom*n); selected "Article title, Abstract, Keywords" AND Search Field 2: (aviation or aerospace); selected "Article title, Abstract, Keywords" AND Search Field 3: (college or university or undergraduate OR postsecondary); selected "Article title, Abstract, Keywords"
ProQuest Technology Collection	Search constructed using the "Advanced option: Search Field 1: (gender or female or wom*n); selected "Abstract" AND Search Field 2: (aviation or aerospace); selected "Abstract" AND Search Field 3: (college or university or undergraduate OR postsecondary); selected "Abstract"
Academic Search Premier [EBSCO]	"Advanced Search": Field 1: AB: gender or wom*n, or female AND Field 2: AB: aviation or aerospace AND Field 3: AB: college or university or undergraduate OR postsecondary

Table 2
Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion criteria
▪ Peer reviewed scholarly journals articles. ▪ Publication years January 2004 – May 2020. ▪ Publications in English. ▪ The article focused aviation or aerospace education at college level. ▪ The article included undergraduate aviation and aerospace students in the sample. ▪ The article addressed gender related issues in aviation and aerospace education.	▪ Article focused on gender gap in the workforce. ▪ Article addressed specialized topics in aviation and aerospace such as aviation medicine and human factors. ▪ Article addressed a non-education related topic. ▪ The article did not address gender related issues in aviation and aerospace education.

Results and Discussion

This section discusses the findings of the study. Three steps were followed in reporting the findings (Petticrew & Roberts, 2006).

Step 1. Mapping - organize the studies, e.g., by outcome, population, level of analysis, and study design. Mapping maps the work that has been done in a field or topic areas. Mapping also helps to inform the decision on where to focus the rest of the analysis. Table 3 was prepared to map the key aspects of the studies used for the systematic analysis. The researchers noted the author(s) and year of publication, title of article, methodology or study design and themes that were apparent in each article. Additional notes were made to supplement the themes identified.

Step 2. Critique within studies using tables. The second step focuses on presenting the assessment of quality for each study in turn. The level of detail can range from the amount of text that fits in a table to lengthy summaries.

Step 3. Critique across studies. This step is the heart of synthesis and the major contribution of systematic reviews. The thematic analysis section provides a critique across the twenty-two scholarly articles used in the systematic review.

Table 3 shows a list with the twenty-two peer reviewed articles included in the final systematic analysis.

Search and Selection Process

A detailed and systematic record search and selection criteria give a systematic review transparency and can be helpful to future researchers wishing to replicate the study (Petticrew & Roberts, 2006). In practice, the search and selection process is a nonlinear process and might involve a back and forth search that must all be reordered for transparency. The inclusion and exclusion criteria shown in table 2 were applied. In addition, Figure 1 shows a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) diagram created for this study based on Moher, Liberati, Altman and The PRISMA group (2009).

Figure 1
PRISMA diagram showing the search, screening, & search criteria. Adapted from Moher et al. (2009).

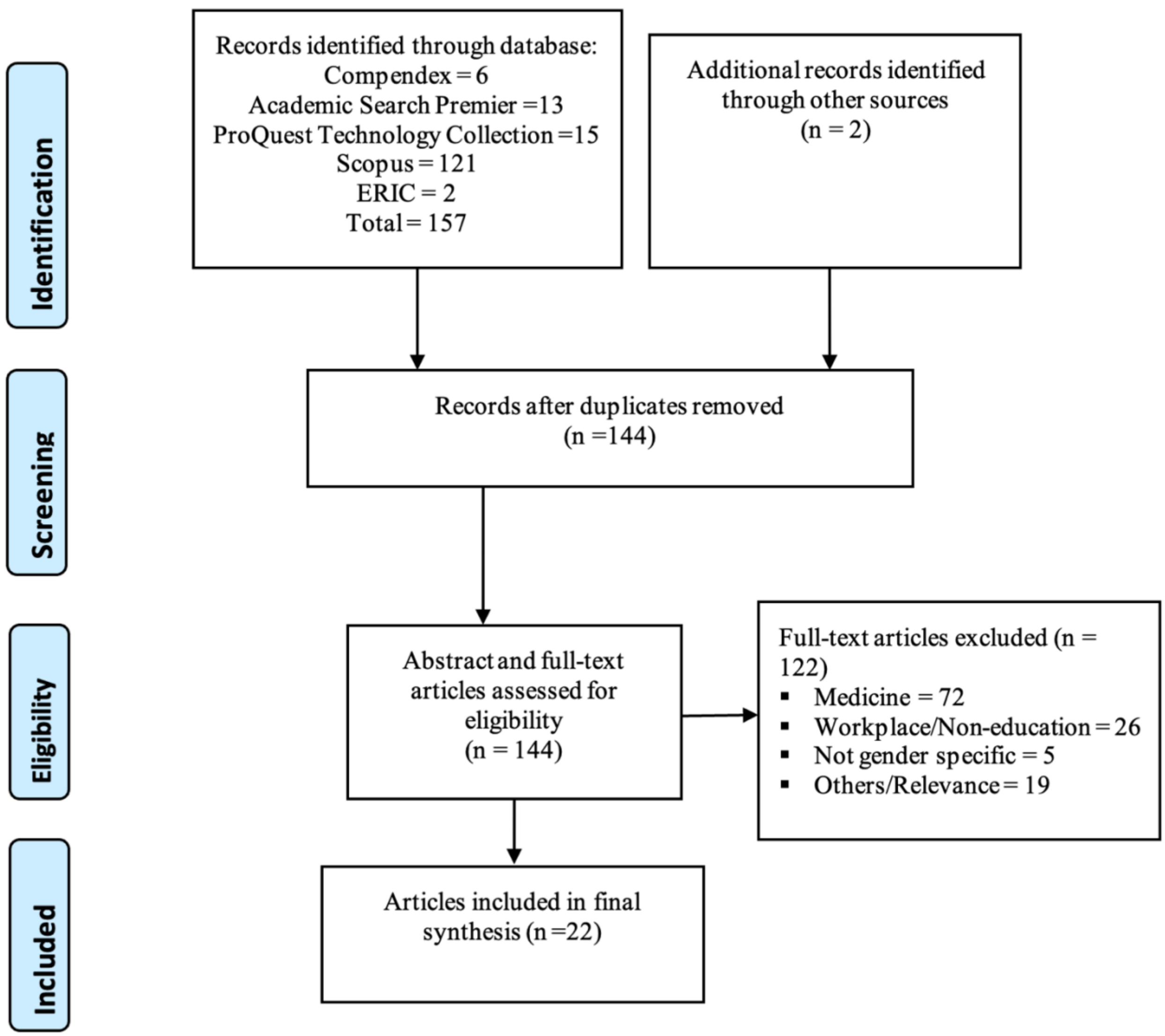

Table 3
List of 22 Scholarly Articles Included in the Final Systematic Analysis

Author (Year)	Title	Methodology	Theme (s)	Additional Notes
Acikel, Turhan and Akbulut (2018)	Effect of multitasking on simulator sickness and performance in 3D aerodrome control training.	Time-series design, quasi-experiment, simulator training, ANOVA.	Characteristics of flight students	This study was not directly related to the issues of gender in collegiate aviation. It shows characteristics of Air Traffic Control (ATC) in training.
Carretta, King, Ree, Teachout and Barto (2016)	Compilation of cognitive and personality norms for military aviators	Multidimensional Aptitude Battery (MAB-II) test and NEO Personality Inventory- Revised (NEO PI-R)	Personality differences, cognitive abilities	Sample include pilot trainees: Military pilot trainees, ROTC, and USAF cadets. Does not address gender differences in aviation education
Clark (2006)	The face of collegiate aviation: Factors impacting self selection of collegiate aviation programs	Survey Chi-square analysis	Passion for aviation, WAI presence; mentorship, scholarships, similar gender faculty.	
Davey (2004)	The impact of human factors on Ab Initio pilot training	Discourse association, Foucauldian analysis, Interviews	Attitudes towards female pilot trainees, use of gendered language, military aviation, masculine culture, risk averseness, gender stereotypes, lack of role models.	This article focused on application of human factors in pilot training and how different aviation professionals, including pilots in training view human factors.
Depperschmidt and Bliss (2009)	Female flight students: Perceptions of barriers and gender biases within collegiate flight programs	Structured questionnaire. Descriptive statistics	Mentorship, parental/family guidance, college recruitment, female staff in the program(mentorship), cost of training, recruitment and retention of female students, education and outreach program, funding, masculine culture, lack confidence in their abilities, strain from course load.	

Table 3. continued. List of 22 Scholarly Articles Included in the Final Systematic Analysis

Author (Year)	Title	Methodology	Theme (s)	Additional Notes
Dittmer (2009)	Evaluating Multimedia Exposure on Pass Rates of Private Pilots	Questionnaire. Post-test only control. t-test; Chi-square test, One-way ANOVA: Scheffe multiple comparison test.	None applicable	This study does not relate directly to gender/female students. The sample used consists of female students.
Ferrel, Carney, and Winter (2011)	Risk perception analysis of a small aircraft transportation system	Survey (Questionnaire) Chi-Square analysis.	None applicable	Sample consists of university faculty only
Furedy (2019)	Gender differences and their relation to hazardous attitudes in pilot training	Standard questionnaire - New Hazardous Attitude Survey (N-HAS) Statistical analysis using SPSS T test Paired t-test ANOVA MANOVA.	Decision-making habits, females tend to adjust to fit gender norms, gender role expectations, pilots' behavior.	Study focused on flight training and decision making between female and male students.
Germain, Herzog, and Hamilton (2012)	Women employed in male dominated industries: lesson learned from female aircraft pilots, pilots in training and mixed gender flight instructors.	Survey. Content analysis	Mentorship, traditional gender roles.	Sample consisted of small part of women flight students
Halleran (2019)	Gender Balance in Aviation.	Conference Proceeding – Paper in review.	College recruitment, outreach programs, mentorship, summer camps and workshops, STEM advocacy.	
Ison (2009)	Have we made progress: Trends in minority participation?	Industry statistics	Mentorship, recruitment, collaboration with industry.	

Table 3. continued. List of 22 Scholarly Articles Included in the Final Systematic Analysis

Author (Year)	Title	Methodology	Theme(s)	Additional Notes
Ison (2010)	The future of women in aviation postsecondary education.	Industry statistics	Mentorship	
Ison, Herron and Weiland (2016)	Two decades of progress for minorities in aviation	Historical data analysis, Chi-square test Z test.	Diversity in STEM programs.	Graduation rate. This study focused on women graduating from aviation colleges as a subgroup of minority groups
Lancia (2017)	"We can and will do it" Female perceptions of pilot as a career	Qualitative study; Interviews	Awareness of aviation, suitability of aviation careers and gender discrimination.	
Lu, Gao, Wang, Bai, Wang, and Wu (2018)	80 Years education of aerospace science and technology in Tsinghua University.	Historical data analysis	None applicable	
Lutte (2018)	Aviation outreach model and gap analysis: Examining solutions to address workforce shortages	Aviation outreach model. Gap analysis	Recruiting youth, outreach programs, mentorship and role models, affiliate organizations.	
Main, Johnson, Ramirez, Ebrahiminejad, Ohland and Groll (2020)	A case for disaggregating engineering education research: The relationship between Co-Op participation and student academic outcomes.	Logit Regression Analysis	Participation in training programs e.g., Co-Op	Study focused of all engineering programs. Sample consists of aerospace engineering female students.
Mattson, Johnson, Olson, and Ferguson (2007)	Gender and multicultural curriculum issues for undergraduate aviation students	Survey questionnaire.	Promoting diversity.	
Scharf and Cross (2019)	Analysis of low time pilot attitudes in University Aviation Association member flight schools.	Standard questionnaire; Survey, factorial analysis.	Self-confidence, pilots' behavior	This study is not directly related to flight education and gender imbalance

Table 3. continued. List of 22 Scholarly Articles Included in the Final Systematic Analysis

Author (Year)	Title	Methodology	Theme(s)	Additional Notes
Sutton, Buset and Keller (2014)	Navigation experience and mental representations of the environment: Do pilots build better cognitive maps?	Simulator training / Virtual Reality.	None applicable	Sample includes female students in flight schools.
Walton and Politano (2016)	Characteristics of general aviation accidents involving male and female pilots	Archival accident data/document analysis. Test of significance (Z test)	Pilots' behavior - Risk averseness and attitudes	This study addressed pilots' behavior such as tendency to take risks. Not directly related to flight education

RQ1. Which aspects of gender imbalance and perceptions of female students in college aviation and aerospace programs are addressed in current literature?

The findings of this study show that there is a dearth of literature that focuses on gender imbalance in collegiate education. In some instances, gender imbalance in collegiate education is included as a sub-section of a larger study (e.g., Dittmer, 2009; Sutton et al., 2014; Ison et al., 2016). Specialized fields of aviation and aerospace education are the least studied. For instance, Main et al. (2020) was the only study that mentions female students in aerospace engineering degree programs, and Açıkel et al. (2018) was the only study that included a sample of female students majoring in Air Traffic Control (ATC) studies.

Mentorship, diversity, college recruitment, and retention appeared most frequently in the existing literature. Mentorship is mentioned in six of twenty-two scholarly papers analyzed. In all instances, mentorship is highlighted as a potential solution to increase enrollment of women in aviation degree programs. Lack of diversity is highlighted as one of the areas of improvement for aviation programs. College recruitment and retention is a suggested solution for increasing the participation of women and other minority groups.

The perception of participation of women in aviation careers does not differ between women and men. Specifically, women enrolled in college aviation programs perceived a career in aviation the same way as their male counterparts. For example, Clark (2006) found that women in-flight programs are as passionate about flying as their male counterparts. Deppershmidt and Bliss (2009) found that women do not leave aviation programs because they are incapable of completing the course requirements. Davey (2004) reported that female cadets were perceived as more likely to succeed if they demonstrated 'type A' personality that is associated with men.

RQ2. What factors have contributed to the current gender gap in aviation and aerospace education?

Research Question 2 sought to identify factors addressed in the twenty-two scholarly articles that may have contributed to the current gender imbalance in aviation and aerospace education.

Theme 1. Lack of mentorship, role models, and networking opportunities

The current gender imbalance in aviation and aerospace education may be attributed to a lack of mentorship and role models in aviation and aerospace professions. Six of 22 articles emphasized identifying a role model and mentorship as challenges for female students. According to Clark (2006), women reported that the presence of WAI on campus is one of the factors that attract female applicants to colleges. WAI provides an opportunity for youth to connect and receive mentorship from experienced female professionals. Several studies (Davey, 2004; Deppperschmidt & Bliss, 2009; Germain et al., 2012; Halleran, 2009; Lancia, 2017) referenced mentorship, role models and networking opportunities as key to attracting young girls to aviation and aerospace careers. Deppperschmidt and Bliss' (2009) study of 262 female flight students from 18 four-year and 12 two-year colleges reported that 50% of the students had no female aviator role models before choosing to pursue flight training. In the same study, less than five percent of the respondents had female flight instructors or flight administrators holding a senior flight management position (e.g., director, manager, or chief flight instructor) in their flight programs. Lancia (2017) reported that flight students in Canada lacked adequate knowledge of professions in the industry, while experienced female professionals described their career paths as lonely. DeLisi et al. (2011) emphasized the importance of collaboration with professionals and peer/near-peer mentorship relationships, which could potentially bridge the gap between industry and schools/educators.

Theme 2. Recruitment, retention, and outreach programs

Four of the 22 articles address recruitment and retention as contributing factors for gender imbalance in aviation programs. In a summative study of the 30 collegiate aviation programs, Depperschmidt and Bliss (2009) reported that 98% of the respondents indicated that their flight programs consisted of less than 25% female students, and 70% had less than 10 percent female students. In addition to the inadequate recruitment practices, little follow up is done to ensure the few enrolled female students are retained in the programs. According to Lancia (2017), besides creating awareness on aviation and aerospace career paths for youth, additional measures need to be taken to retain women in aviation programs. In the study conducted in Canada (Lancia, 2017), several female flight students expressed concerns that no one had ever asked about the challenges they faced as female pilots in training. Collaborative working and mentorship were identified as great opportunities for attracting girls into aviation and aerospace education (DeLisi, 2011), for example, a collaboration between high school students, college students, and industry professionals.

Theme 3. Lack of diversity in STEM education

Despite more women being enrolled in colleges and universities, enrollment of women in STEM degrees is lower than that of men. A study of 20 years of data on the participation of minorities (including women) in the aviation industry (Ison, 2010) reported that total minority enrollment in colleges increased to 22.2% in 2014 from 16.5% in 1997. Notably, while there was an increase in the general minority groups, the numbers for women were reported to be decreasing. In addition, the number of women enrolled in four-year professional flight programs was the lowest among all aviation professions in aviation higher education. Halleran (2019) proposed that “universities and colleges should establish outreach programs that promote female STEM awareness as well as establish industry relationships to create collegial partnerships that lead to recruiting female students” (para. 1). Increasing awareness of STEM careers was the focus of one study (DeLisi et al., 2011). According to DeLisi et al. (2011), early exposure to STEM education can help women to persist through a career in STEM education.

Theme 4. Gender stereotypes and traditional women's role

The study of power effect on human factors in a cadet training program (Davey, 2004) found that the few women who made it to the program were often described as ‘good communicators’, ‘obedient’, ‘responsible’, and ‘less likely to take the risk’. Lancia (2017) identified the suitability of aviation as a career as a concern for female students in Canada. According to Germain et al. (2012), most women do not enroll in flight training with the goal of becoming professional commercial pilots, instead, women are more interested in flight to fulfill a childhood dream or because they think it is a fun experience. This finding contrasts with the findings by Clark (2006) who posited that students in four-year aviation programs enroll with the goal of training to be commercial airline pilots, regardless of gender.

Theme 5. Masculine culture in the aviation and aerospace professions

Women who choose careers in male dominated industries are associated with masculinity or “type A” personality (Davey, 2014; Lancia, 2017). According to Davey (2014), women who choose careers as pilots are expected to display masculine qualities to ‘fit in’. “Female ab initio pilots are perceived as competent because they have to survive in a male dominated environment” (Davey, 2004, p. 640). In the study by Germain et al. (2012), female students said they felt that plane seats in training aircraft were uncomfortable. Nonetheless, while more women have joined the flight profession, aircraft designs have not changed to accommodate the female physique. This gender bias is also expressed by 53% of the students in the study by Depperschmidt and Bliss (2009). According to Depperschmidt and Bliss (2009), many students believed there exists a gender bias in their collegiate flight programs whether knowingly or unknowingly. As one student states in the Depperschmidt and Bliss (2009) study, gender gaps may exist not because of the gender bias but because it has been the norm for the industry.

Discussion

The objective of this study was to systematically identify scholarly literature on gender imbalance in collegiate aviation and aerospace education, identify aspects of gender imbalance and perceptions of female students addressed in current literature, and identify factors that may be contributing to gender imbalance in collegiate aviation and aerospace education. The findings of this study show that there are few studies that have focused on gender imbalance in collegiate aviation and aerospace education for the period between January 2004 to May 2020. Furthermore, in the last three decades, representation of women in aviation and aerospace education has remined low. The small numbers of women in aviation and aerospace education may be attributed to challenges that have persisted in the aviation and aerospace industry for decades. For instance, gender stereotypes and the misconception that aviation and aerospace careers are for men only. Although women have demonstrated passion and capability as competent aviation and aerospace professionals, the profession remains male dominated. The paucity of studies that focus on gender imbalance in collegiate aviation and aerospace education are consistent with the findings of Ison et al. (2016).

The findings of this study show that gender stereotypes and persistent masculine culture are among the factors that may be contributing to gender imbalance in aviation and aerospace education. Whereas female students perceive themselves as capable of pursuing careers in aviation and aerospace professions, other parties may not perceive them in the same way (Carretta et., 2016; Davey, 2004). Women are expected to behave a certain way to be considered competent aviation and aerospace professionals. Surprisingly, qualities such as ‘good communicator’ and ‘listener’ that are associated with a good pilot are only used to describe female pilots but not their male counterparts (Davey,2004). The viewpoint that some career paths are for females and others for males is outdated. To bridge the current gender gap in aviation and aerospace collegiate education, all stakeholders should take measures to eliminate gender stereotyping and promote a positive culture where female students feel welcome to pursue careers they are passionate about.

As indicated by themes one to three, measures are needed to increase mentorship, increase recruitment and retention, and promote STEM careers for women in male-dominated career paths. While there are initiatives directed towards increasing the participation of females in aviation and aerospace careers, more proactive measures are needed to close the current gender gap in collegiate aviation and aerospace education. For example, collaborations between schools and industry may bridge the gap on mentorship as more youths will have opportunities to interact with successful female professionals. Furthermore, colleges and universities should actively aim to recruit female students to their programs. In addition, companies, colleges, universities, and all pertinent parties should actively try to eliminate the masculine culture that is so persistent today.

Given the recent policy developments including the establishment of the Women in Aviation Advisory Board by the FAA (FAA, 2020), this study is timely. To bridge the current gender gap in aviation and aerospace collegiate education, it is crucial to understand how women are perceived in aviation and aerospace careers, and factor that may be contributing to the persistent gender gap in the field. The findings of this study may be used by colleges and universities recruiters and policymakers to promote gender balance in collegiate aviation and aerospace education.

Limitations

The limitations of this study include, firstly, the number of females included in most scholarly articles in the systematic literature review was significantly small. Therefore, the studies may not be reflective of the true picture of all females in all aviation and aerospace programs. Secondly, the scholarly articles considered for this systematic review were published between January 2004 to May 2020. Studies have been published since May 2020 that may show new findings.

Conclusion and Recommendations for Future Studies

This systematic literature review examines the current gender gap in aviation and aerospace collegiate education. Twenty-two peer reviewed journal articles were systematically identified from five databases and analyzed. The findings of the study suggest that women perceive themselves as competent and capable of pursuing careers in aviation and aerospace field however, other parties may perceive women differently. The authors identified five major factors that may be contributing to the current gender gap in collegiate aviation and aerospace education. The findings of this study may be useful to college and university recruiters and policy makers looking to increase enrollment of women in aviation and aerospace college programs. Researchers of this study recommend that future research should focus on gender imbalance in aviation and aerospace education as the primary topic. For instance, an analysis of the trends in enrollment of women in aviation and aerospace programs. Future studies may also focus on women in specific aviation and aerospace specializations such as aerospace engineering or aerospace engineering technology.

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The Current State of Safety Reporting in Unmanned Aircraft Maintenance and Manufacturing: An Opportunity for Improvement

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Currently, unmanned aircraft system (UAS) safety reporting processes regarding maintenance and manufacturing-related hazards are nearly non-existent or immature. A review of recent UAS safety reporting data suggests the overall reporting of UAS incident and accident data needs to improve. In addition, the accelerating growth of UAS innovation requires more robust processes that proactively identify product-related defects or failures and support the FAA's performance-based certification of UAS. This review explores current programs used in traditional aviation and other industries to identify best practices that may provide a path forward for developing similar programs for the UAS industry. First, this review compares existing manned aviation safety reporting and risk management procedures with the current state of safety reporting in the UAS industry. Second, this review explores the safety reporting processes of different industries such as automotive, consumer electronics, and the food and drug industry. Third, researchers reviewed safety risk data from the UAS insurance industry, including a cost comparison of insurance premiums and coverages. Ultimately, this review suggests practices and strategies that may improve safety reporting in the UAS industry.

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Safety reporting is an integral part of high consequence industries such as healthcare, nuclear, and aviation (Lercel, 2013). NASA and the FAA first established the foundation of aviation safety reporting in 1976 with the inception of the Aviation Safety Reporting System (ASRS) (FAA, 2021b). Fast forward to today when UAS operations are increasing exponentially and close to 863,000 UAS are registered in the United States (FAA, 2021d). With the influx of UAS operations, there is a need for a more robust safety reporting process for UAS manufacturers and maintenance providers (GAO, 2019; Greenwood, 2021; Speijker, 2018; Weldon et al., 2021).

To gain perspective of the current state of reporting in the UAS industry in comparison with related industry segments, researchers reviewed literature associated with safety management and reporting. Specifically, this effort explored safety management systems (SMS) for non-part 121 operators (FAA, 2015), safety reporting in manned aviation and other high consequence industries, and the current state of safety reporting for commercial UAS. This research draws comparisons of these processes and highlights some potential best practices that may serve as a starting point for the UAS industry.

Literature Review

A review of the literature initially considered SMS for non-part 121 operators and FAA's manufacturer failure, malfunctions, and defect reporting. To better identify and rectify such safety issues, the FAA may issue airworthiness directives (ADs) as corrective actions, which are legally enforceable regulations.

SMS for Non-Part 121 Operators (FAA)

An SMS program for non-Part 121 operators was created by the FAA in 2015 "to voluntarily develop and implement an SMS" (pp. 1, FAA, 2015). The SMS is comprised of four components and 12 elements (FAA, 2015), mainly safety policy, safety risk management, safety assurance, and safety promotion. These components provide an adequate basis to manage hazards, comply with the high safety standards of the aviation industry, and maintain safety throughout the organization. In addition, an SMS goes beyond preventive measures and instills a predictive approach to managing safety. However, of the approximately 5,012 FAA certificated aviation service providers (FAA, 2021c), less than 5% are currently enrolled in the FAA's Voluntary SMS Program, and no UAS service providers are enrolled (Roberts, 2021).

FAA Manufacturer Failure, Malfunctions, and Defect Reporting

The FAA first established a manufacturer failure, malfunction, and defect reporting process in 1970 through Advisory Circular (AC) 21-9. In 1982 the FAA issued a revision (21-9A) to the AC, which included a requirement that any holder of a type certificate, parts manufacturer approval (PMA), or a technical standard order (TSO) authorization, and licensee of a type certificate to notify the FAA of any failure (FAA, 1982, pp.1). Subsequently, a second revision to this AC (21-9B) broadened this requirement to include manufacturers of aeronautical products (FAA, 2010). Below is an outline of this FAA reporting process (FAA, 2010, p. 2).

a) "Ensure an understanding of the rules,"
b) "Establish the most expeditious means of conveying the required information in a manner and form acceptable to the FAA,"
c) "Determine the person(s) to be contacted,"
d) "Establish a means of keeping the appropriate FAA office informed of progress and providing additional information on those cases where only preliminary information has been reported."

Leveraging the aspects of manned aviation and applying them to unmanned may be an effective strategy in developing a similar UAS reporting structure. UAS registration data under Part 107 may be considered a starting point for a reporting failure database and help in establishing a UAS reporting program for manufacturers and maintenance providers – assisting both the manufacturers and the FAA in managing product-related safety issues.

Airworthiness Directives (ADs)

The FAA states, "Airworthiness Directives (ADs) are legally enforceable regulations issued by the FAA in accordance with 14 CFR part 39 to correct an unsafe condition in a product. 14 CFR part 39 defines a product as an aircraft, engine, propeller, or appliance" (FAA, 2021). Manned aviation has enhanced the process of carrying out corrective actions based on failure reports. The FAA scrutinizes these reports, which may result in a corrective action of an unsafe condition through the issuance of an AD (FAA, 2002). This reporting process and the resulting corrective action plan contribute to an ongoing assurance that a product is safe.

Currently, the UAS segment of aviation lacks many of the safety reporting processes found in traditional aviation, such as product failures and defects. This is not unexpected given the technological advances and rapid adoption of UAS. However, as the proliferation of UAS increases, so too does the need for strategies that address unsafe conditions associated with UAS products, such as the Unmanned Aerial Vehicle (UAV), the ground control station (GCS), or software. By better identifying unsafe conditions related to UAS products, these processes may contribute to an acceptable level of safety in the National Airspace System (NAS).

Developing processes that support the reporting of product failures and defects improves safety practitioners' ability to proactively identify and address these hazards and risks. Building upon this process, practitioners may capture reports from consumers, maintenance providers, and insurance companies more broadly. Assessment of manufacturer-provided information, coupled with failure, malfunction, and defect reports, may help the FAA formulate a data-driven approach for managing risks associated with UAS products, such as the newly developed regulatory policies regarding UAS flight over people and anticipated beyond visual line of sight operations. These policies are heavily dependent on product reliability data to support future approvals (FAA, 2019).

UAS Safety Reporting

The Center for Unmanned Aircraft Systems for Public Safety stated in 2018 that "the issues of UAS legality, safety, and technology are just now beginning to be explored, largely because of the scarcity of data available. Key to the evaluation process is the process of reporting and data collection" (GAO, 2019; Greenwood, 2021; Speijker, 2018; sUAS in Public Safety, 2018; Weldon et al., 2022). The FAA established a Part 107 accident reporting system through its UAS-specific website, FAA DroneZone (14 CFR Part 107, 2021). Recently, FAA and NASA established a reporting system for UAS through NASA's ASRS system. The following section reviews the FAA DroneZone and the newly integrated ASRS UAS safety reporting process, followed by a discussion on safety reporting in other industries.

The FAA DroneZone enables Part 107 operators to report accident reporting, whereby law the UAS operator must submit a report under the following circumstances (14 CFR Part 107, 2021),

1. If serious injury to any person or any loss of consciousness occurs,
2. The incident results in damage to any property, other than the sUAS unless one of the following conditions is satisfied,
   a. The cost of repair (including materials and labor) does not exceed $500,
   b. The fair market value of the property does not exceed $500 in the event of total loss.

Even though the DroneZone provides a platform to report UAS accidents, it is only for incidents that occur during operations that meet a minimum reporting threshold. This reporting structure likely does not capture less severe incidents, which are often precursors to more severe events (Reason, 2016). Furthermore, the DroneZone is not explicitly intended for manufacturers and maintenance providers to report product defects or failures.

A more formal UAS safety reporting process was introduced into NASA's ASRS reporting program in April 2021 through advisory circular AD-00-46F (FAA, 2021a). The advisory was to encourage the users of the NAS and other people to report UAS-related safety incidents. This reporting system is open for all types of UAS operators, such as recreational flyers, Part 107 crews, public operators, and Part 135 operators (ASRS, 2021). Users can report incidents such as "Collision or Near Mid Air Collision with another UAS, Aircraft, or Object, Equipment Issues (hardware/software/automation), Lost Link, Fly Away, Uncontrolled Descent, Airspace Incursions (e.g., Flying too close to an airport), Environmental Hazards, Miscommunication, Procedural Issues, Human Error / Mistakes, and Injuries" (ASRS, 2021). Although this new ASRS reporting process is a positive step towards improving UAS related safety reporting, like the DroneZone, it lacks the focus and specialization of the current FAA product defect reporting process used in manned aviation.

A review of the recent ASRS reports suggests an in-flight component failure caused only two UAS incidents. These events included a loss of link and structural fatigue cracks on the UAS (2021). Even though the ASRS safety reporting system enables reporting of UAS operations, there is no means to track data by UAS manufacturers. The ASRS reporting system also provides UAS operators similar protections as manned operators, which states "protection against civil penalty and certificate suspension in exchange for filing an ASRS report as this is indicative of a constructive attitude which will tend to prevent future violations" (ASRS, 2021). These reporting protections are a positive development and may help encourage more UAS reporting in the future.

One potential issue is that the FAA DroneZone and the ASRS systems may be perceived as duplicative by UAS stakeholders and may lead to confusion regarding the reporting requirements and where to report. For example, it is unclear if the ASRS reporting system fulfills the FAA regulatory reporting requirements or if this information must be reported via the DroneZone. In addition, it is unclear if these two databases are inter-connected – meaning does a report submitted to DroneZone also populate in the ASRS database. A review of these reporting formats found significant differences in the reporting forms, which suggests they likely do not cross populate. A review of reports across these databases also found no cross population of reports. The overall UAS reporting structure may be improved by ideally developing a single point of reporting or at least connecting the DroneZone and ASRS reporting systems to allow for a cross population of data. This combined reporting structure may then have a common reporting platform, which streamlines the process and allows for a single information source that supports a more robust safety library. In addition, developing a single system of reporting may reduce the administrative costs of supporting multiple systems (Lercel, 2013).

UAS defect, malfunction, and failure data will increasingly become a vital source of information for safety practitioners to manage safety risks, mainly as operational complexity further develops (i.e., drone delivery, air taxi, etc.). In addition, this type of data is essential in supporting the FAA's move towards performance-based decision-making with regards to UAS product and operational certifications (14 CFR Part 21, 2018). However, hazardous UAS situations arising from component issues are not widely documented nor communicated. Due to the absence of a historical database, UAS regulators and consumers are often left to rely solely on the manufacturers' after-sale customer service for product defects and associated corrective actions. Currently, safety-related decisions related to regulatory waivers or advanced UAS operations are often based primarily on the applicant's operational safety risk management plan and their experience or qualifications (14 CFR Part 107, 2021; FAA, 2022b) – often the actual manufacturer's product reliability and testing data, performance record, or technical specifications are not considered in the decision to approve or deny the application.

Safety reporting processes of Other Industries

This research reviewed the safety reporting process of the automotive, food and drug, and consumer electronic industries. This review may further assist in developing a similar safety reporting process for UAS.

National Highway Traffic Safety Administration (NHTSA)

The National Highway Traffic Safety Administration (NHTSA, 2021c) is tasked with the primary regulatory oversight of the automobile industry in the United States (Rupp & Taylor, 2002). Therefore, researchers reviewed these applicable policies to gain perspective of the automotive industry's safety reporting process.

The NHTSA defines a safety defect as "a problem that poses a risk to motor vehicle safety and may exist in a group of vehicles or equipment of the same design and/or manufacturer" (NHTSA, 2021a). Manufacturers and customers may report safety issues to the NHTSA regarding automotive parts or components such as seats (child and adult), tires, vehicles, and after-market equipment. The safety report is then stored in a dedicated database by the NHTSA. The vehicle safety reporting process is as follows,

1. Complaints: The first step of the reporting process is to file a complaint. Vehicle users can report an issue by submitting a voluntary form through the NHTSA website (NHTSA, 2021b).
2. Investigation: The NHTSA then reviews the complaints to determine the course of the investigation. They analyze the respective complaints and decide whether to accept or deny the petition. An accepted petition is then investigated and has two significant outcomes: a recall recommendation or a finding of no safety-related defects (NHTSA, 2021b). The investigation stage is divided into preliminary evaluation (PE) and engineering analysis (EA). The PE process takes up to 4 months with three possible outcomes: recall, close, or upgrade (NHTSA, 2021b). The EA process includes a detailed technical analysis, which may result in the issuance of a product upgrade. During the EA process, the NHTSA physically inspects the vehicle and conducts safety testing, which may take up to 12 months (Rupp, 2004).
3. Recall Management: The NHTSA supervises the recall process in this final step. It ensures that the vehicle owner is notified of the recall recommendation and tracks the completion of each recall (NHTSA, 2021b).

The manufacturer must notify the NHTSA in writing when initiating a voluntary recall (Rupp, 2004). When the NHTSA is notified, they post these notifications to a publicly available database (Rupp, 2004). The NHTSA also requires the manufacturer to notify the vehicle owner via mail within 60 days of the report. The NHTSA then monitors each recall and oversees its completion.

Consumer Product Safety Commission

The Consumer Product Safety Act established the Consumer Product Safety Commission (CPSC) to protect the public against unreasonable risks of injury associated with consumer products; assisting consumers in evaluating the comparative safety of consumer products, developing uniform safety standards for consumer products; and promoting research and investigation into the causes and prevention of product-related deaths, illnesses, and injuries. (Reczek & Benson, 2021, pp. 2). The CPSC's handbook defines the following safety reporting process (CPSC, 2012),

1. Reporting: The manufacturer, importer, distributor, or retailer is responsible for reporting safety issues to the Office of Compliance and Field Operations (CPSC, 2012). The concerned entity can submit reports on the CPSC website. This reporting form is distinct for consumers and manufacturers.

2. Identification: The defect identification process primarily relies on the reporting entity to provide information on the issue. Such information assists the CPSC in the evaluation process and is used to identify the hazard to consumers (CPSC, 2012).
3. Evaluation: The defect evaluation process involves determining risks associated with the hazard. The CPSC (2012) categorizes hazards into,
   a. Class A: "Exists when a risk of death or grievous injury or illness is likely or very likely, or serious injury or illness is very likely" (CPSC, 2012, pp. 14).
   b. Class B: "Exists when a risk of death or grievous injury or illness is not likely to occur but is possible, or when serious injury or illness is likely, or moderate injury or illness is very likely" (CPSC, 2012, pp. 15).
   c. Class C: "Exists when a risk of serious injury or illness is not likely but is possible, or when moderate injury or illness is not necessarily likely, but is possible" (CPSC, 2012, pp. 15).
4. Correction: Concerned companies are responsible for developing a corrective action plan.
5. Communication: Companies are then advised to use multiple modes of communications to inform customers about product defects and recalls, such as email, ground mail, phone, etc.
6. Monitoring: Once the customers are informed of the recall, companies must maintain a record of each recall in accordance with the CPSC.
7. Policy Development: Companies must develop an organizational policy and action plan to manage product recalls.
8. Records Maintenance: The company must maintain a record of the corrective actions and the product.

Researchers reviewed the CPSC database for any reports related to UAS or drones. This review found only three related incident reports (CPSC, 2022).

TÜV SÜD

TÜV SÜD is an international organization that develops safety standards that may apply to various products. According to a report by TÜV SÜD (2019), consumers are becoming increasingly aware of such safety standards and ratings. As it applies to this research, TÜV SÜD also conducts "drone testing and certifications," wherein they evaluate various aspects of the UAS. These aspects of testing include electrical, batteries, functionality, environmental, mechanical, chemical, and radio frequency/wireless testing (TÜV SÜD, 2021). This testing is intended "to minimize the risk of non-compliance and product liability" (TÜV SÜD, 2021).

Underwriters Laboratories (UL)

Similar to TÜV SÜD, UL is an organization that helps companies "demonstrate safety, enhance sustainability, strengthen security, deliver quality, manage risk and achieve regulatory compliance" (UL, 2021). With regards to UAS, UL recognized the increase in commercial applications and developed UAS safety standards. For example, in 2018, the UL developed the UL 3030 safety standard, which focuses on UAS electrical systems and batteries.

Consumer Electronics Industry

The consumer electronic industry has a broader safety reporting scope and includes private entities. In addition to CPSC oversight, Underwriters Laboratories (UL) and TÜV SÜD also conduct safety tests, create standards, and provide product certifications for consumer electronics.

Food and Drug Administration (FDA)

Another industry this research explored is the Food and Drug Industry. The US Food and Drug Administration (FDA) is the authority responsible for “protecting the public health by ensuring the safety, efficacy, and security of human and veterinary drugs, biological products, and medical devices” (FDA, 2018). Accordingly, the FDA established a reporting process for adverse hazards or issues associated with medicine and food in the United States. Apart from reporting problems, the FDA also enables people to report emergencies, non-emergencies, and unlawful sales of medical products.

FDA Mandatory Medical Devices Reporting

Manufacturers, importers, and users (such as hospitals, clinics, etc.) of medical devices are required to file a report regarding issues and adverse events related to these devices (FDA, 2020). Reports are filed on the MedWatch portal by submitting Form 3500 A. Manufacturers and importers have 30 days to report serious injuries and malfunctions and five days to report hazardous conditions and risks that may be eliminated or reduced by some preventive action (FDA, 2020). The regulatory requirement for this reporting is outlined in 21 CFR Part 803 (2021). The FDA reviews these reports, and information regarding product withdrawals, recalls, and safety alerts are issued in the form of press releases and public notices (FDA, 2021).

Risk Management in the Insurance Industry

Next, this research explores risk management in the insurance industry. Increasingly, customers require commercial UAS operators to have proper liability insurance. Generally, insurance companies provide coverage for damages or losses caused by the UAS (liability), while some provide additional coverage for damage or loss of the UAS itself (hull). The need for insurance companies to have a formal and robust risk management process became prominent after the 2008 global financial crisis (NAIC, 2021) when companies incurred significant financial losses.

Researchers reviewed a sample of risk management processes UAS insurance providers may prefer or require as part of their process of assessing risk in organizations. Some of these processes are listed below as defined by Global Aerospace (2021), which is a major UAS insurance provider in the United States.:

1. Training: UAS-related operations and safety training.
2. Safety Management: Documented safety management system along with various checklists and pilot flight logbooks.

3. Maintenance: Scheduled maintenance programs are conducted as per the manufacturer's instructions. Maintenance is to be done regularly to ensure the UAS is in a condition for safe operation.
4. Environmental Hazards: UAS operators shall have situational awareness of the operating environment before, during, and after the flight. Factors like wind, clouds, manned aircraft, and even people shall be considered.
5. Privacy Issues: Ethical use of UAS and safeguarding public privacy.

Furthermore, the literature found that insurance providers give historical data the most significant weight when analyzing risks. Therefore, researchers contacted three UAS insurance providers to gain perspective on the cost to insure a popular model of UAS. Researchers used the following basic criteria when requesting this insurance coverage and premium pricing:

1. Hull coverage for a DJI Mavic 2 Enterprise valued at $2,000.
2. $1M liability coverage (bodily injury and property damage).
3. Commercial operations in accordance with FAA CFR Part 107.

A summary of the received cost quotations is provided below in Table 1.

Table 1
Hull Insurance Premium of DJI Mavic 2 Enterprise

Entity	Insured Value of UAS	Deductible	Premium
Insurer 1	$2,000	$280	$160
Insurer 2	$2,000	$200	$192
Insurer 3	$2,000	$250	$180

Researchers referenced the DJI Mavic 2 Enterprise in their insurance application. In addition, researchers reviewed industry resources to identify any risk assessment of UAS products by the insurance industry but were unable to find a publicly available database. These providers likely maintain such data but consider it proprietary as it may provide them a competitive advantage. However, a system that encourages data sharing across organizations may provide safety practitioners a powerful source of information that supports more robust safety risk management across the UAS community (FAA, 2019).

Discussion

This research reviewed various safety reporting processes used in the automobile, consumer electronics, manned aviation, and food and drug industries. Reviewing the safety reporting processes of other industries, UAS safety practitioners may identify best practices that help create similar safety reporting processes for UAS. As discussed earlier, further maturation is required for UAS safety reporting to approach the performance level of manned aviation. Reviewing the literature and current data regarding UAS-related failures, researchers found a deficient number of reports; therefore, one may conclude that the UAS safety reporting processes, for various reasons, are underutilized or ineffective (GAO, 2019; Greenwood, 2021; Speijker, 2018; Weldon et al., 2021). For example, the ASRS (2021) database search resulted in only 13 reports over an eight-month period, which is significantly lower than manned aviation over this same period and likely does not serve as a representative sample of the UAS population operating in the NAS. Further data queries of the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) database resulted in 104 UAS reports, with the latest report from August 2014 (FAA, 2022a). Requests for FAA DroneZone incident reports resulted in less than 30 reports. The literature discusses the importance of effective safety reporting as a critical component of a robust SMS; however, since no small UAS operators or manufacturers are enrolled in the FAA's voluntary SMS program (Roberts, 2011), this further suggests a lack of effective safety reporting across the industry.

With the ever-increasing number of commercial UAS applications, the FAA issuance of special airworthiness certifications for UAS has also increased, mainly in the experimental category (14 CFR Part 21, 2021). As part of this process, the FAA may review and assess any available UAS product reliability performance data before issuing an airworthiness certificate. Similar to other consumer products, UAS manufacturers are likely to perform some level of testing of their product prior to customer delivery, or what many may consider as self-certification (Perritt, & Plawinski, 2016). Additionally, the FCC requires some UAS to be tested with regards to transmitter power and frequency (Wiley Rein, 2021), such as the ground control station. These system tests and subsequent tests results may be reviewed by the FAA when considering the issuance of an airworthiness certificate. At their discretion, the FAA may request to witness the actual system testing (14 CFR Part 21, 2021). These performance-based test results may provide evidentiary data of an acceptable level of reliability and, by extension, an acceptable level of risk.

As the advantages of UAS are being recognized, companies are increasingly opting for special airworthiness certificates to conduct advanced operations or utilize larger and more complex UAS. However, to a large extent, this data, and any corrective action, is proprietary or simply not available to consumers or regulators. As more UAS-platforms are certified, consumers may have the ability to purchase these UAS based on their performance capabilities. With the increase in a performance-based model of certification, the need for a documented form of UAS defects, failures, and malfunctions data may prove beneficial. Data obtained from UAS defects, failures, and malfunctions may be utilized by UAS regulatory bodies to determine the reliability of a particular UAS system and proactively address any problems. Likewise, this data may help establish future airmen certification standards for those operating high-performance UAS, conducting complex operations, or maintenance technicians.

The ASRS UAS reporting process does provide the FAA a system by which they can capture a breadth of safety-critical information regarding UAS operation (ASRS, 2021), but these reports currently lack the attributes found in other industry reporting systems. For example, a review of the ASRS (2021) UAS reporting found no attributes regarding UAS related defects at the maintenance and manufacturing levels. However, other industries, including manned aviation, provide separate processes that support manufacturer defect reporting. Attributes such as risk evaluation have proven beneficial in a safety reporting process where safety practitioners may analyze these failures to proactively avoid similar issues in the future. Likewise, a system that supports UAS manufacturers' and maintenance providers' reporting of product defects and warranty information would enable a more informed safety risk assessment. Such data is an integral part of an SMS and may support a UAS airworthiness directive process – similar to what is currently used in manned aviation.

At present, UAS consumers have little information regarding product safety because there is a lack of transparency regarding UAS manufacturers' safety performance, such as product recalls, defects, warranty, and repair data - information that is often considered critical to commercial UAS operators and regulators. Most consumers are left to do their own product research, primarily through publicly available sources, such as any manufacturer websites, consumer magazines, or social media (Fisher, 2019; Krishnamurthy & Kumar, 2018; Mechanics, 2022; Park et al., 2007). From a safety management perspective, these types of data are unreliable, inefficient, and not conducive to supporting robust safety decisions. Making product safety data available to consumers and regulators through a more systematic process will likely help them in making more informed purchase and policy decisions, and spur UAS manufacturers to have a greater focus on the quality and safety of their products (Cicchino, 2014; Consumer Reports, n.d.; J.D. Power, n.d.; NHTSA, 2021c).

Limitations

This research comprehensively looked at different industry safety reporting processes and attempted to form a basis for UAS safety reporting, especially for manufacturers and maintenance providers. However, while the researchers carried out a comprehensive literature review and database search, they did not perform any actual UAS product evaluation or testing, which may be a limiting factor for this research. In addition, researchers were unable to obtain UAS manufacturer and maintenance warranty or repair data.

Future Research

As the number of commercial UAS operations increases, the need for a safety reporting process to report component defects, malfunctions, and failures may increase. Safety certification of all aspects of the UAS (electrical, mechanical, airworthiness, chemical, functional, and wireless) may reduce the risk of UAS malfunctions and defects. In the future, researchers anticipate a system where consumers and manufacturers may report issues regarding UAS components to the aviation regulatory body – encouraging the sharing of safety-related data. Such a database may assist federal regulatory agencies to better manage UAS-related risks. This system will support a proactive approach to safety through improved incident investigation and evaluation. The regulatory body may then publish corrective actions, like an AD, to reduce risks associated with a UAS and improve safe commercial operations. Further research is required to explore best practices in establishing a more effective UAS safety reporting process, subsequent corrective measures, and policies that encourage UAS stakeholders to report safety issues.

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Exploration of Natural Language Processing (NLP) Applications in Aviation

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As a result of the tremendous boost in computational power, the current prevalence of large bodies of data, and the growing power of data-driven algorithms, natural language processing (NLP) has recently experienced rapid progressions in multitudinous domains, one of which is aviation. In this study, we explore the current standing of NLP in aviation from the perspective of both research and industry. We identify safety reports analyses, aviation maintenance, and air traffic control as the three main focus areas of NLP research in aviation. We also list currently available NLP software and how they have been used in the aviation industry. Finally, we shed a spotlight on some of the existing challenges posed by the aviation domain on standard NLP techniques, discuss the current corresponding research efforts, and put forward our recommended research direction.

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Introduction

Natural language processing (NLP) is a subfield of artificial intelligence that deals with the computational processing of human or natural language. It is concerned with analyzing text or speech to automatically perform tasks like text classification, information retrieval, sentiment analysis, document summarization, and machine translation, ultimately leading to natural language understanding and natural language generation. With the growing capacity to gather enormous volumes of data, the continuous development of powerful data-driven algorithms, and the substantial increase in computational power, NLP has recently made giant strides in a wide variety of domains (Kalyanathaya et al., 2019; Roadmap, 2020), one of which is aviation.

The purpose and contribution of this study are to explore and synthesize the recent applications of NLP in the aviation domain. We opted for applications from 2010 through 2022 and used search terms like "NLP," "NLP in aviation," and "NLP software in aviation" to narrow down search results. Specifically, our study identifies three areas of application in aviation into which NLP research has been making inroads. The study also provides a list of existing NLP software and their current applications in the aviation industry. Lastly, we briefly discuss some of the current challenges faced by NLP in aviation and prospective future research directions.

NLP Research in Aviation

This section presents three application areas of NLP research in aviation: safety reports, aviation maintenance, and air traffic control. For each area, we provide a brief introduction followed by a summary of the research that has recently been ongoing.

Safety Reports

In aviation, an incident refers to any abnormal event that has either compromised the general safety of aviation operations (Tanguy et al., 2016) or could have progressed into an accident but did not. Incidents occur much more frequently than actual accidents (Dong et al., 2021; Tanguy et al., 2016). Reporting systems exist where people report the incidents or accidents as well as access their probable causes and risks (Buselli et al., 2021; Rose et al., 2020; Tanguy et al., 2016). These reports serve as an invaluable source of data whose quantitative analysis conduces to insightful statistics (Buselli et al., 2021; Dong et al., 2021; Tanguy et al., 2016) and can be used to uncover underlying trends (Kierszbaum & Lapasset, 2020; Tanguy et al., 2016;), patterns, and anomalies (Rose et al., 2020). The reporting systems permit the early discovery of potential threats to aviation safety so that preventative measures may be taken (Buselli et al., 2021; Dong et al., 2021; Tanguy et al., 2016). These systems may be used to pinpoint and examine the leading and contributory factors that culminate in the incident or accident, substantially paving the way for better-informed operational decisions and firm prevention plans (Dong et al., 2021; Tanguy et al., 2016).

From a pragmatic perspective, experts and safety managers need to briefly characterize each of the reports to realize analytical tasks on safety reports, generally through their manual assortment according to predefined taxonomies (Pimm et al., 2012; Tanguy et al., 2016). The process of manual categorization is inherently quite complex, error-prone, and resource-consuming (Buselli et al., 2021; Marev & Georgiev, 2019; Pimm et al., 2012; Tanguy et al., 2016). This is not only because of the breadth and perplexity of the taxonomies but also due to the increasing number of reports submitted (Buselli et al., 2021; Pimm et al., 2012; Tanguy et al., 2016) in correspondence to the expansion of commercial and private aviation industries (Dong et al., 2021). In consequence, a legitimate pressing demand for automating the analysis of incident and accident reports has risen (Buselli et al., 2021). Since the reports are in the form of free text written in natural language, with a few of them also incorporating supporting metadata presented in a predetermined, usually tabular, format (Buselli et al., 2021; Dong et al., 2021; Kierszbaum & Lapasset, 2020; Klein et al., 2021), advanced NLP techniques have recently been employed in this automation process (Marev & Georgiev, 2019; Tanguy et al., 2016).

Text Classification

One of the principal research directions has been to apply text classification techniques to categorize reports according to the cause of the incident or accident, making use of preset labels either extracted from existent taxonomies (Tanguy et al., 2016; Tulechki, 2015) or manually annotated by domain experts (Buselli et al., 2021). Such a classification problem (either single-label or multi-label) has been frequently tackled by training supervised machine learning (SML) models, like the support vector machines used by Tanguy et al. (2016), to associate each report with the appropriate label. A fundamental issue with SML algorithms is their reliance on the availability of large, labeled datasets for adequate training. To address this issue, Dong et al. (2021), Klein et al. (2021), and Marev & Georgiev (2019) attempted not to train a classification model from scratch but to utilize a well-trained language model (LM), like the RoBERTa model (Liu et al., 2019). They further fine-tuned the model for the classification task at hand, exploiting what the LM has already learned from its thorough pre-training on huge corpora of textual data. A different approach to handling the problem of scarce labeled training datasets was adopted by Madeira et al. (2021). They proposed a semi-supervised label spreading algorithm (Zhou et al., 2003) that propagates labels from the limited labeled dataset to the much larger mass of untagged data.

Topic Modelling

Even with a pre-trained language model or a semi-supervised learning technique, an immanent deficiency in the text classification process itself persists; it inherently cuts down on the amount and variety of information that can be extracted from reports and reduces the patterns that can be detected within the data (Buselli et al., 2021). This is because it relies on a fixed set of labels in a dynamic environment where new technological innovations emerge each day, calling for a more adaptive approach that is capable of detecting the novel risks introduced as a consequence (Pimm et al., 2012; Tanguy et al., 2016). The restrictiveness of the labels also stems from the fact that they are normally too broad to capture slight variations between events (Tanguy et al., 2016). On these grounds, Buselli et al. (2021), Kuhn (2018), Robinson (2019), Rose et al. (2020), and Tanguy et al. (2016) opted for topic modeling, an unsupervised clustering-based approach that infers a chosen number of categories, or topics, from the narratives of the reports themselves such that more than one topic can be identified in a single report. By tailoring the number of topics to be extracted by the model, the resulting categories can be as generic or as specific as necessary (Tanguy et al., 2016), thus revealing disparate levels of knowledge without the need for prior labeling.

Other Approaches

It can be argued that the very nature of causal factor categories, regardless of using supervised or unsupervised methods, dictates a compromise between expressiveness, which too basic categories lack, and feasibility, put at stake by fine-grained categories, which demand much more expensive computations (Pimm et al., 2012). On that account, a different approach to automatically analyzing incident and accident reports was proposed by Pimm et al. (2012) and Tanguy et al. (2016), where, given a new report, they identified and pulled out from the database other reports sharing similar characteristics. They measured content similarity and maximum lexical overlap between the new report and all others; thus, providing insights about whether the underlying event is happening for the first time, is rare with only a few similar occurrences in the past, or is recurring and perhaps fits in a wider trend. Another approach was presented by Zhang et al. (2021), who aimed to spot patterns in sequences of events and learn their associations with possible adverse consequences. They are used as input either event sequences noted from accident investigation reports or the raw text narratives representing them into a long short-term memory (LSTM) neural network. The network captured long-term temporal dependencies and predicted whether an accident or an incident would eventuate, whether the aircraft would be damaged, and whether fatalities would be likely.

Aviation Maintenance

Aircraft maintenance, repair, and overhaul (MRO) operations are of the most critical in the aviation industry owing to their utmost cruciality to aviation safety and aircraft performance. Two of the main applications that NLP has found in aircraft maintenance are the support of the switch to predictive maintenance and providing MRO technicians with assistance in the maintenance procedures themselves.

The primary objective of predictive maintenance is determining the ideal time for performing maintenance (Akhbardeh et al., 2021; Carchiolo et al., 2019) such that it is not as late as with reactive approaches or as frequent as preventative ones. Reactive approaches wait for components to fail and then repair them. Preventative actions require adherence to a fixed, overly precautious schedule (Selcuk, 2017). Consequently, predictive maintenance boosts safety as well as enhances operational efficiency by eliminating unplanned component downtime (Dangut et al., 2021) and repair time, all while reducing costs by avoiding unnecessary inspections (Carchiolo et al., 2019). To determine the optimal time for maintenance, informed predictions of foreseeable faults and component failures are to be made early enough such that maintenance can be performed before any malfunctions occur (Dangut et al., 2021). These predictions are based on extensive analyses of historical maintenance logbooks (Dangut et al., 2021), which contain records of past maintenance issues (Akhbardeh et al., 2020) with noted details about the time, type, and causes of component failures, a description of the faulty part (Dangut et al., 2021), and a summary of the repairing operation (Carchiolo et al., 2019). The classification of those records is essential to realizing predictive maintenance systems (Akhbardeh et al., 2021), and, for the reasons discussed in the section on Safety Reports, its automation is vital. One of the most prevalent challenges encountered in the automation process is the inherent imbalance in maintenance records (Akhbardeh et al., 2021; Dangut et al., 2021; Usuga-Cadavid et al., 2021); instances belonging to classes describing certain causes for maintenance substantially outnumber those belonging to others resembling much rarer factors (Dangut et al., 2021). Akhbardeh et al. (2021) investigated the classification of technical issues described in maintenance logbook records using a deep neural network (DNN) (Dernoncourt et al., 2017), an LSTM neural network (Suzgun et al., 2019), a recurrent neural network (RNN) (Pascanu et al., 2013), a convolutional neural network (CNN) (Lin et al., 2018), and a pre-trained BERT (Devlin et al., 2018). They considered several techniques for handling the class imbalance problem and established the superiority of the feedback loop strategy. The aim of Dangut et al. (2021) was to leverage the history of logged component failures to predict, using NLP techniques (TF–IDF and Word2vec) and ensemble-learning, future breakdowns of a certain component (binary classification) or of all components (multi-class classification). Since logbook entries corresponding to actual component failures are remarkably rare compared to ones describing routine maintenance (Dangut et al., 2021), they opted for overcoming the imbalance problem through exploring patterns only in this minority class. The objective of Usuga-Cadavid et al. (2021) was to exploit maintenance logs to tackle three classification problems: whether an unplanned failure will occur (binary classification), how long will the breakdown take (multi-class classification), and what will the cause of this failure be (multi-class classification). They compared the performance of transformer-based models, CamemBert (Martin et al. 2020) and FlauBERT (Le et al. 2020), with that of classic machine learning models. They also experimented with different data-level and algorithm-level techniques for mitigating the effect of class imbalance and found that the random oversampling (ROS) technique was the most convenient when computational complexity was not an issue.

When MRO technicians, especially new or less experienced ones, are carrying out their operations, they tend to occasionally turn to maintenance textbooks and manuals or more experienced technicians for instructions, inquiries, and guidance. Hence, Abdullah & Takahashi (2016) worked on creating an easily queried Wisdom Knowledge Database from past maintenance records and daily reports, which they categorized according to the described maintenance operation using an ontology-based semantic classification rule engine that they developed. Besides written documents, they video-recorded senior technicians while executing the different maintenance operations, extracted the voice from the videos, performed speech-to-text conversion using the iSpeech API (2007), classified the output text in the same sense, and lastly incorporated the corresponding videos into the database. Alternately, Integrated Electronic Technical Publications (IETP) combine maintenance-related documentation from various sources for convenient consultation by technicians while undergoing their MRO operations (Marques et al., 2021). For the sake of reducing the time it takes to retrieve relevant IETPs, Marques et al. (2021) proposed an interactive voice search tool using voice recognition and information retrieval techniques, allowing MRO technicians to readily access the desired publications through voice commands.

Air Traffic Control

For seamless navigation of flights to their intended destinations, air traffic controllers (ATCOs) provide pilots with the requisite guidance by means of communicating, primarily through speech (Badrinath & Balakrishnan, 2022), real-time traffic information (Lin, 2021; Sun & Tang, 2021). The smoothness of air traffic, and hence flight safety, critically rely on the accuracy, effectiveness, and promptness of this communication (Sun & Tang, 2021). Accordingly, research in air traffic control (ATC) largely focuses on eliminating communication errors and assisting ATCOs and pilots in fully and more easily comprehending the verbal messages they exchange (Lin, 2021). For instance, Abdullah et al. (2017) suggested that an automatic categorization of incoming messages can be of great help to both parties. They proposed converting communicated speech into text and then assigning it to its semantically relevant category using a knowledge-based approach. Besides following an end-to-end speech recognition architecture in developing an automatic speech recognition (ASR) model that is adapted to the ATC domain, Badrinath & Balakrishnan (2022) aimed at using NLP techniques on the generated transcripts of ATC communications to extract key operational information: the runway number associated with each flight and the call-sign uniquely identifying it. While adopting a rule-based grammar approach in extracting runway information, they used a named entity recognition (NER) model that is based on a deep CNN in classifying word sequences in the unstructured transcripts into categories representing the different call signs. Sun & Tang (2021) proposed monitoring ATC communications and raising alerts when a communication error is probable, thus, lowering the chance of losses of separation (LoS) where distances between aircraft in controlled airspace fall below the allowed minimum. They estimated not only the conditional probabilities of different types of communication errors based on key features of the communication but also the probability of LoS given those error types. To determine the communication features, the researchers first transcribed the ATC communications using IBM Watson Speech-to-Text (IBM, 2018) and then used NLP tools like LinguaKit (2018) and Cortical.io (2011) to extract features such as the number of words per message and whether there is a reference to a certain speed, altitude, or direction. From a slightly different angle, Wang et al. (2019) suggested that erroneous ATCO instructions resulting in conflicts can be recognized in advance by analyzing each of the instructions and predicting corresponding future trajectories. To facilitate the automation of this analysis, Wang et al. (2019) proposed that ATCO commands follow a certain structured template, and they provided a method of transforming complex unstructured control messages into simple structured ones. This method included ASR of spoken ATC commands followed by the application of NLP techniques like semantic role labeling and NER to semantically analyze the resulting transcript and eventually obtain the structured instruction.

NLP Software Products in the Aviation Industry

There are software companies currently offering NLP solutions aimed at automating the process of text analysis in disparate industries. Software tools that are specifically tailored to serve the aviation industry are not sufficiently prevalent, but they are growing in number. In this section, we highlight a representative sample of those software tools, whether provided by institutions that are primarily concerned with the aviation domain or by companies that develop solutions for several industries, one of which is aviation.

Some companies do not target one specific application area in aviation; they instead develop several general-purpose products that handle major text analytics tasks in NLP and can be incorporated into different solutions. Among those companies are IBM with its IBM Watson (IBM, 2010), Algodom Media whose analytics tool, BytesView (Algodom Media, 2020), supports airline and airport operations, and the aviation research and development company Mosaic ATM (2004). On the other hand, some products are only intended for a particular aviation application. For instance, several products are built to leverage historical maintenance records and logbook data, gain valuable insights, and boost aircraft maintenance, repair, and overhaul (MRO) processes. Examples of such products include DeepNLP (SparkCognition, 2018), Avilytics (EXSYN Aviation Solutions, 2020), LexX Air (LexX Technologies, 2018), and ILARA (Church, 2021) developed by the U.S. Army Engineer Research and Development Center, Information Technology Laboratory (ERDC-ITL). Other products focus on the application of NLP in ATC; from transcribing the communicated aviation audio, which is one of the functionalities of Stratus Insight (Appareo, 2020), to assisting the aircraft crew through active interactions in natural language, as carried out by Smart Librarian (Arnold, 2020) from Airbus and the project VOICI (Clean Sky 2, 2020). Other companies devote their NLP products to improving the interactions with and support provided to customers in the airline industry or to better quantifying customer experiences, like Lexalytics and its Airlines Industry Pack (Amherst, 2015).

For details about the area of application in the aviation industry that is targeted by each product and the underlying NLP tasks it performs, see Appendix.

Discussion

While NLP is expanding into the aviation domain, its continued advancement is considerably hindered by challenges. Two of these challenges are the domain's inherent complexity (Bhatia & Pinto, 2021) and its use of technical language that is characterized by a heavy reliance on domain-specific vocabulary and abbreviations (Tulechki, 2015). One consequence is that the performance of state-of-the-art NLP models trained on standard corpora is immensely degraded upon their application to such a specific domain (Brundage et al., 2021; Dima et al., 2021). For that reason, there is a need for extensive annotated domain-specific corpora on which NLP models can train (Dima et al., 2021), or pre-trained language models can be further fine-tuned (Bhatia & Pinto, 2021). Although there have been some recent efforts to put together relevant corpora, like in the work of Akhbardeh et al. (2020), they are limited.

Since domain-specific terminology is lacking in available knowledge bases, Bhatia & Pinto (2021) and Abdullah et al. (2017) suggest the development of aviation-focused knowledge bases that are more suited for usage in such technical applications. Furthermore, research has been directed toward tailoring language processing tools to satisfy the needs of technical domains through what is referred to as technical language processing (TLP) (Brundage et al., 2021; Dima et al., 2021; Nandyala et al., 2021). More specifically, TLP is a human-in-the-loop workflow that iteratively improves resources, such as data representations and agreed-upon entity sets and hierarchies used as annotations, in an attempt to address the challenges introduced by the technical domains (Brundage et al., 2021). Hence, industrial leaders, along with domain experts and researchers, ought to unite to make TLP a reality (Brundage et al., 2021).

It is suggested that aviation domain experts should team up with analysts and researchers to put together aviation-specific corpora and knowledge bases, as well as develop appropriate TLP tools. A multi-disciplinary approach is recommended due to the extensive knowledge in both aviation and NLP. Together, by combining individual strengths, future efforts can lead to new or improved domain-focused NLP applications addressing challenges in aviation safety.

Conclusion

Considering the expansion of artificial intelligence into almost every facet of our lives, it only makes sense that NLP is carving its way into the aviation domain. Current research shows a benefit in classifying safety reports and, in turn, allowing for the discovery of possible trends and potential threats to aviation safety. In aviation maintenance, NLP has been used not only in the analyses of maintenance logbooks to predict foreseeable component failures but also in the assistance of MRO technicians with access to technical sources. In air traffic control, NLP has been mainly leveraged to detect or reduce communication errors as well as clarify verbal messages exchanged with pilots. NLP software that automates text and speech analyses have been growing in number and is increasingly used in the aviation industry. More specifically, NLP software has been utilized in the areas of aviation safety report analyses, maintenance operations, air traffic control, and customer interactions.

Despite the applications discussed in this paper, the full potential of NLP is not even close to being fulfilled in the aviation domain. Owing to the technical and domain-specific challenges that researchers and domain experts need to tackle, NLP still has a long way to go in aviation research. There are also multiple avenues for expansion of NLP employment in the aviation industry, especially when practitioners, notably in general aviation maintenance, are using primarily paper and pen or saved template documents. At the same time, large airlines and companies with significant resources are developing specialized artificial intelligence software solutions that improve safety and forecasting. With the cost of developing such tools continuously going down, the expansion of NLP software such that it reaches smaller operators in the aviation industry is possible and is currently a work in progress.

This paper can serve as a starting point for future research in NLP aviation applications. By tailoring existing NLP tools to the technical aviation domain, there may be potential ways to improve the existing applications or expand them into other aviation areas such as air traffic management, communication between pilots and technicians, and maintenance activities.

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Appendix

NLP Software Products in the Aviation Industry

Product (Institution)	Product Released (Institution Founded)	Application Area(s) in Aviation				Underlying NLP Task(s)								
		Safety Reports	Maintenance, Repair & Overhaul	Air Traffic Control	Customer Interactions	Natural Language Understanding	Natural Language Generation	Text Classification	Topic Modeling	Information Retrieval	Semantic Similarity Assessment	Document Summarization	Speech Recognition	Machine Translation
IBM Watson (IBM)	2010 (1911)		x	x	x	x	x	x	x	x	x	x	x	x
(Mosaic ATM)[a]	(2004)	x	x		x	x	x	x	x	x			x	
ILARA (ERDC – ITL)	2021 (1998)		x					x						
Stratus Insight (Appareo)	2020 (2003)			x		x							x	
VOICI (Clean Sky 2)	2020 (2014)			x		x							x	
DeepNLP (SparkCognition)	2018 (2013)		x			x		x		x				
Avilytics (EXSYN Aviation Solutions)	2020 (2013)		x					x						
Airlines Industry Pack (Lexalytics)	2015 (2003)				x			x				x		
Smart Librarian (Airbus)	2020 (1970)			x		x		x		x			x	
BytesView, Airline & Airport operations (Algodom Media)	2020 (2019)	x	x	x	x			x	x	x	x			
LexX Air (LexX Technologies)	2018 (2012)		x			x				x				

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