Collegiate Aviation Review International

Volume 41 | Issue 1
Spring 2023

UAA
UNIVERSITY AVIATION ASSOCIATION

CV MAGAZINE
AVIATION & AEROSPACE AWARDS 2020

The Peer Reviewed
Journalof the University
Aviation Association

ISSN: 1523-5955

COLLEGIATE AVIATION REVIEW INTERNATIONAL

A PEER REVIEWED JOURNAL OF THE

UNIVERSITY AVIATION ASSOCIATION

COLLEGIATE AVIATION REVIEW INTERNATIONAL
2023 VOLUME 41 ISSUE 1
Yi Gao, Editor

ISSN: 1523-5955

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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:

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- 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

REVIEWER ACKNOWLEDGEMENT

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Airspace Ownership Controversies in the United States: A Concise History

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Ownership and control of airspace has long been a controversial, confusing, and difficult area of study within aviation law. Throughout the twentieth century, there was copious debate surrounding the rights of property owners and the authority of aviation regulatory agencies to govern airspace. The invention of the airplane and a burgeoning concern about aerial trespass vigorously fueled that debate. In the contemporary context, airspace ownership questions center primarily on debates over low-altitude airspace and subsequent legal remedies available for improper use, illegal entrance, or unwanted occupation of that airspace. This review examines the history of airspace ownership controversies in the United States through an analysis of legal cases, scholarly debates, academic journal articles, and primary sources. The purpose of this paper is to assist aviation scholarly and industry personnel in forming a better understanding of the historical and contemporary debates that have surrounded the question of airspace rights. It is a particularly meaningful time to review this area of aviation legal history because the advent of novel aviation technologies—namely, drones, Urban Air Mobility (UAM), and Advanced Air Mobility (AAM) air taxis—is creating an industry ripe for new airspace ownership and control controversies in the coming decades.

Recommended Citation:
Simoneau, T. (2023). Airspace ownership controversies in the United States: A concise history. *Collegiate Aviation Review International,* 41(1), 1-28. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9386/8467

A publication of the University Aviation Association, © 2023, ISSN: 1523-5955

> "When aircrafts become so numerous… their frequent passing will cease to be a novelty and if the presence of planes is so constant as to amount to a nuisance, the present day friendly attitude may unfortunately turn to one of open hostility."
>
> – John A. Eubank, 1930

Introduction

There is a myriad of interactions among airplanes, aviation industry personnel, and the law. Consequently, the aviation industry provides scholars with numerous thought-provoking legal questions. One of these legal questions is an intriguing sub-topic of property law and, in some cases, constitutional law: To what extent do property owners actually own the airspace above their land? This question, and its variations and progenies, have been the cause of controversy for over a century. They have served as the catalyst for copious debate surrounding the rights of property owners and the authority of aviation regulatory agencies. The invention of the airplane and a burgeoning concern about aerial trespass vigorously fueled that debate.

In the contemporary context, airspace ownership questions center primarily on debates over low-altitude airspace, namely, the vertical extent of one's control of property and subsequent legal remedies available for improper use, illegal entrance, or unwanted occupation of that airspace. For decades, many law review articles have been published addressing the topic, and many cases have been argued in various courts. There is ample literature and case law to review and voluminous perspectives to consider. Rule (2012) notably commented, "It is unsurprising that courts and legal scholars have long struggled to formulate rules to govern its [airspace] use" (p. 6).

It is a particularly meaningful time to review this area of aviation legal history. The advent of novel aviation technologies, drones, and electric air taxis for Urban Air Mobility (UAM) and Advanced Air Mobility (AAM) operations, for instance, has created an industry ripe for new airspace ownership controversies in the coming decades. UAM is best described as "a system for air passenger and cargo transportation within an urban area, inclusive of small package delivery and other urban unmanned aerial services" (Andritsos et al., 2022, p. 3). AAM extends the concept of UAM operations to include non-urban areas. It also may be used to describe the broader integration of other disruptive aviation technologies to airspace systems for the purpose of "transport[ing] people and things to locations that are not traditionally – or regularly – served by the current modes of air transportation" (Andritsos et al., 2022, p. 5). As one legal scholar has observed, "UAM operations implicate important property-related questions—on and above the ground… Whether local authorities will oversee the highways—literally, the airspace—needed for UAM above their geographic boundaries is unclear, however" (Ravich, 2020, p. 677).

No matter which side of future airspace controversies one may find themselves on, the importance of understanding the historical context surrounding low-altitude airspace ownership uncertainty cannot be understated. This paper examines the history of airspace ownership controversies in the United States (U.S.) in the format of a literature review, aiming to provide historical context about past and current airspace control legal issues. The purpose of this paper is to assist aviation scholarly and industry personnel in forming a better understanding of the debate that has surrounded the question of airspace rights. Legal cases, scholarly debates, academic journal articles, and primary sources were analyzed to provide the reader with context surrounding airspace ownership issues. One need not be a legal scholar to comprehend the issues and historical turning points addressed in this paper, nor be familiar with the entirety of aviation, constitutional, or property law. There is a certain complexity to many of the legal concepts addressed in this paper, but they are presented in a clear, accessible manner. Part I of the literature review begins with the origin of airspace law and covers salient airspace ownership controversies through the 1946 seminal case on the subject, *United States v. Causby*. Part II of the review covers *Causby* and the subsequent major legal rulings and developments that rely upon the *Causby* precedent. Part III of the review provides an analysis of recent airspace ownership controversies, cases, and published academic literature and relates the historical analysis provided in parts I and II to issues of emerging aviation technologies.

I

The Ancient Maxim

Most early airspace ownership controversies originated with an ancient maxim of English common law (Ball, 1928; Rule, 2012). The maxim reads, "*Cujust est solum eius est usque ad coelum et ad inferos,*" which, when translated from Latin, means, "'He who owns the soil owns everything above and below, from heaven to hell'" (Rhyne, 1944, p. 94; Lashbrook, 1946, p. 143). Much of early American jurisprudence—that is, the legal system itself—was constructed via common law doctrines derived from England (Banner, 2008). This *ad coelum* doctrine, as it will be referred to for the remainder of this paper, was no exception (Donohue, 2021). Ball (1928) identifies Cino da Pistoia as the doctrine's pronouncer in the early fourteenth century. Lashbrook (1946) asserts the doctrine was a component of the Justinian Code around 1200 AD. Donohue (2021) maintains that Franciscus Accursius established the concept in *Glossa Ordinaria*, and even then, the idea was "far from a novel concept" (p. 1). There appear to be conflicting answers to the question of where and when the doctrine originated. Preceding its integration with the common law, the doctrine was conceived in Roman law and even appeared in the famous Napoleonic Code (Eubank, 1930; Klein, 1959). Wherever its true origins, one fact is certain: The doctrine was integrated into English and American common law throughout the 17th, 18th, and 19th centuries (Lashbrook, 1946; Rule, 2012; Donohue, 2021).

Essentially, under the *ad coelum* doctrine's rule, a property owner's rights and ownership of land extends beyond merely the surface of that property to the vertical airspace above the property, all the way to the heavens, and below it, to hell (Rhyne, 1944; Lashbrook, 1946; Thrope, 1947; Rule, 2015). Under this concept, property owners own *all* of the airspace above their property. Such a doctrine, of course, presented a problem for the aviation industry as aircraft must frequently traverse the airspace above the properties of private landowners while flying to their destinations. If applied in the literal sense, an intrusion into a private landowner's airspace would be a trespass (Cummings, 1953). Fast forward to the 1900s, "courts in the United States were applying it [the doctrine] to find trespass for even minor intrusions into neighboring airspace" (Rule, 2012, p. 427).

One example occurred in 1902 when the Iowa Supreme Court ruled that extending an arm into another's property was, in fact, a trespass, and damages may be recovered for this unlawful intrusion (*Hannabalson v. Sessions,* 1902). The court cited the *ad coelum* doctrine, reasoning, "[i]t is one of the oldest rules of property known to the law that the title of the owner of the soil extends, not only downward to the center of the earth, but upward *usque ad coelum*" (*Hannabalson v. Sessions,* 1902, p. 3).

Four years later, New York's Court of Appeals ruled the actions of a telephone company that had strung a wire above a landowner's private property constituted a trespass because "Unless the principle of *usque ad coelum* is abandoned any physical, exclusive and permanent occupation of space above land is an occupation of the land itself and a disseisin of the owner to that extent" (*Butler v. Frontier Tel. Co.,* 1906, p. 5).

These court opinions, along with similar decisions from other courts, cemented the *ad coelum* doctrine's place in American jurisprudence. Not only was the doctrine rooted in American common law but there was now also legal precedent—opinions issued by courts—that validated its principle of absolute ownership of the airspace above private property. From the perspective of private property owners, the *ad coelum* doctrine bolstered their rights. From the perspective of a budding domestic aviation industry, however, the doctrine (and the legal precedents that relied upon it) created a serious dilemma.

Powered Flight Presents a Problem

The invention of the powered airplane was a critical turning point in the history of airspace ownership law. The emergence of powered flight technology provided exciting opportunities for an industry still in its infancy but was not without controversy (Whitnah, 1966). As Ball (1928) observed, "The advent of the aeronaut has created the possibility of a number of unprecedented factual situations to confront our courts" (p. 1). Consequently, the expansion of U.S. civil aviation in the 1920s created important legal questions about airspace ownership and aerial trespass.

"Ownership of air space is certain to become a question of great importance in the future as air transportation increases in volume," identified the *New York Times* (1929, p. 1), citing an aviation legal scholar of the day. Indeed, the key problem for the emerging aviation industry was that, if literally applied, the *ad coelum* doctrine would produce a court decision that would hold any flight over land, no matter the altitude of the flight, as a trespass (Kingsley & Mangham, 1932). Thus, it appeared a technical common law property rule had the potential to "ground the incipient aircraft industry" (Banner, 2008, p. 9). Yet it was not certain that such potential would become a reality. In forthcoming aerial trespass cases, it would still be up to the courts to decide whether the *ad coelum* doctrine of *total* airspace ownership was valid. Thus, the arrival of powered flying machines combined with the resulting problem of aerial trespass required thoughtful attention.

Some scholars concluded, in hindsight, that a strict application of the *ad coelum* doctrine's endless airspace ownership theory could not survive the advent of the airplane (Rhyne, 1944; Klein, 1959; Anderson, 1961). Still, there remained important questions about low-altitude airspace ownership.

At that time, there was a consensus that an airplane passing through low-altitude airspace over private property would be committing an aerial trespass. This view was embraced by many. For example, in 1919, a U.S. Senator introduced a bill that would allow property owners to collect damages in the event of an aerial trespass by airplane, recognizing a property owner's right to control the airspace above their land (Eubank, 1930). A group of lawyers decided during a moot court exercise that airplanes flying over private property were, in fact, trespassing. A New Jersey judge even placed a large warning sign on the top of his roof, alerting aviators not to overfly his property (Banner, 2008).

Yet some remained unconvinced. In 1930, one "expert on aeronautical law" told a class of students at New York University: "[T]he extent of the superincumbent airspace subject to the exercise of the landowners' rights has, for obvious reasons, never been exactly defined in the course of judicial expression" (New York Times, 1930, p. 20). More clearly stated, it was this expert's opinion that "a property owner does not control the rights to the navigable airspace above his land holdings" (New York Times, 1930, p. 20). Others believed the doctrine was "obsolete," had "no modern application," and should "be disregarded" (Eubank, 1930, p. 87). Another lawyer thought the New Jersey judge's warning sign was "funny enough to include in his compilation of amusing anecdotes for lawyers to tell to juries" (Banner, 2008, p. 12).

Even if the doctrine was not to be applied literally, it remained the perspective of many legal scholars throughout this period that airplanes might still be committing aerial trespass (Reeves, 1909; Banner, 2008). One particularly illustrative perspective came from aviation legal scholar John A. Eubank (1930) when he stressed the importance of this burgeoning issue:

> Today no one objects to the occasional airplane that passes over his property. This is true no matter how soured one may be toward his fellow men. In fact, the passing of an aircraft usually arouses curiosity and sufficient excitement to cause the whole family to stumble over the house cat and out the back door to wave a friendly greeting to the aeronaut in flight. When aircrafts become so numerous, however, their frequent passing will cease to be a novelty, and if the presence of planes is so constant as to amount to a nuisance, the present day friendly attitude may unfortunately turn to one of open hostility (p. 82–83).

History shows us that Eubank's concern was legitimate. Throughout the 1930s, many people held openly hostile attitudes toward airplanes traversing the skies above their property. Even though by 1937, according to one scholar, "no one…seriously advocat[ed] a literal interpretation" of the *ad coelum* doctrine (Hackley, 1937, p. 775), there was still a belief that a property owner could at least control *some* of the airspace above their land in certain circumstances. A series of trespass lawsuits against aircraft operators commenced. The first prominent ruling resulting from these lawsuits came from the Massachusetts Supreme Court in 1930 (Garland, 1937). More rulings would follow, and some would contradict others.

Another airspace problem encountered throughout this period was the issue of inconsistent state laws governing the use of airspace. An imperative question that arose as the development of airplane technology flourished was whether the issue of airspace control should be turned over to the federal government or divided amongst the states. Air travel was, to be sure, very much an example of interstate commerce. Because airplanes, and the aeronauts that flew them, would often cross state lines, it certainly would have made sense for that interstate activity to be controlled by the federal government. After all, the power to regulate commerce, according to the U.S. Constitution, rested primarily with the federal government. But at this moment, and until a Supreme Court ruling a couple of decades later, the federal government's authority to regulate aviation "was not at all clear" (Banner, 2008, p. 103–104). The alternative to such uncertainty was for the states to take it upon themselves to address the issue of airspace ownership and sovereignty (Banner, 2008).

That is exactly what some states did. In 1921, a Uniform State Law for Aeronautics (USLA) was drafted and approved by the National Conference of Commissioners on Uniform State Laws (Rhyne, 1944). The law included many provisions, but the sections about airspace and aerial trespass were the "most important parts" (Banner, 2008, p. 126).

"The ownership of the space above the lands and waters of this state is declared to be vested in the several owners of the surface beneath, subject to the right of flight described in Section 4" (Uniform State Law for Aeronautics, 1922, p. 6). The "right of flight" exception in Section 4 of the USLA provided that:

> Flight in aircraft over the lands and waters of this state is lawful unless at such a low altitude as to interfere with the then existing use to which the land or water or the space over the land or water is put by the owner, or unless so conducted as to be eminently [sic] dangerous to persons or property lawfully on the land or water beneath (Uniform State Law for Aeronautics, 1922, p. 6).

The airspace provisions of the USLA were spiritedly debated (Rhyne, 1944). By 1930, 12 states had adopted the USLA and "declared their sovereignty in the airspace over the lands and waters" (Eubank, 1930, p. 79). By 1944, 23 states had enacted the airspace provisions contained within the USLA (Rhyne, 1944). Covering the complete history of state airspace laws enacted throughout the early twentieth century is well outside the scope of this paper. Doing so would betray the concise historical narrative this review aims to provide. If interested, though, one will find a detailed history and analysis in Banner (2008). Still, it is important to identify and acknowledge the roles that states and their airspace laws played in early twentieth-century airspace ownership controversies. One will see that in early court opinions about airspace ownership and trespass issues, state laws governing airspace ownership were a focal point in the legal reasoning used by courts.

Early Theories of Airspace Ownership

As courts began to decide the issues of airspace ownership and aerial trespass, a few common trends in how courts went about deciding the issue began to emerge. Rhyne (1944) identified five theories of airspace ownership based on these court decisions:

> (1) The landowner owns all the air space above his property without limit in extent.
> (2) The Landowner Owns the Air Space Above His Property to an Unlimited Extent Subject to an "Easement" or "Privilege" of Flight in the Public.
> (3) The Landowner Owns the Air Space Above His Property Up to Such Height as is Fixed by Statute with Flights Under That Height "Trespasses."
> (4) The Landowner Owns the Air Space Up as Far as it is Possible for Him to Take Effective Possession but Beyond the "Possible Effective Possession Zone" There Is No Ownership in Air Space.
> (5) The Landowner Owns Only the Air Space He Actually Occupies and Can Only Object to Such Uses of the Air Space Over His Property As Does Actual Damage (p. 155–161).

The first theory, as one may immediately recognize, is representative of the *ad coelum* doctrine (Rhyne, 1944). Theories four and five become increasingly more complex as additional requirements are added for a property owner to possess any right to the airspace above their land. These theories were all derived by Rhyne (1944) from court decisions in early twentieth-century aerial trespass cases, several of which are discussed next.

Disagreement Amongst the Courts

Unsurprisingly, different courts interpreted the aerial trespass issue in dissimilar ways. There are four salient 1930s cases worth detailing in this review to illustrate the ways in which the court opinions diverged from one another.

Mr. and Mrs. Smith had become annoyed with the "'loud, penetrating, piercing, unpleasant and incessant noise'" created by airplanes flying in and out of the airport adjacent to their property, owned by New England Aircraft Company (Logan, 1930, p. 316). They sued the airport owners, arguing that because the aircraft was flying so low over their property, they had committed a trespass, and the flights were a nuisance. A trial court disagreed with the nuisance argument but found the trespass issue to be a "question of law" that had to be decided by a higher court (Logan, 1930, p. 317). The case was appealed to the Massachusetts Supreme Court.

Interestingly, as observed by Logan (1930), the Smiths "did not contend for an unlimited application of the" *ad coelum* doctrine in their arguments to the court (p. 317). Instead, they asserted that flights taking place between 100 feet and 1,000 feet constituted a trespass. This was significant because such an argument meant they had "abandoned the doctrine of the maxim in so far as it is limitless in application" (Logan, 1930, p. 318). Essentially, the Smiths were not attempting to argue that they owned all the airspace above their property extending to the heavens. New England Aircraft Company fervently disagreed with the Smiths' 100 to 1,000 feet argument and even went so far as to argue the *ad coelum* doctrine was "not law" and "had never been applied or intended to be applied to such heights as were involved in this case" (Logan, 1930, p. 318).

The court unanimously disagreed with the New England Aircraft Company (Banner, 2008). In *Smith v. New England Aircraft Co.* (1930), the court determined that "under settled principles of law," the low-altitude flights over the Smiths' property were a trespass (p. 530). However, the court's conclusion was not that simple. The court determined, in accordance with interpretations of state and federal law, that flights above 500 feet over private property were not a trespass. This was representative of the third theory of airspace ownership identified by Rhyne (1944)—flights below an altitude established by law (in this case, 500 feet) are a trespass. That, according to Logan (1930) and Banner (2008), created even more questions—none of which were answered by the *Smith* court. According to Rhyne (1944), an altitude established by a statute was meant to serve as a safety rule and not "have any application to air space rights" (p. 159).

Perhaps even more confusing: While it appeared the court had ruled in favor of the Smiths by stating there had been a trespass, no evidence of actual damages was presented; so, the Smiths were not entitled to a legal order prohibiting future low-altitude flights over their private property (Banner, 2008). In other words, the Smiths did, in fact, own some of the airspace above their property but did not win their case. In short, *Smith* was a significant airspace ownership controversy because it highlighted the confusing, conflicting, and unsettled aspects of the aerial trespass question.

Meanwhile, in Richmond Heights, Ohio, another airspace controversy was developing, a case that Banner (2008) argues was "[t]he most important aerial trespass case of the 1930s" (p. 175). In 1929, the Curtiss Airports Corporation purchased 272 acres of property across from 135 acres of private property owned by the Swetlands. The company intended to construct an airport on its recently purchased property (*Swetland v. Curtiss Airports Corp.*, 1932). This plan was not well received by the Swetlands. The couple sued Curtiss Airports Corporation hoping to prevent the company from building an airport on its property. From their perspective, if Curtiss Airports Corporation were to build an airport so close to their own property, it "would destroy their property for residential purposes" (*Swetland v. Curtiss Airports Corp.*, 1932, p. 202). The first judge to hear the case, Judge Hahn, disagreed with the Swetlands' argument that Curtiss Airports Corporation should not be allowed to build an airport on its property. "They [the Swetlands]," wrote Judge Hahn, "must now yield to change and progress of the times" (*Swetland v. Curtiss Airports Corp.*, 1930, p. 934).

Separately, the Swetlands also argued, like the Smiths had in their case, that "airplanes were trespassing by flying over their land" (Banner, 2008, p. 177). Judge Hahn agreed with this argument. He had reviewed the lengthy history of the *ad coelum* doctrine, cases such as *Hannabalson v. Sessions* and *Butler v. Frontier Telephone Co.*, and scholarly commentary on the doctrine's validity. He noted a court had never conducted an in-depth analysis of the *ad coelum* doctrine's meaning, and "there is much doubt whether a strict and careful translation of the maxim would leave it so broad in its signification as to include the higher altitudes of space" (*Swetland v. Curtiss Airports Corp.*, 1930, p. 938). But he would not need to rely upon the *ad coelum* doctrine because, as pointed out by Banner (2008), "[b]oth the United States and Ohio had set five hundred feet as the minimum altitude for flight" (p. 177). He ultimately sided with the Swetlands, concluding that the takeoffs and landings conducted by the aircraft occurred below 500 feet, so they were a nuisance. Again, such as in *Smith*, the third theory of airspace ownership had been applied.

Judge Hahn's decision was appealed to the U.S. Court of Appeals for the Sixth Circuit. There, Judge Moorman, writing for the court, reached essentially the same conclusion: in the upper stratum of airspace, a property owner has no rights to prevent airplanes from traversing that airspace; but in the lower stratum of airspace, a property owner did possess an ownership right. Encroaching upon that ownership right would be an unlawful trespass or nuisance (*Swetland v. Curtiss Airports Corp.*, 1932; Banner, 2008).

Not all courts reached the same conclusion about the aerial trespass issue. Specifically, there were two cases that stood in stark contrast to the conclusions in *Smith* and *Swetland*. "What was meant by low flying?" questioned Georgia Supreme Court Justice Bell in 1934, "In the absence of any statement of the altitude or other circumstances, it does not show that the act amounted to a trespass" (*Thrasher v. City of Atlanta*, 1934, p. 531). The *act* referred to by Justice Bell was an allegation made by Clovis Thrasher that airport operations at a city-owned airport, Chandler Field, "constituted a nuisance, with resulting damage to the plaintiff [Thrasher]" (*Thrasher v. City of Atlanta*, 1934, p. 515). In the *Thrasher* case, the court concluded that airplanes flying over Thrasher's property at low altitudes were *not* trespassing. The court reasoned a pilot flying over private property is "merely a transient" and that "[s]o long as the space through which he moves is beyond the reasonable possibility of possession by the occupant below, he is in free territory" (*Thrasher v. City of Atlanta*, 1934, p. 530). The *Thrasher* case was representative of the fourth theory of airspace ownership identified by Rhyne (1944).

Two years later, the U.S. Court of Appeals for the Ninth Circuit went further. The court ruled that airplanes flying over private property were *not* trespassing. In *Hinman v. Pacific Air Transport* (1936)—a case with remarkably similar facts to the *Smith*, *Swetland*, and *Thrasher* cases—the court determined "[t]he air, like the sea, is by its nature incapable of private ownership, except in so far as one may actually use it" (p. 758). The court continued:

> We own so much of the space above the ground as we can occupy or make use of, in connection with the enjoyment of our land. This right is not fixed. It varies with our varying needs and is coextensive with them. The owner of land owns as much of the space above him as he uses, but only so long as he uses it. All that lies beyond belongs to the world (*Hinman v. Pacific Air Transport,* 1936, p. 758).

Mr. and Mrs. Hinman, the court concluded, had not occupied or been utilizing the airspace above them. Accordingly, the court found no aerial trespass above their property had been committed, even though the aircraft were often flying below 100 feet.

Thrasher and *Hinman* were the exceptions. "The other courts that had addressed the trespass question had all held… that extremely low overflights could constitute trespasses (although they disagreed on exactly how low)" (Banner, 2008, p. 239). In other words, the conflicting opinions created a mess. The Ninth Circuit's opinion in *Hinman* was appealed to the

U.S. Supreme Court in hope of finding some clarity. But the highest court in the land denied the petition to hear the case. Hackley (1937) believed the Supreme Court had "lost an excellent opportunity to express its views on a question three centuries old and yet, oddly enough, a question of considerable importance to modern aviation" (p. 773). That opportunity, however, would be recognized by the Supreme Court a short decade later with another airspace controversy originating on a chicken farm in North Carolina.

II

The Chicken Farm

Thomas Lee Causby was a chicken farmer. In 1934, he and his wife purchased a plot of land adjacent to Greensboro–High Point Airfield in North Carolina. The airport had, historically, little traffic. The aircraft that did utilize the airport "didn't make much noise and didn't need a long runway" (Banner, 2008, p. 227). By 1937, the Causbys had built a house for themselves and several "outbuildings" which were used to raise their chickens (Banner, 2008; *United States v. Causby et ux.,* 1946, p. 258). With approximately four hundred chickens and a farm producing enough income to support their family, the Causbys had established what Thomas viewed as a "'good business'" (Banner, 2008, p. 227). But the year 1942 brought trouble for the Causbys' successful chicken farm. Now that the U.S. had entered World War II, there was increasingly a need for the U.S. Army Air Forces (USAAF) to utilize airports for various military activities (Banner, 2008). In May 1942, the USAAF entered into a lease agreement to begin flying military aircraft—namely bomber, transport, and fighter aircraft—in and out of the airfield located just 2,220 feet from the Causbys' chicken farm (*United States v. Causby et ux.,* 1946, p. 258–259; Leavitt, 1947; Cahoon, 1990).

An unforeseen consequence of the USAAF lease agreement for Greensboro–High Point Airfield was the destruction of the Causbys' successful chicken farm business (Banner, 2008). Consider how bomber and fighter aircraft, among others, flying at low altitudes on approach into the airfield, immediately above the Causbys' chicken farm, would adversely affect the farm's operations. The aircraft came "close enough at times to appear barely to miss the tops of the trees and at times so close to the tops of the trees as to blow the old leaves off" (*United States v. Causby et ux.,* 1946, p. 258). As one might imagine, the noise created by these low passes was "startling" (*United States v. Causby et ux.,* 1946, p. 258). Resultantly, "[l]ife on the farm would never be the same" (Banner, 2008, p. 228).

Because of the noise created by these low flying military aircraft, the chickens became frightened and flew "into the walls from the fright" (*United States v. Causby et ux.,* 1946, p. 259). Tragically, for the chickens, such a flight into the wall was fatal. "As many as six to ten of their [the Causbys'] chickens were killed in one day" and "the total chickens lost in that manner was about 150" (*United States v. Causby et ux.,* 1946, p. 259). By this point, the Causbys' chicken farming business was all but physically destroyed. They ceased business operations and sold the surviving chickens "at a loss" (Banner, 2008, p. 229). What is more, the Causbys were "frequently deprived of their sleep" and had "become nervous and frightened" (*United States v. Causby et ux.,* 1946, p. 259; Cahoon, 1990). They felt as if they were living "in a state of constant uneasiness" and attributed their inability to sleep at night "to the noise of the planes passing over their house and to the glare of their lights" (*Causby v. United States*, 1945, p. 350–351). Thomas and his wife were also worried that one of these airplanes would "crash into their house" (Banner, 2008, p. 228).

Like preceding airspace controversies, the situation on the Causbys' chicken farm was "a classic case of both trespass and nuisance" (Banner, 2008, p. 229). Yet unlike preceding airspace controversies, this time the trespasser and the origin of the nuisance was the federal *government*. This fact was particularly significant because it meant the legal theory used by the Causbys to sue the government would be fundamentally different from the theories used to argue and settle disputes between private parties (Banner, 2008). With the federal government as the defendant, this case had now raised an important question of constitutionality.

A Fifth Amendment Claim

The Takings Clause of the Fifth Amendment to the U.S. Constitution reads: "[N]or shall private property be taken for public use, without just compensation" (U.S. Const. amend. V). Justice John Paul Stephens palpably articulated the meaning of these words in a 2002 opinion: "When the government physically takes possession of an interest in property for some public purpose, it has a categorical duty to compensate the former owner" (*Tahoe-Sierra Preservation Council, Inc., et al. v. Tahoe Regional Planning Agency et al.*, 2002, p. 322, as cited in *United States v. Pewee Coal Co.*, 1951). For the Causbys, that the low-flying military aircraft over their property constituted a governmental taking of their property for public use was a plausible argument (Banner, 2008).

Whether the USAAF's low-flying military aircraft over the Causbys' chicken farm constituted a taking under the Fifth Amendment was left to the Court of Claims to determine. Banner (2008) identified the alleged damages suffered by the Causbys, according to the petition filed by their attorney: "The petition alleged that the value of the Causbys' land and buildings had been reduced from $6,035 to zero, and that the loss of the chicken farming business had cost them another $1,000" (p. 230). Four judges on the Court of Claims' panel would decide the validity of the Takings Clause argument. They decided in favor of the Causbys (*Causby v. United States*, 1945; Banner, 2008).

Judge Whitaker authored the 1945 opinion for the Court of Claims delivered in *Causby v. United States*. First, Judge Whitaker outlined how the government's actions constituted a trespass, citing the *ad coelum* doctrine, *Butler v. Frontier Telephone Co.,* and *Smith v. New England Aircraft Co.,* among other authorities:

> Under the old common law doctrine of *cujus est solum ejus est usque ad coelum et ad inferos* a landowner not only owns the surface of his land, but also owns all that lies beneath the surface even to the bowels of the earth and all the air space above it even unto the periphery of the sky. Under this doctrine any erection over the land of another, or any passage through the air space above it, is a trespass… However, especially since the days of airplanes, this common law doctrine has received substantial modification. But even so, there can be no doubt that today a landowner owns the air space above his land as completely as he does the land itself or the minerals beneath it, at least insofar as

> it is necessary for his full and complete enjoyment of the land itself (*Causby v. United States*, 1945, p. 352).

But importantly, the chief question that required an answer from the Court of Claims was not whether the government had trespassed on the Causbys' property, but whether its actions constituted a Fifth Amendment Takings Clause violation (Banner, 2008). Citing Supreme Court precedent, the Court of Claims concluded it had. For there to have been a taking, the trespass must have been "sufficiently frequent" or have "destroy[ed] the owner's use and enjoyment of his property" (*Causby v. United States*, 1945, p. 353). It was clear to Judge Whitaker, and the other three judges on the panel, that:

> [T]here [had] been frequent invasions of the air space above plaintiffs' land, and the evidence shows an intention to continue these invasions whenever the wind blows in a certain direction. As a result plaintiffs [the Causbys] have been deprived of the use of their property as a chicken farm (*Causby v. United States*, 1945, p. 353).

Despite winning the constitutional argument, the Causbys were not awarded their requested amount in damages. Instead of the $7,035 initially requested in their petition, the Court of Claims awarded $2,000 in damages to the chicken farmers (Banner, 2008; *Causby v. United States*, 1945). The government chose to appeal the decision of the Court of Claims to the Supreme Court, not because it had to pay the Causbys $2,000, but because the central holding of the opinion authored by Judge Whitaker meant the same logic could be used to initiate numerous "lawsuits from the neighbors of the hundreds of military air bases scattered throughout the United States" (Banner, 2008, p. 238).

Recall the earlier airspace ownership controversy in *Hinman v. Pacific Air Transport*, the case in which the U.S. Court of Appeals for the Ninth Circuit departed from other courts by holding that aerial trespass was not unlawful (*Hinman v. Pacific Air Transport*, 1936). The Court of Claims decision in *Causby v. United States* nearly a decade later, of course, stood in stark contrast with the Ninth Circuit's *Hinman* opinion and also the Georgia Supreme Court's opinion in *Thrasher*. This, along with the other opinions that conflicted with the *Hinman* and *Thrasher* holdings, created a split among judicial authorities. Such a split required an answer from the highest court in the land, the Supreme Court (Banner, 2008). Therefore, the Supreme Court granted the government's writ of certiorari, meaning it agreed to hear the case (*United States v. Causby*, 1946).

The Supreme Court's Opinion

Justice William O. Douglas delivered the opinion of the Supreme Court. Appointed to the Court in 1939 by President Franklin D. Roosevelt, Douglas was the longest continuously serving member of the Court—a thirty-six-year tenure (Domnarski, 2006). One of Douglas's law clerks wrote that he had "an uncanny knack of putting his finger on the essential issue of a confusing and difficult problem" and that his writing style was "easy" and "fluid" (Cohen, 1958, p. 6). Such characteristics are well illustrated within Douglas's landmark 1946 opinion in *United States v. Causby*. Airspace and the broader question of who owns the sky—as illustrated throughout this paper—was indeed a confusing and difficult problem.

The Court sided with the Causbys, holding that the government's actions constituted a taking under the Fifth Amendment (*United States v. Causby*, 1946). But like so many Supreme Court opinions, the complete opinion of the Court was far more complicated. The *Causby* plurality reached a series of important conclusions, authored by Justice Douglas.

First, Justice Douglas, writing for the Court, declared the *ad coelum* doctrine "has no place in the modern world" (*United States v. Causby et ux.*, 1946, p. 261). This was, clearly, significant as it officially and formally ended the notion that private property owners possessed a right to control, literally, all the vertical airspace within the bounds of their property lines. The Court noted that "[t]he air is a public highway, as Congress has declared" and that "[c]ommon sense revolts at the idea" postulated by the *ad coelum* doctrine (*United States v. Causby et ux.*, 1946, p. 261). Although, while this holding verified the understanding that the air was indeed a public highway, not to be subjected to private ownership, the key question of low-altitude ownership rights remained unanswered at this point in the opinion (Banner, 2008).

Second, the *Causby* plurality analyzed the reasoning that validated the Causbys' claim for compensation under the Takings Clause of the Fifth Amendment. That discussion centered on what constituted *navigable airspace*. Under the Air Commerce Act of 1926, as amended by the Civil Aeronautics Act of 1938, the federal government controlled navigable airspace (Civil Aeronautics Act, 1938). This was particularly significant. After all, if the government's aircraft had been operating in the navigable airspace, it would not have been possible for there to have been a taking of property, or so the government argued (*United States v. Causby et ux.*, 1946). Justice Douglas provided a scenario for one to consider that issue:

> The navigable airspace which Congress has placed in the public domain is "airspace above the minimum safe altitudes of flight prescribed by the Civil Aeronautics Authority." 49 U.S.C. § 180. If that agency prescribed 83 feet as the minimum safe altitude, then we would have presented the question of the validity of the regulation. But nothing of the sort has been done. The path of glide governs the method of operating—of landing or taking off. The altitude required for that operation is not the minimum safe altitude of flight which is the downward reach of the navigable airspace… Hence, the flights in question were not within the navigable airspace which Congress placed within the public domain (*United States v. Causby et ux.*, 1946, p. 263–264).

Through this paragraph, the Court illustrated the importance of how navigable airspace is defined. Justice Douglas goes on to explain "[t]he Civil Aeronautics Authority has, of course, the power to prescribe air traffic rules. But Congress has defined navigable airspace only in terms of one of them—the minimum safe altitudes of flight" (*United States v. Causby et ux.*, 1946, p. 264). Still, at this point in the opinion, Douglas had refrained from addressing the specific question to which so many hoped for an answer to—low-altitude airspace ownership (Banner, 2008).

Finally, Justice Douglass—to the dismay of his colleagues, who, according to Banner (2008), would have preferred the young justice not address the issue—turned to the question of low-altitude airspace ownership. Contending that most airspace is indeed a public highway, Douglas wrote “it is obvious that if the landowner is to have full enjoyment of the land, he must have exclusive control of the immediate reaches of the enveloping atmosphere” (*United States v. Causby et ux.,* 1946, p. 264). Justice Douglas reasoned that if this were not the case, “buildings could not be erected, trees could not be planted, and even fences could not be run” (*United States v. Causby et ux.,* 1946, p. 264). Accordingly, relying upon *Hinman v. Pacific Air Transport*, he asserted “[t]he landowner owns at least as much of the space above the ground as he can occupy or use in connection with the land. [citation omitted] The fact that he does not occupy it in a physical sense—by the erection of buildings and the like—is not material” (*United States v. Causby et ux.,* 1946, p. 264). Justice Douglas continued:

> The superadjacent airspace [that is, the airspace *directly* above property] at this low altitude is so close to the land that continuous invasions of it affect the use of the surface of the land itself. We think that the landowner, as an incident to his ownership, has a claim to it and that invasions of it are in the same category as invasions of the surface (*United States v. Causby et ux.,* 1946, p. 265).

But how is *immediate reaches* defined? Where does the transition occur from airspace immediately above the land that may be *enjoyed* to the navigable airspace that is part of the public domain? “We need not determine at this time what those precise limits are” wrote Justice Douglas (*United States v. Causby et ux.,* 1946, p. 266). He noted that “[f]lights over private land are not a taking, unless they are so low and so frequent as to be a direct and immediate interference with the enjoyment of the land” (*United States v. Causby et ux.,* 1946, p. 266). Despite the ambiguity, in the view of Rule (2011) the Court had “made clear that landowners held enforceable property interests in the usable airspace above their parcels” (p. 282).

The Court noted that the factual record in the trial court supported a diminution in value: “For the findings of the Court of Claims plainly establish that there was a diminution in value of the property and that the frequent, low-level flights were the direct and immediate cause” (*United States v. Causby et ux.,* 1946, p. 266). The Court did conclude, however, that the damages awarded to the Causbys by the Court of Claims were not properly determined because the lower court had failed to provide a precise, or accurate, description of the specific property taken (*United States v. Causby et ux.,* 1946). Accordingly, the Court instructed the Court of Claims to “make the necessary findings in conformity with this opinion” (*United States v. Causby et ux.,* 1946, p. 268). Upon reassessment, the Court of Claims ultimately awarded a total of $1,435 in damages to the Causbys (Banner, 2008).

Not all justices were satisfied with Douglas’s opinion. Two justices, Hugo Black and Harold Burton, dissented. The dissent, authored by Justice Black, argued that “[t]he concept of taking property as used in the Constitution has heretofore never been given so sweeping a meaning” (*United States v. Causby et ux.,* 1946, p. 270). In Justice Black’s view:

> The future adjustment of the rights and remedies of property owners, which might be found necessary because of the flight of planes at safe altitudes, should, especially in view of the imminent expansion of air navigation, be left where I think the Constitution left it, with Congress (*United States v. Causby et ux.,* 1946, p. 271).

Congress, in Justice Black's opinion, had the full authority to control airspace—even airspace at lower altitudes above what constituted the minimum safe altitude defined by law (Field & Davis, 1996). Nevertheless, Justices Black and Burton were in the minority and Douglas's opinion was the controlling authority.

While there was, to be sure, technically an answer to whether low-altitude airspace ownership rights existed derived from *Causby*, there remained many ambiguities within Justice Douglas's opinion—especially as to the question of where specifically the line is drawn. Now, there were two zones of airspace: the upper zone and lower zone (Cummings, 1953). But even more significant, the Court had utilized the Constitution to reach its conclusion. Explained by Banner (2008):

> The Court was imposing a uniform nationwide rule, a rule that no state legislature and no state court had the power to change… Because the rule derived from the Constitution, no one had the power to change it in the future except the Supreme Court (p. 256).

Redefining Navigable Airspace

The significance of the term *navigable airspace*, and its definition, were strongly illustrated in the *Causby* opinion. In 1946, the definition of navigable airspace did not include any such provision for the glide paths of aircraft taking off or landing to be considered part of the navigable airspace that was controlled by the federal government—nay, as described previously, *navigable airspace* was merely defined as "'airspace above the minimum safe altitudes of flight prescribed by the Civil Aeronautics Authority [CAA] [citation omitted]'" (*United States v. Causby et ux.*, 1946, p. 256). For aircraft taking off and landing to be considered flying within the navigable airspace, the definition referenced by Justice Douglas would need to be changed.

There was also the issue of states' rights to regulate navigable airspace. Recall the airspace provisions of the Uniform State Law for Aeronautics that had been adopted by twenty-three states. Cooper (1948) reasoned that the *Causby* "opinion does not indicate what rights, if any, the subjacent State has in that part of the navigable airspace public domain lying over its surface territory" (p. 27). Concerned that "[i]f the Federal Government alone has sovereign rights in the navigable airspace… then the statutes of such States do not govern crimes committed or other wrongful acts occurring in the navigable airspace," Cooper (1948) suggested "these are serious questions – the answers to which should not be delayed" (p. 28).

Congress got to work. In 1958, the Federal Aviation Act was passed. This Act, among other things, abolished the CAA, created the Federal Aviation Agency, and redefined what constituted navigable airspace. Now, navigable airspace was defined as "airspace above the minimum altitudes of flight prescribed by regulations issued under this Act, and shall include airspace needed to insure safety in take-off and landing of aircraft" (Federal Aviation Act, 1958, p. 739).

Applying the *Causby* Conclusion

Beyond leading to a new definition of navigable airspace, the Supreme Court's opinion in *Causby* has been, as one may imagine, an important precedent in airspace law since 1946. A search of the NexisUni database at the time of this writing reveals that *Causby* has been cited in 894 court decisions, at all levels of the judiciary, including both federal and state courts.

Importantly, the notion that noise generated from low flying aircraft constituted a taking of property, as held in the Court's *Causby* opinion, was the first time such a conclusion had been reached (Thorpe, 1947). The consequences were significant. Subsequent airspace ownership cases now often involved suing government-owned airports under the same Takings Clause logic that had created a legal victory for the Causbys (Banner, 2008). One example of the application of the *Causby* logic was the case of *Ackerman v. Port of Seattle* in 1960. The Washington Supreme Court concluded in *Ackerman* that "continuing and frequent low flights over the appellants' [the Ackermans] land amount[ed] to a taking of an air easement for the purpose of flying airplanes over the land" (*Ackerman v. Port of Seattle*, 1960, p. 412).

Two years after *Ackerman*, another Supreme Court case, *Griggs v. Allegheny County*, also applied the *Causby* approach. The Court's opinion in *Griggs*—which too was written by Justice Douglas—reaffirmed *Causby's* central holding. This time, it was not the federal government that had committed a taking. Instead, it was a local government: Allegheny County, Pennsylvania. Applying the *Causby* logic, Justice Douglas, writing for the Court, concluded Allegheny County "was the promoter, owner, and lessor of the airport" and was "the one who took the air easement in the constitutional sense" (*Griggs v. Allegheny County*, 1962, p. 89).

More cases—*United States v. 15,909 Acres* (1958), *Bacon v. United States* (1961), *A.J. Hodges Industries, Inc. v. United States* (1966), *Speir v. United States* (1973), *Palisades Citizens Ass'n, Inc. v. Civil Aeronautics Board* (1969), *Lacey v. United States* (1979), and *Brown v. U.S.* (1996), and others—also applied the *Causby* precedent to instances with similar facts and questions. The Wisconsin Supreme Court recently examined the issue in *Brenner v. New Richmond Reg'l Airport Comm'n* (2012):

> We [the Wisconsin Supreme Court] conclude that a taking occurs in airplane overflight cases when government action results in aircraft flying over a landowner's property low enough and with sufficient frequency to have a direct and immediate effect on the use and enjoyment of the property (p. 325–326).

Later in that opinion, and after reviewing the precedent set by *Causby* and *Griggs*, the Wisconsin Supreme Court offered a readable summary of the present state of airspace ownership law. The summary may also serve as a clear description of the key takeaways from part II of this review:

> [F]lights that are not directly over a person's property cannot "take" the person's property. Flights that are *above* the government-defined minimum safe altitude of flight are very unlikely to take a person's property. But overflights that invade the person's superadjacent block of airspace, even takeoffs and landings, may constitute a taking for

which compensation is required (*Brenner v. New Richmond Reg'l Airport Comm'n*, 2012, p. 304).

III

In 2015, Austin and Bret Haughwout decided to post two videos to YouTube involving the use of a drone—or, in legalese, an *uncrewed aircraft system* (UAS). First, was a video that showed a handgun attached to a drone that was "firing several times" (*Huerta v. Haughwout*, 2016, p. 2). Second, was a video that showed a "flame-throwing contraption" attached to a drone being used to "spew[] intense streams of fire to scorch a turkey carcass" (*Huerta v. Haughwout*, 2016, p. 2). The videos "went 'viral'" and the FAA "opened an investigation" (*Huerta v. Haughwout*, 2016, p. 2). This recent case, *Huerta v. Haughwout*, was about whether the FAA had the authority to investigate the Haughwouts for their actions involving a drone in the videos uploaded to YouTube. The court concluded that it did (*Huerta v. Haughwout*, 2016). The Haughwouts' creative use of a drone is a strong example of how novel aviation technologies, such as drones, are complicating the civil aviation regulatory regime.

One of these complications is the issue of airspace rights. Although the key issue in the *Haughwout* case was not directly about airspace, Judge Meyer did briefly address the matter. "It appears from oral arguments as well as from the FAA's website" wrote Judge Meyer, "that the FAA believes it has regulatory sovereignty over every cubic inch of outdoor air in the United States (or at least over any airborne objects therein) [citation omitted]" (*Huerta v. Haughwout*, 2016, p. 8). Quoting the fundamental conclusion in *Causby* that "'[t]he landowner owns at least as much of the space above the ground as he can occupy or use in connection with the land,'" Judge Meyer wondered, "does it follow that this foundational principle must vanish or yield to FAA dictate the moment that a person sets any object aloft… no matter how high in the airspace outside one's home?" (*Huerta v. Haughwout*, 2016, p. 9). Mirroring the words of Justice Douglas in *Causby*, Judge Meyer conceded "[t]his case does not yet require an answer to that question" (*Huerta v. Haughwout*, 2016, p. 9). But Judge Meyer asserted that "the next generation of drones and similar flying contraptions will continue to challenge and shape the law that governs them" (*Huerta v. Haughwout*, 2016, p. 9). He then encouraged readers to "*see generally*" Banner (2008) (*Huerta v. Haughwout*, 2016, p. 9).

Airspace and Drones

The current airspace ownership legal landscape is best described by the Wisconsin Supreme Court in *Brenner*. However, while that description may be digestible for many, the *Brenner* opinion, along with the others—*Causby*, *Griggs*, etc.—is not as specific as some legal scholars, attorneys, or property owners might prefer. Consequently, there remains fiery debate about low-altitude airspace ownership. The advent of drones, and air taxis, is fueling that debate. A preponderance of recent academic literature supports this notion (Rule, 2012; Rule, 2015; Gustafson, 2017; Ravich, 2020; Miller, 2020; Donohue, 2021; Skorup, 2022a; Rule 2022).

Indeed, the *Haughwout* case is just one example of how novel technologies will "challenge and shape the law that governs them" (*Huerta v. Haughwout*, 2016, p. 9). As to the question of drones and low-altitude airspace, the Court of Appeals of Michigan wrote in *Long Lake Twp. v. Maxon* (2021):

> Although the United States Supreme Court has rejected the ancient understanding that land ownership extended upwards forever, landowners are still entitled to ownership of some airspace above their properties, and intrusions into that airspace will constitute a trespass no different from an intrusion upon the land itself. [Citation omitted]. Drones fly below what is usually considered public or navigable airspace. Consequently, flying them at legal altitudes over another person's property without permission or a warrant would reasonably be expected to constitute a trespass. We do not decide whether nonpermissive drone overflights *are* trespassory, because we need not decide that issue" (p. 539–540).

Ambiguities remain to be explored in future cases. In 2020, the Government Accountability Office (GAO) recognized as much. The GAO explored the current legal issues surrounding low-altitude airspace in the context of drone operations. GAO (2020) identified several unresolved areas consistent with the preponderance of academic literature, including:

> Whether Congress may use its power under the U.S. Constitution's Commerce Clause to regulate all UAS operations, including non-commercial, non-interstate, *low-altitude operations* [emphasis added] over private property, and if so, whether Congress has authorized FAA to regulate all such operations in FMRA or other legislation (p. 4).
>
> And:
>
> What impact possible Fifth Amendment-protected property rights held by landowners in the airspace within the "immediate reaches" above their property, as recognized by the U.S. Supreme Court in *United States v. Causby* and other legal precedents, may have on federal, state, local, and tribal authority over low-altitude UAS operations (p. 4).

As to the question of what constitutes navigable airspace for UAS operations, according to GAO (2020), the Department of Transportation's (DOT) perspective is "'for the purposes of the definition of the term navigable airspace, zero feet ('the blades of grass') is the minimum altitude of flight for UAS'" (p. 6), a position also held by the FAA. Moreover, the FAA's position is its authority to regulate air commerce—a term not constrained by the definition of navigable airspace—gives the agency full authority to regulate drones at low altitudes (GAO, 2020).

In contrast to the FAA's perspective, GAO (2020) also found "some state and local governments and legal commentators… have questioned the FAA's authority to regulate UAS operations at low altitudes, at least those conducted purely intrastate and over private property" (p. 8). Similar doubt was expressed by Judge Meyer in *Haughwout*. What is more, Donohue (2021) has declared "it is remarkable" the FAA has taken this perspective and argued "that history and law establish that property owners, and states, control the airspace adjacent to the land [low-altitude airspace, that is]" (p. 2).

Besides the question of federal or state or local regulatory authority, Rule (2015) identified another important airspace question raised by drones, specifically the concept of drone package delivery operations:

> Suppose, for instance, that a U.S. Postal Service office were to begin regularly sending drone flights through the airspace above a neighboring parcel of land as part of a new drone delivery program. Suppose further that the drone flights were relatively quiet but that they occurred several times a day at an average altitude of just fifty feet directly over the neighbor's backyard. Would these regular drone overflights give rise to a compensable Fifth Amendment takings claim? (p. 171–172).

Rule (2015) describes the approach taken by courts to takings claims as an "ad hoc test, which requires courts to make multiple subjective judgments" and contends that this approach "could make it difficult for government entities interested in flying drones over private property to know where they stand under the law" (p. 172). Miller (2020) further investigated the potential issue of takings claims resulting from drone delivery operations. Observing that "most drones would travel within 500 feet of the ground," Miller (2020) suggested, "As of now, it is unclear who owns this airspace" (p. 140). Donohue (2021) offers another argument: "Navigable airspace, as an anchor for expanded federal control, cannot extend to the ground without violating property rights and state sovereignty" (p. 34).

Skorup (2022a) asserts "Constitutional law questions and property rights precedents… will pose daunting legal impediments to broad claims of federal authority over low-altitude airspace and to drone operations above private land" (p. 160). The solution to overcoming that challenge, argued by Skorup (2022a) and Skorup (2022b), is for the FAA to establish drone highways in the sky, designed to facilitate drone delivery operations, among other applications. "[P]ublic officials should lease corridors of airspace above the public rights-of-way, opening up millions of miles of new drone highways while still protecting landowner property rights" (Skorup, 2022a, p. 160).

Yet, some perspectives diverge on the issue. Not all agree with the *unclear* nature of low-altitude airspace ownership, or, for one example, the argument made by Donohue (2021). Turner & Baxenberg (2018) criticized an attempt by the Uniform Law Commission to restrict UAS operations "from flying below 200 feet without express, individual permission from every landowner below" (p. 1). The absence of a clear definition as to the scope of the landowners "exclusive control of the immediate reaches" (*United States v. Causby et ux.*, 1946, p. 264), and a recognition by the Supreme Court in *Causby* itself that the act passed by Congress permitting "the public right of navigation through the sky" is valid, Turner & Baxenberg (2018) argue this "suggests that the federal government has flexibility in defining what lies in the public domain" (p. 2). Counter to Donohue (2021), Turner & Baxenberg (2018) argue "[t]he idea that property owners have the right to exclude drones flying above their property simply 'has no place in the modern world'" (p. 2).

Moreover, Turner & Baxenberg (2020) argue that "[p]roperty rights advocates overread Causby and [m]isunderstand aviation law" (p. 2). In their interpretation of *Causby*, "the only 'claim' that a property owner has in regard to airspace occurs when frequent flights within the airspace affect the use of the ground" (Turner & Baxenberg, 2020, p. 2). Emphasizing that "Causby *Did Not Establish a Property Right in Airspace*" (Turner & Baxenberg, 2020, p. 2) (emphasis in original), Turner & Baxenberg (2020) argue the *Causby* precedent does *not* support the argument that there should be a statutorily defined altitude at to which the "immediate reaches" of property extends.

Further, in a legal brief submitted to the U.S. Court of Appeals for the District of Columbia Circuit (D.C. Circuit), Turner & Baxenberg (2021) argued that in *Causby*, "the Supreme Court confirmed that real property owners do not have a property right in the adjacent airspace that would allow them to exclude aircraft from flying over that property" (p. 26). "Just as low-altitude airspace regulated by the FAA must be considered 'navigable airspace,' [citation omitted]," state Turner & Baxenberg (2021), "that airspace cannot be subject to the ownership or control of millions of private property owners across the country" (p. 27).

Conversely, in a brief submitted to the D.C. Circuit in the same case, Rupprecht et al. (2021) argued, "While FAA is statutorily authorized to regulate the airspace above minimum altitudes of flight prescribed by regulation, FAA, and Congress, have never specifically prescribed minimum altitudes for drones. Only maximum, not minimum, altitudes are prescribed [citation omitted]" (p. 62). This brief challenged recent rulemaking conducted by the FAA arguing, among other things, but germane to this review that this particular "rule's use of the term 'airspace of the United States' claims unfettered authority to regulate all airspace, including down to non-navigable airspace in a private backyard" (Rupprecht et al., 2021, p. 62). The D.C. Circuit's opinion in this case did not specifically address the question of low-altitude airspace ownership in a property rights context (*Brennan v. Dickson*, 2022). The court wrote only that "the FAA identified its statutory authority" in both the proposed and final rules challenged in the case, without expanding on the issue any further (*Brennan v. Dickson*, 2022, p. 39).

Congress has also caught wind of the low-altitude airspace issue. In May 2017, Senators Feinstein, Lee, Blumenthal, and Cotton introduced the Drone Federalism Act. The legislation would, among other things, direct the FAA to:

> [E]nsure that the authority of a State, local, or tribal government to issue reasonable restrictions on the time, manner, and place of operation of a civil unmanned aircraft system that is operated below 200 feet above ground level or within 200 feet of a structure is not preempted (Drone Federalism Act, 2017, p. 2–3).

If enacted, the Drone Federalism Act could resolve some of the low-altitude airspace ambiguities, at least with respect to a state government's authority to regulate low-altitude airspace. Additional proposed legislation would require the FAA to "update the definition of 'navigable airspace'" and provide a formal statutory definition for "immediate reaches of airspace" (Drone Integration and Zoning Act, 2021, p. 4, 2). That definition is, with respect to UAS operations, "any area within 200 feet above ground level" (Drone Integration and Zoning Act, 2021, p. 2).

Airspace and Air Taxis

In addition to the low-altitude airspace debate caused by drones, the impending arrival of air taxis has also sparked some commentary. Air taxis designed for use in Urban and Advanced Air Mobility operations (UAM and AAM, respectively), similar to drones, will operate at low altitudes in busy airspace (FAA, 2020). Ravich (2020) identified airspace as a legal and regulatory barrier to the integration of UAM. Unlike traditional commercial aviation operations, UAM operations are likely to take place within one state or city. Such operations, in the view of Ravich (2020), "seemingly fall within the police powers of local governments in matters related to general healthy, safety, and welfare" (p. 677).

Yet recent moves by the FAA to claim authority "over all airspace 'above the grass'" adds complexity to this burgeoning controversy (Ravich, 2020, p. 677). Additionally, Ravich (2020) notes that the FAA's ability to regulate airspace also extends to "aeronautical activities on the ground," citing a 1944 Supreme Court case, *Northwest Airlines v. Minnesota*, further obfuscating the issue (Ravich, 2020, p. 678). Still, Ravich (2020) maintains that it is "unclear… whether federal authorities (not local or state regulators) will have the power to regulate access and control of the altitude airspace *beneath* the NAS (*e.g.*, 400 – 500 feet above ground level)" (p. 680).

Similarly, Immel & Langlinais (2020) commented that high volumes of UAM operations might "give rise to a claim that the operations are 'substantially' interfering with the landowner's enjoyment of his property" (p. 2). A nuisance claim could also be brought (Immel & Langlinais, 2020).

All this is to highlight the various perspectives scholars, practicing lawyers, and courts seem to be taking in addressing the airspace issue for the contemporary age of aviation. At the time of this writing, the FAA appears to be unpersuaded by any scholarly debate thus far. The agency's position remains: "FAA rules apply to the entire National Airspace System -- there is no such thing as 'unregulated' airspace" (FAA, 2021).

Conclusion

Airspace ownership, *to wit*, low-altitude airspace ownership, is a complex and inexact legal issue. Innovative aviation technologies and operational concepts, such as drones and UAM air taxis, are poised to define the modern age of aviation operations. Yet historic and contemporary literature highlights regulatory gaps and areas within the law that are unclear as to the governance of certain novel aviation operations. The history of airspace ownership controversies, from the *ad coelum* doctrine to *Causby*, and now to more recent controversies, shows that low-altitude airspace ownership remains an important, contested issue. This review should serve as a guide for future research and scholarship examining that important, contested issue. To be sure, that future research and scholarship must continue to suggest solutions to the complexities presented by this policy challenge.

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #2

3-27-2023

A Bibliographical Analysis of Pragmatic Strategies Responding to the Pandemic Crisis in Aviation

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The aviation industry has suffered from the COVID-19 pandemic since early 2020. Airlines, airports, and manufacturers reacted to fight against the disease to protect passengers as well as remain sustainable. The purpose of this study is to analyze existing archives and discover strategic plans implemented by essential actors of the commercial aviation system. Using inductive qualitative analysis in conjunction with VOSviewer bibliographical data visualization, this study unveils the practical strategies of resilience enacted by the airline industry, manufacturers, and commercial airports during the pandemic time. Based on the Crisis Response Matrix from Suk and Kim, airlines' survival strategies during COVID-19 include passenger protection, operational retrenchment, innovation, and long-term managerial plans. Manufacturers' main approaches are expanding business with maintenance, repair, and overhaul (MRO) on top of alternative fuel innovations for emission reduction. Remarkably, airports adopt policies and protocols to screen and protect passengers, share information about infected passengers, and create a contactless airport environment for the prevention and control of pandemic infectious diseases. Synthesis tables containing discoveries are provided for practitioners' future reference.

Recommended Citation:
Lu, C, Yin, T., Cheng, M., Karanki, F. & Fu., H. (2023). A Bibliographical Analysis of Pragmatic Strategies Responding to the Pandemic Crisis in Aviation. *Collegiate Aviation Review International*, 41(1), 29-55. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9402/8468

Introduction

The aviation industry is one of the most popular modes of international transportation. The United States Federal Aviation Administration (FAA) stated that aerospace and other related industries made up 5.2% of the U.S. gross domestic product (GDP) in 2016 (Federal Aviation Administration [FAA], 2020). Based on Bureau of Transportation Statistics (BTS) data, after the COVID-19 pandemic hit at the beginning of 2020, passenger volume dropped to below 400 million passengers, a 62.2% decrease in passenger count and a 68.6% decrease in revenue-passenger-miles (RPM) leading to a net loss of USD$42 billion among US carriers, as of quarter two of the 2021 fiscal year (BTS, 2021). Despite the exponential increase in air cargo shipping in 2019 during the COVID-19 pandemic outbreak (International Air Transportation Association [IATA], 2019, 2021), only 4.5 billion passengers traveled on 38.3 million flights traveling around the world (International Civil Aviation Organization [ICAO], 2019).

The global pandemic is not new to the aviation industry. China took aggressive emergency management measures to successfully restore the business scale during the severe acute respiratory syndrome (SARS) outbreak between 2002 and 2003. During the Middle East Respiratory Syndrome (MERS) outbreak between 2012 and 2017, South Korea reported a 12% decline in revenue-passenger-kilometers (RPKs) right after the confirmation of MERS transmission via aircraft (IATA, 2020). The outbreak of Ebola between 2013 and 2016 infected 28,602 people causing Sierra Leone alone a 13% decline in seat capacity in 2014 (Amankwah-Amoah, 2016). However, these numbers would pale in comparison to the worldwide COVID-19 pandemic (World Health Organization [WHO], 2022). While the aviation industry is gradually recovering from the impact of coronavirus, strategies being successfully developed and deployed shall be known so the aviation industry can learn and prepare for the future public health crisis.

Literature Review

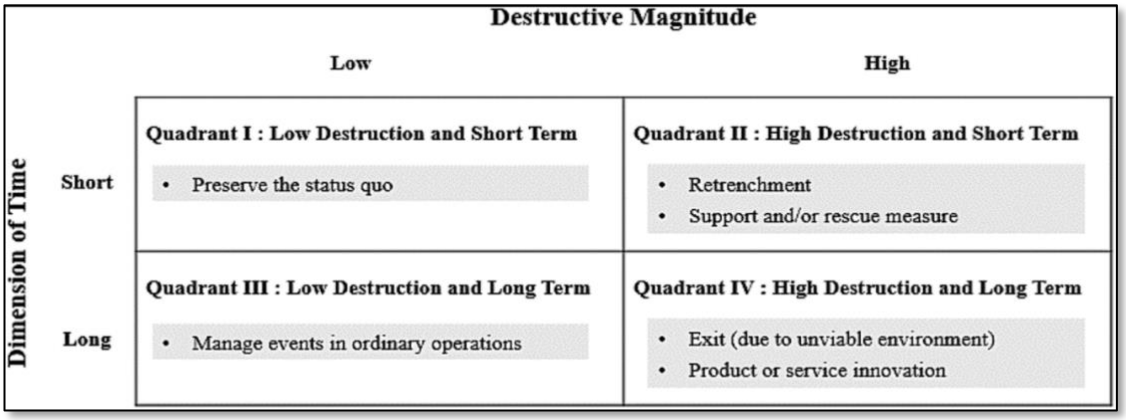
The aviation industry is very fragile, as examined by the SARS, MERS, and H1N1 pandemics that struck in the last two decades, which sheds light on the criticality of infectious disease prevention programs (Centers for Disease Control and Prevention [CDC], 2019). In tandem, IATA (2022), in response to the COVID-19 global health crisis, has created an effective Health Safety Checklist for Air Providers (IHSC) that encapsulates the essential aspects of disease spread prevention. The IHSC suggests systemic approaches for airline operations by providing a new standard of safety protocols and sanitation. The IHSC advocates a communication avenue between passengers and airlines from pre-departure to post-arrival, staff training, cleaning, and sanitation process, installation of onboard high-efficiency particulate air (HEPA) filters, embarking and disembarking procedures as well as employee self-awareness working processes (IATA, 2022). IATA also expresses the adoption of the epic Safety Management System (SMS) to identify health concerns and pandemic hazards prior to an etiological incident. Following the health SMS (HSMS), IATA suggests a health safety risk management (HSRM) to assess the risk (likelihood and severity) of each hazard imposed by the pandemic (IATA, 2022). These systems are crucial to identifying failure points in the system for the airline to take advanced action. The robust ideas that HSMS and HSRM bring to the aviation industry yield an effective ability to offer proactive solutions.

Challenges and Response of Airlines

Amankwah-Amoah (2016) stated how the airlines followed three influential stages in mitigating the evolution of an epidemic into a pandemic, including 1) the recognition stage - disease analysis and policy development; 2) the retrenchment stage – reduction of air service to and from high-risk regions, and 3) recovery stage - return to new and normal operations with improved tactics of disease prevention (Amankwah-Amoah, 2016). Moreover, Suk and Kim (2021) give the 2 x 2 matrix describing the varying responses that a health crisis might invoke based upon the dimension of time and the destructive magnitude of the crisis (see Figure 1).

Figure 1

Quadrants of Response Strategy Matrix



		Destructive Magnitude	
		Low	High
Dimension of Time	Short	**Quadrant I : Low Destruction and Short Term** • Preserve the status quo	**Quadrant II : High Destruction and Short Term** • Retrenchment • Support and/or rescue measure
	Long	**Quadrant III : Low Destruction and Long Term** • Manage events in ordinary operations	**Quadrant IV : High Destruction and Long Term** • Exit (due to unviable environment) • Product or service innovation

In the case of COVID-19, many airlines initially moved quadrants from Quadrants I to Quadrants II once the severity of the pandemic started hitting the industry. Quadrants II is where the industry seeks governmental help when the liquidity of assets is an immense struggle for airlines. Airlines receive aid in the form of grants and loans such as the Coronavirus Aid, Relief, and Economic Security (CARES) Act. Furthermore, airlines begin hunkering down in Quadrant II, cutting back on revenue loss such as reducing flights, laying off employees, and other methods. For a longer impact, airlines would move from Quadrant II into Quadrant IV, where airlines consider initiatives to change the business model and continue surviving (Suk and Kim, 2021). Airlines would move from Quadrant IV to Quadrant III, maintaining realistic operations while hoping to grow into the new normal (Suk & Kim, 2021).

Challenges and Response of Airports

Airports, serving as the node of daily aviation operations, process passengers and cargo from different countries. As the major country's point of entry for international visitors, airports are undoubtedly the focal point of epidemic prevention. WHO’s Article 20 of the International

Health Regulation (IHR) (2005) indicates airports possess unique characteristics, which require the highest level of sanitation, control, and reporting procedures during pandemics (WHO, 2005). For instance, Singapore Changi International Airport, Dubai International Airport, and Doha Hamad International Airport, where only international flights process a large volume of transit traffic, would carry significant responsibility for executing epidemic prevention plans. These responsive plans include four intertwined levels: policy, process, technology, and individual levels (Arora, Tuchen, Nazemi, & Blessing, 2021). For policy and process levels, Changi airport developed the Transit Holding Areas (THA) concept, which requires transit passengers to deboard after arrival and are immediately directed to the transit holding area to avoid cross-contamination. Technological innovations such as no-touch security screening, online check-in systems, e-boarding passes, and facial recognition are enacted to interfere with communicable paths (Berry, Danaher, Aksoy, & Keiningham, 2020). Like the IATA's HSRM, a pandemic threat matrix provides the danger levels of a public health problem as well as corresponding recommendations, while the terminal design should have the characteristic of geometrical simplicity and modularity, which allows converting the function of terminal layout for a dynamic emergency demand (Shuchi, Drogemuller, & Buys, 2017; Štimac, Pivac, Bračić, & Drljača, 2021).

Airports in the Post-Public Health Crisis Era

The Airports Council International (ACI) provides a series of experience-based guidelines: operational and managerial recommendations offering new concepts and standards based on the latest technology trend (Airport Council International, 2020). Abeyratne (2020) promulgates systematic general training for airport managers, as most do not realize what artificial intelligence (AI) and statistical algorithms can be useful for disease forecast and prevention during a public health crisis. However, the collaborative synergy among airports worldwide regarding information sharing would be imperative, while ACI, IATA, and ICAO can be the platform to coordinate the existing data for analysis. During the COVID-19 pandemic, airports are deemed dangerous places due to populated passengers and employees. Establishing safety protocols to ease passengers' fear of aviation is necessary. Some researchers have suggested and enacted safety procedures to create a comfort zone or onboard social distancing against possible infections (Abeyratne, 2020; Tuchen, Arora, & Blessing, 2020). The learning curve of rebuilding passengers' confidence in airport safety will take a relatively long time, but archived lessons and experiences would be useful for risk analysis and proactive controls.

Aviation Manufacturers Survivability

During the downturn in the aviation industry in the aftermath of the 2001 terrorist attacks, the purchasing and leasing of aircraft decreased, but the aviation parts industry was able to be profitable due to an exponential increase of both C and D checks or overhauls (Schneider, Spieth, & Clauss, 2013). This can be seen in Boeing's financials which showed a backlog of $377 billion and 535 added net commercial orders, and $16 billion in revenue. In 2021, the delay of Air Force One, the failure of the Starliner Launch, and the continued difficulties in getting China to approve the airworthiness of the 737-MAX (Boeing, 2022) while Airbus experienced a €62 billion increase in order intake, nearly doubling their 2020 order intake despite 264 orders being canceled resulting in record net income of €4.2 billion for the year (Airbus, 2022). While there will not be a noticeable immediate effect regarding new orders of large aircraft, Boeing earned significant profits from the global market of Maintenance, Repair, and Overhaul (MRO). Besides, a recent trend shows flexibility in layout configuration rather than compactness and efficiency in response to the international passenger reduction due to travel restrictions, flight cancellations, or lockdowns (Bouwer, Saxon, & Wittkamp, 2021; Collings, Corbet, Hou, Hu, Larkin, & Oxley, 2021). On the other hand, Airbus has strongly gained the upper hand in the battle between the American and European juggernauts. What Airbus did was an abandonment of practices that led to "Eurosclerosis"[1] (Archibugi, 2020, p.2). That said, to recover from COVID-19, European companies came together across national lines, avoided over-regulation, and embraced emergent technologies that Airbus has already been successful.

Supply Chain During the Pandemic

Another less visible hit by the pandemic is the jet fuel industry. With severe reductions in the use of AvGas and Jet A, major fuel stocks stood at 95% fuel storage capacity resulting in a drop in fuel prices (Tisdall, Zhang, & Zhang, 2021). Economists are worried that COVID-19 might result in unique long-term consumer behavioral changes that could shape the benefit of reducing global CO_2 emissions (Youssef, Zeqiri, & Dedaj, 2020). The fuel price has been in a promptly changing marketplace. The gruesome fluctuations, currency inflation, and ill workers have impeded the smooth fuel supply chain to be functional, from delayed loading and unloading process to ground transportation congestion. Moreover, the aviation industry typically does not use maritime cargo shipping parts or components due to the nature of time sensitivity as well as the corrosive sea salt. As a result, difficulties in securing space in air cargo have generated an additional financial burden for shippers. Another challenge is the recruitment, retention, and payment of a highly skilled workforce. Businesses must invest heavily in the workforce as competition is fierce (Paul, Chowdhury, Moktadir & Lau, 2021) while considering cost efficiency, agility, flexibility, and carefully leveraging environmental footprint (Farooq, Hussain, Masood, & Habib, 2021). The aviation supply chain has been affected substantially related to aviation fuel production, aircraft parts shipment, currency exchange rate, and lack of skilled professionals.

Global Governance of Pandemics

The aviation industry inevitably inherits the nature of uncertainty and complexity of global governance responding to COVID-19. Both ICAO and WHO establish regulations and recommended practices for fighting against global health crises, such as ICAO's Article 14 of the Convention on International Civil Aviation (ICAO, 2004) and WHO's International Health Regulations (IHRs) (WHO, 2016). However, Cuinn and Switzerr (2019) point out that the global governance of the public health crisis in the aviation industry is highly complex and hard to predict in the past due to the lack of interactions between countries and corresponding laws. Fortunately, the Severe Acute Respiratory Syndrome (SARS) in 2003 demonstrated an opportunity to resolve the conflicts and regulatory gaps between ICAO and WHO in coping with the pandemic. ICAO reviewed and modified existing Standards and Recommended Practices

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[1] "Overly rigid labor markets and overregulation of the economy in favor of established special interests in Europe in the `70s and the `80s"

(SARPs) in the Chicago Convention related to passenger and crew health, considering global public health issues (ICAO, 2004). Two huge modifications to SARPs include creating a Passenger Locator Form, which helps track passengers who are potentially exposed to infectious diseases during a flight. A Universal Precaution Kit has been introduced on board to help crew members manage possible in-flight infectious disease incidents.

ICAO took a further step to create a “coordinating group” in 2016 under the Collaborative Arrangement program for the Prevention and Management of Public Health Events in Civil Aviation (CAPSCA). Currently, the CAPSCA acts as a linkage between countries of the IHR and the Chicago Convention (Cuinn & Switzerr, 2019). Non-governmental organizations, such as International Air Transport Association (IATA) and Airports Council International (ACI), as well as experts and private foundations within the aviation and public health fields, have been actively involved in such programs helping design detailed guidelines and suggestions under the laws and regulations published by ICAO and WHO. The ICAO SARPs have limited effects on stopping the transmission of the contagious virus via air transportation, while a state/country could add uncertainty and barriers interrupting the harmonic collaboration. Lockdowns and strict border controls posted by various countries during the COVID-19 pandemic directly resulted in the massive cancellation and suspension of international flights (Arora, Tuchen, Nazemi, & Blessing, 2021). Karns et al. (2015) pointed out that the vital actors in global governance are generally identified as states, intergovernmental organizations, non-governmental organizations, experts and epistemic communities, networks and partnerships, multinational corporations, and private foundations. By the time of this study, global governance of the public health crisis in the aviation industry remains challenging such as protocols and policies between China and U.S.A.

Lu & Sun (2021, December) completed a reference list including studies and guidelines concerning aviation operations when facing communicable diseases. A comprehensive reference list was provided, but it only focused on gathering information with no detailed summary of the specific practices. Lu and Sun’s study presented a macroscopic view but did not deliver pragmatic solutions, which shapes an opportunity for an in-depth study.

Research Questions

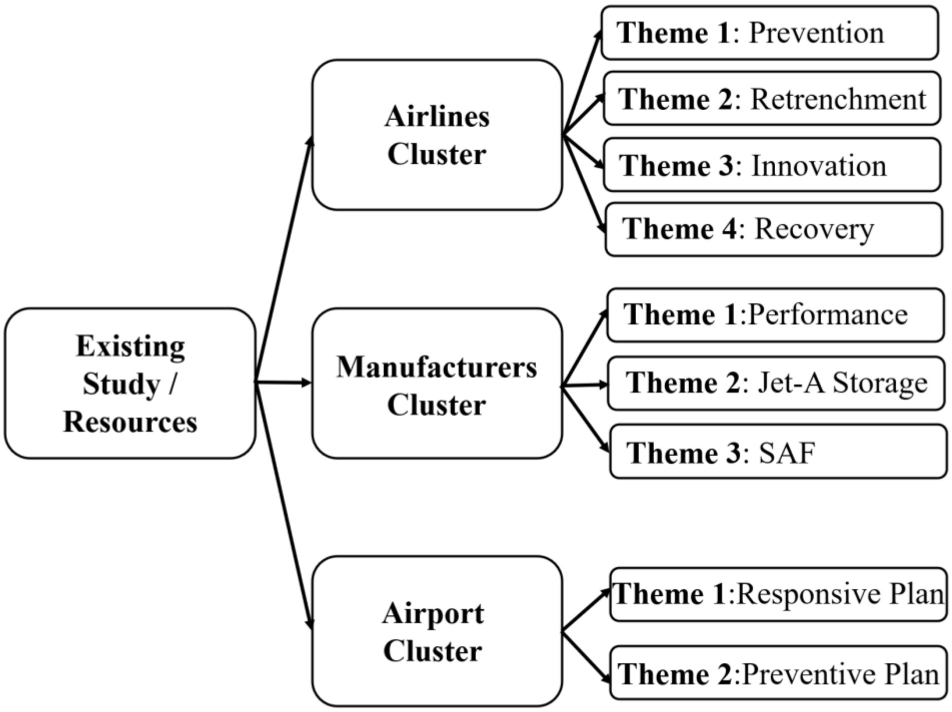
For aviation emergency response education, this study intends to understand three essential segments of the aviation industry – airlines, manufacturers, and airports, regarding what active defenses have been implemented to fight against the COVID-19 pandemic. The research questions are then defined as follows:

1. What were the strategies of resilience enacted by the airline industry during the public health crisis?
2. How did manufacturers remain sustainable during the global pandemic?
3. What innovations did commercial airports implement to cope with the global pandemic?

Research Methodology

The authors use a qualitative approach with inductive Meta-Analysis as the methodology to collect and analyze archives in conjunction with the application of VOSviewer for bibliographical visualization (Martínez-López, Merigó, Valenzuela-Fernández, & Nicolás, 2017). As defined by Timulatk (2009), Meta-Analysis is based on existing finished research that provides a more comprehensive analysis and findings regarding the given topic. The trustworthy documentation is reviewed concerning pandemic outbreaks, including 2003 SARS, 2012 MERS, 2013 Ebola, and COVID-19. Figure 2 briefly shows the data collection approach of this study.

Figure 2
Data Collection Illustration



To avoid trait error, this study purely focuses on existing finished research and cases and has no interference with people. The inter-rater tactic is used to secure the reliability of the result (Schwarz-Shea & Yanow, 2013). This study uses criterion validity to measure how the result reflects on present implementation (Salkind, 2018).

Findings

Strategies of Resilience Enacted by the Airline Industry

Looking into the myriad of studies, many common thematic areas displayed themselves. This study inductively categorizes four main stages that the airlines go through, those being the

P.R.I.M., namely Prevention (P), Retrenchment (R), Innovation (I), and Long-term Management (M), representing the primary strategies of resilience.

Prevention

During the Prevention stage, airlines focused on monitoring and assessing the situation and crisis at hand while closely looking upon governmental guidance and instruction on how to proceed. Especially after governmental instruction, many studies found that airlines began to alter their networks in response to passenger volume change and simultaneously mitigate the possibility of the virus spreading (Abate, Christidis & Purwanto, 2020; Amankwah-Amoah, 2020; Bielecki et al., 2021; Suk & Kim, 2021; Tuite, Watts, Khan, & Bogoch, 2019). Additionally, airlines implemented new standard operating procedures in the hope of eliminating the spread of active health threats to crew members and other passengers, including altering boarding and exiting patterns, enhancing cabin cleaning procedures, crew protective equipment, and elevating cabin hygienic and air-circulation standards (Amankwah-Amoah, 2016; Amankwah-Amoah, 2020; Bielecki et al., 2021; Chikodzi, Dube, & Nhamo, 2021; Cohen et al., 2016; IATA, 2022; Mangili & Gendreau, 2005; Suk & Kim, 2021; Thaichon, 2021).

Retrenchment

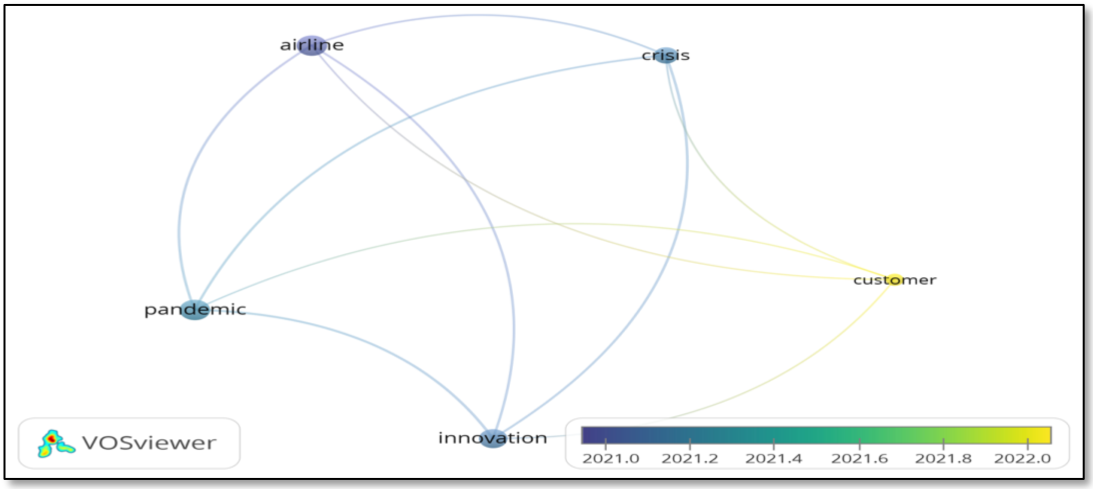
Retrenchment is seeking to restructure the financial portfolios of its fleet through a variety of means such as leasing, bank loan refinancing, initial public offers, etc. The Retrenchment stage can take many forms with the goal of maintaining operations and staying out of financial trouble while preserving a good public image. Through the Retrenchment strategy, many airlines acted to survive due to reduced air travel and took reactive actions by removing less profitable flight routes (Abate, Christidis & Purwanto, 2020; Albers & Rundshagen, 2020; Amankwah-Amoah, 2020; Cohen et al., 2016; Czerny, Fu, Lei, & Oum., 2021; Suk & Kim, 2021; Tuite, Watts, Khan, & Bogoch, 2019), furloughing workers or offering early retirement packages (Amankwah-Amoah, 2020; IATA, 2022; Thaichon, 2021), canceling procurement contracts or postponing aircraft deliveries, retiring costly or aged aircraft, grounding less efficient aircraft (Albers & Rundshagen, 2020; Amankwah-Amoah, 2020; Bjelicic, 2012), and liquidating assets via aircraft sales among other methods (Albers & Rundshagen, 2020; Bjelicic, 2012; Chikodzi, Dube, & Nhamo, 2021; Suk & Kim, 2021). Airlines would be patient and attempt to wait out the worst timeframe of the global health crisis and see the resurgence of air travel.

Innovation

The Innovation stage brings to light that airlines attempt to produce revenue in regularly unconventional ways, such as reconfiguring aircraft to accommodate greater cargo storage and shipping needs. Many airlines reconfigured their passenger aircraft fully into cargo aircraft or efficiently divided useful aircraft spaces while transporting fewer passengers (Abate, Christidis & Purwanto, 2020; Albers & Rundshagen, 2020; Cain & Pascual, 2021; Chikodzi, Dube, & Nhamo, 2021; Cohen et al., 2016; Czerny, Fu, Lei, & Oum., 2021; Islam, Lahijani, Srinivasan, Namilae, Mubayi, & Scotch 2021; Leder & Newman, 2005; Mangili & Gendreau, 2005; Suk & Kim, 2021; Thaichon, 2021). Additionally, airlines continued searching for means to refinance and leverage aircraft and other assets. Some airlines restricted frequent flyer programs allowing for more cashflow (Abate, Christidis & Purwanto, 2020; Albers & Rundshagen, 2020; Bjelicic, 2012; Cain & Pascual, 2021; Chikodzi, Dube, & Nhamo, 2021; Czerny, Fu, Lei, & Oum., 2021; Suk & Kim, 2021). Using VOSviewer, the bibliographical clusters are provided below (see Figure 3), showing Innovation, Crisis Management, Pandemic Control, and Customer are intertwined and closely correlated.

Figure 3

Airline Resilience Strategies Facing Public Health Crisis



Long-term Management

Lastly, when airlines are facing a lengthened global health crisis, airlines would adopt new procedures, such as requiring face masks, prescreening passengers, distancing passengers, and frequently cleaning cabins, just to name a few, in order to stay operational until the full return of normal air travel (Amankwah-Amoah, 2016; Amankwah-Amoah, 2020; Bielecki et al., 2021; Chikodzi, Dube, & Nhamo, 2021; Cohen et al., 2016; IATA, 2022; Islam, Lahijani, Srinivasan, Namilae, Mubayi, & Scotch 2021; Mangili & Gendreau, 2005; Read, Diggle, Chirombo, Solomon, & Baylis., 2014; Suk & Kim, 2021; Thaichon, 2021; Tuite, Watts, Khan, & Bogoch, 2019). Table 1 below shows the *Bibliographical Overview of Airline Actions Facing Public Health Crisis*.

Table 1

Bibliographical Overview of Airline Actions Facing Public Health Crisis

	Prevention			**Retrench**				**Innovate**		**Recovery**
Sources	Assessment and Monitoring	Network Alteration	Implement New SOPs	Flight Removal	Lay Off Workers	Retire Aircraft	Liquidate Assets	Refinance	Restructure Aircraft	Manage
Abate et al. (2020)		X		X				X	X	
Albers & Rundshagen (2020)				X		X	X	X	X	
Amankwah-Amoah (2016)		X	X							X
Amankwah-Amoah (2020)	X	X	X	X	X	X				X
Bielecki et al. (2020)	X	X	X							X
Bjelicic (2012)						X	X	X		
Cain & Pascual (2021)								X	X	
Chikodzi at al. (2021)			X				X	X	X	X
Cohen et al. (2016)	X		X	X					X	X
Czerny et al. (2021)				X				X	X	

Sources	Prevention			Retrench				Innovate		Recovery
	Assessment and Monitoring	Network Alteration	Implement New SOPs	Flight Removal	Lay Off Workers	Retire Aircraft	Liquidate Assets	Refinance	Restructure Aircraft	Manage
IATA (2022)			X		X					X
Islam et al. (2021)	X								X	X
Leder & Newman (2005)	X								X	
Mangili & Gendreau (2005)	X		X						X	X
Read et al. (2014)			X							X
Suk & Kim (2021)		X	X	X			X	X	X	X
Thaichon (2021)			X		X				X	X
Tuite et al. (2019)		X		X						X

Manufacturers' Strategies to Remain Sustainable During the Global Pandemic

In contrast to many other parts of the aviation industry discussed above, the aviation parts manufacturing industry did not experience a major recession during the public health emergency. Yet, the aviation supply chain has been impacted greatly. This study analyzes nineteen (19) articles and summarizes them into three thematic categories: Aviation Parts Manufacturing, Jet-A Storage, and Sustainable Fuels. The focus of each article and the corresponding theme are provided in Table 2.

Table 2
Overview of Article Bibliographies

Source	Aviation Manufacturing Performance	Jet-A Fuel Storage	Alternative Sustainable Fuels
Archibugi, 2020	x		
Airbus, 2022	x		
Boeing, 2022	x		
Bombardier, 2022	x		
Bouwer et al., 2021	x		
Collings et al., 2021	x		
COMAC, 2020	x		
Faber et al., 2022			x
Farooq et al., 2021	x		
GE, 2022	x		
Hosseini, 2022		x	
Nie et al., 2022			x
Paul et al., 2021			x
Santos & Delina, 2021			x
Schneider et al., 2013	x		
Tisdal et al., 2021		x	
Youssef et al., 2020		x	
Yusaf et al., 2022			x

Aviation Parts Manufacturing Industry

All the big players: Airbus (2022), Boeing (2022), GE Aviation (2022), Bombardier (2022), and COMAC (2020), experienced growth and profits due to heavy demands in Maintenance, Repair, Overhaul (MRO) services during the pandemic (Farooq, Hussain, Masood, & Habib, 2021). Both reduction of demand for new aircraft and the sheer size of the backlog of producing aircraft eclipse the number of active aircraft in the market. However, the fact is that many factories did not shut down due to the aviation manufacturing industry being considered essential maintenance work (Collings, Corbet, Hou, Hu, Larkin, & Oxley, 2021). This has been consistent compared to the case of SARS and Ebola pandemics (Archibugi, 2020). One informative aspect during the COVID-19 was that the demand for large aircraft like Boeing B777 and Airbus A380 in the early 2000s shifted to the need for smaller, more efficient aircraft due to the lack of passengers and flight cancellations (Schneider, Spieth, & Clauss, 2013). The impetus on aviation manufacturers is leaning toward fuel efficiency from smaller jets rather than relying on large capacity sizes (Bouwer Saxon & Wittkamp, 2021).

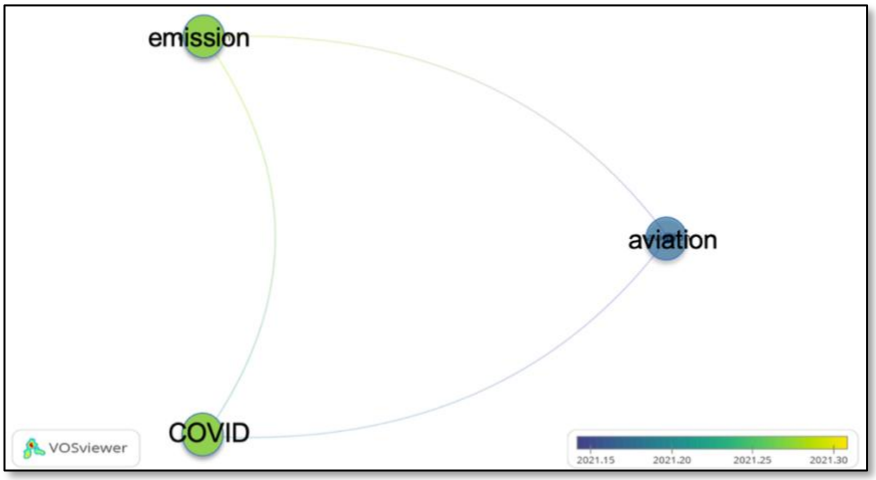
Jet-A Fuel Storage

A major problem many people may not be aware of in the aviation industry caused by the pandemic revolves around the usage and storage of aviation fuel (Youssef, Zeqiri, & Dedaj, 2020). Crude oil is the source of gasoline, kerosene (Jet-A), diesel, asphalt, petroleum, lubricants, and various plastics, which are all produced consistently during the refining process. Whenever gasoline is refined from crude oil, all other products are also created regardless of whether they are in demand or not. With the airline industry experiencing a major downturn between May 2020 and December 2021, the reserves of Jet-A fuel have been almost at capacity causing Jet-A to be sold at a loss to keep up with gasoline production (Tisdall, Zhang, & Zhang, 2021). Yet, through sanctions against Russian oil, imports of crude oil have gone down, which has had two effects on the Jet-A industry: 1) less Jet-A is being produced, and 2) using more fuel around restricted Russian airspace. While most countries have lifted travel restrictions, however, at the time of this study, China, the second largest airline market, continues reinforcing the "Dynamic COVID Zero" strategy and airline "Circuit Breaker" policy. The usage as well as storage of Jet-A in the long-term stays unpredictable (Hosseini, 2022).

Sustainable Fuels

Regardless of COVID-19, the aviation industry is tackling the aviation fuel economy and "emissions reduction" challenge by researching alternative, enviro-friendly, or renewable fuels (Paul, Chowdhury, Moktadir, & Lau, 2021). One way this is being handled is by reducing the aromatics (n-alkanes, iso-alkanes, cyclo-alkanes, and methyl/ethyl components) found in Jet-A fuel specifically consumed by large aircraft. Another way being researched is the development of high-energy-density liquid aerospace fluids which are being compiled with new technologies to mimic the hydrocarbon properties of traditional fuels without many of the problematic carcinogens (Nie, Jia, Pan, Zhang, & Zou, 2022). One exciting potential fuel alternative is hydrogen which is abundant, clean, and produces no carbon emissions, which has the potential to help ease Global Warming. The main argument against hydrogen includes its high price and the fact that mixing hydrogen and fossil fuels creates a slighter thrust (Santos & Delina, 2021). But as seen in the reports from Boeing, Airbus, COMAC, and Bombardier, helping researchers to achieve environmentally friendly fuels has been at the forefront. While the air transportation industry started to recover from the major pandemic impact, the environment briefly absorbed less quantity of pollutants due to the lack of air travel (Santos & Delina, 2021). Figure 4 below demonstrates three critical bibliographical themes including fuel technology embracing emission reduction during the pandemic time between 2020 and 2021.

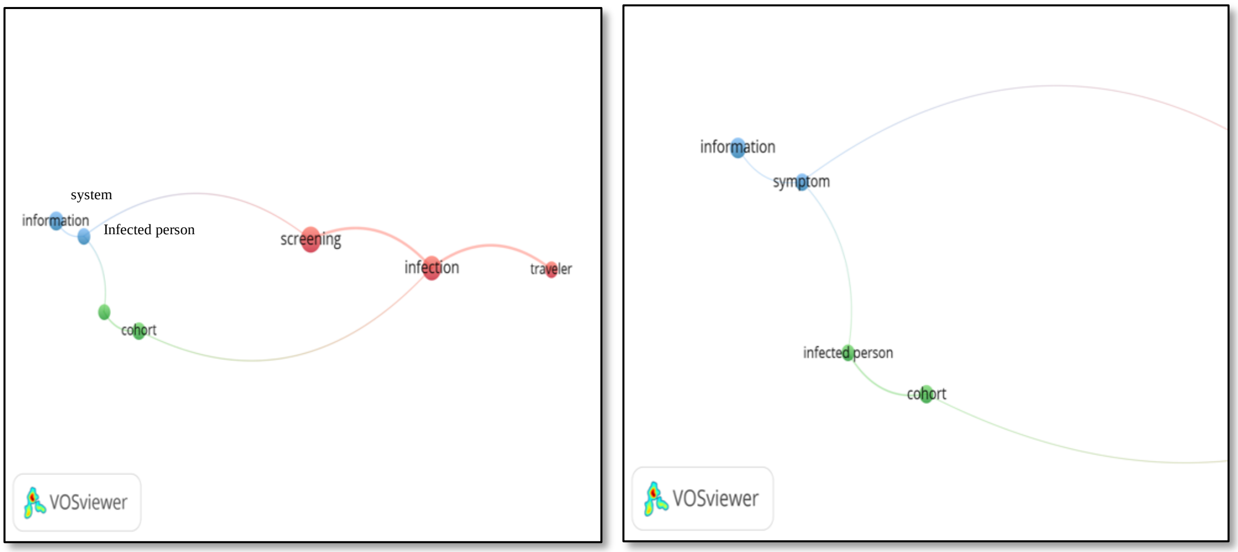
Figure 4
Fuel Technology Innovation - Emission Reduction



Commercial Airports Innovations When Coping With Public Health Crisis

A request for proposal of Transportation Research Board (TRB) Airport Cooperative Research Program (ACRP) 04-25 demanded the development of a web-based reference for airports' response to communicable diseases (TRB, 2021). To understand, this study reviews the responsive plans, preparedness, and sustainability plan of twelve (12) airports. Seven (7) airports are identified as reactive-oriented, as the actions were taken after the existence of a new communicable disease. Using VOSviewer, the authors demonstrate essential bibliographical clusters showing intercorrelated connections among three thematic areas, namely Passenger Screening (red color cluster), Cohort Groups (green color cluster), and Information Sharing (blue color cluster) as the primary emergency response approaches at airports (See Figure 5).

Figure 5
Airport Thematic Areas – Responses to Pandemics



Regardless, the holistic preventive plans as precautions that airports have taken when encountering an outbreak of public health crisis are presented below and in Table 3.

Temperature Screening & Identification

Six (6) out of twelve (12) airports in this study included temperature screening of passengers and staff at airports as one of the procedures against contagious disease spread. It is worth noticing that those six airports are all large in passenger volumes, which means they could be riskier for virus transmission in frequently populated areas. Other airports in this study also mentioned the temperature monitoring policy, but they relied more on the passengers/employees to report voluntarily.

Physical Distancing

All twelve airports in this study included physical distancing as a standard procedure to prevent or slow down the transmission of the communicable virus. Some airports have detailed quarantine/isolation plans, including treating passengers and crews according to the public health emergency policy. Some airports require aircraft doors to remain closed, and passengers and crew must remain on board until permission from the national/local public health agencies if a contagious disease is discovered in flight (Kapiti Coast Airport, 2019; Wichita Airport Authority, 2015). Airports also establish temporary isolation and quarantine locations/facilities at the airport to take care of infected personnel (Fairbanks International Airport, 2019; Kapiti Coast Airport, 2019; Philadelphia International Airport, 2020; Seattle-Tacoma International Airport - Port of Seattle, 2020; Wichita Airport Authority, 2015). Other physical distancing methods such as closing a portion of the terminal, removing seats at airport restricted areas, and 6 feet/1-meter social distancing requirements published by U.S. C.D.C. or equivalent foreign agencies. In conjunction with the required face masks, physical distancing has proven to be the most widely used and the most effective action for an airport to prevent transmission during the pandemic.

Sanitizing & Cleaning

Frequent sanitizing and cleaning the airport facilities, using human beings or robots, is another widely adopted action by airports worldwide. It is believed that frequent sanitizations can significantly reduce the chances of disease transmission happening at the airport, and it is recognized as an essential procedure during the pandemic (ACI, 2020).

Contact Tracing

Only two (2) airports in this study adopted contact tracing as one of their preventive programs facing a public health crisis. One of them is Tulsa International Airport but enforcing it on employees only (Tulsa Airports Improvement Trust, 2020). Another airport, Kapiti Coast Airport, included it under physical distancing as a response to identifying potentially infected staff after a contagious disease has been discovered post disembarkation (Kapiti Coast Airport, 2019). Other airports would provide a passenger’s data only if the national/local public health agencies required it.

Information Seeking

Twelve airports would notify corresponding local or national public health agencies to seek professional guidance and instructions when dealing with a communicable disease (Fairbanks International Airport, 2019; Kapiti Coast Airport, 2019; Melbourne International Airport – Australia, 2020; Minneapolis-St. Paul International Airport, 2021; Narita International Airport, 2020; Pensacola International Airport, 2020; Philadelphia International Airport, 2020; Phoenix-Mesa Gateway Airport, 2009; Seattle-Tacoma International Airport - Port of Seattle, 2020; St. Pete-Clearwater International Airport, 2020; Tulsa Airports Improvement Trust, 2020; Wichita Airport Authority, 2015). Some airports have limited information dealing with new contagious diseases. As a result, more detailed guidelines and instructions published by professional agencies and international organizations are much needed for the airport to eliminate the transmission of diseases at the begging. Several international agreements and protocols require airports to notify public health agencies when discovering the existence or tendency of transmission of disease during operations. The World Health Act 1956 is the most common reference listing most infectious diseases and corresponding procedures an airport should take to reduce the possibility of disease spread (Kapiti Coast Airport, 2019).

Information Dissemination

Airports, except Tulsa International Airport and Phoenix-Mesa Gateway Airport, suggest that information communication with the general public is vital and indispensable to minimize the impact on public health. Communication in the early phase of virus transmission is critical to increasing public awareness, so the general public can take protective measures such as Personal Protective Equipment (PPE) accordingly. Transparent information communication during the pandemic can help rebuild public confidence to travel, which is vital for the industry's recovery from a public health crisis (Melbourne International Airport – Australia, 2020). Airports can also restate information gathered from international or national health agencies to help disseminate essential information.

New Technology

Two airports responded that the implementation of new technology would help contain disease transmission listed in their emergency response programs (ERPs). Understandably, an ERP can only reactionarily adopt the latest technology at the airport. But both airports mentioned that the new touchless technology such as biometrics and advanced kiosks could largely eliminate personal contact and thus reduce the risk of virus transmission (Melbourne International Airport – Australia, 2020; Seattle-Tacoma International Airport - Port of Seattle, 2020).

Target Procedure

Target procedure means the specific procedure that will only apply to a certain type of virus outbreak based on the virus's unique characteristics. In this study, eight airports have target procedures or similar equivalent actions in response to the contagious disease. The most common target procedure is the checklist. Airport authorities tailor-make checklists for a particular type of virus with support from international/national organizations to help quickly identify the spreading tendency and reduce the risk of transmission (Melbourne International Airport – Australia, 2020; Minneapolis-St. Paul International Airport, 2021; Narita International Airport, 2020; Philadelphia International Airport, 2020; Phoenix-Mesa Gateway Airport, 2009; Seattle-Tacoma International Airport - Port of Seattle, 2020; Tulsa Airports Improvement Trust, 2020; Wichita Airport Authority, 2015). A bibliographical overview of the airports' responsive as well as preventive plans to cope with public health crises is provided below in Table 3.

Table 3

Bibliographical Overview of Airports' Plans When Facing Public Health Crisis

	Responsive Plans							
Airport Name	Information Seeking	Information Dissemination	Screening & Identification	Physical Distancing	Sanitizing & Cleaning	Contact Tracing	New Technology	Target Procedures
Melbourne International Airport	x	x	x	x	x		x	x
Minneapolis-Saint Paul International Airport	x	x	x	x	x			x
Pensacola International Airport	x	x	x	x	x			
Philadelphia International Airport	x	x	x	x	x			x
Seattle-Tacoma International Airport	x	x		x	x		x	x
St. Pete-Clearwater International Airport	x	x		x	x			

Tulsa International Airport, NZ	x			x	x	x		x
Preventive Plans								
Kapiti Coast Airport, NZ	x	x		x	x	x		
Fairbanks International Airport	x	x		x				
Tokyo Narita International Airport, Japan	x	x	x	x	x			x
Phoenix-Mesa Gateway Airport	x		x	x	x			x
Wichita Dwight D. Eisenhower National Airport	x	x		x	x			x

Conclusion

The aviation industry is extremely vulnerable to a global health crisis. This study delivers a holistic review for airlines, airports, and manufacturing/MRO industries to sustain from ongoing and future communicable diseases outbreak. The previous studies on a similar topic either only focus on one of the three specific segments of the aviation industry or only provide a macroscopic view of the reference lists. This study provides a list of best practices for each segment of the aviation industry. The operator can use the result of this study as a checklist to identify the most effective approaches to preparing for or recovering from an outbreak of communicable diseases with the consideration of the unique local situation.

This study finds that airlines conduct four main stages, prevention, retrenching, innovation, and recovery, of operations during the public health crisis while expecting a full recovery. For the aviation manufacturing industry, the pandemic did not have a significant impact compared to that of both airline or airport industries due to the increased opportunities to perform MRO and optimized reconfigurations of airplanes for cargo services. Airlines are focusing on the efficiency of smaller aircraft with more environmentally friendly and sustainable operational features. Moreover, the balance point between aviation fuel usage and storage remains unpredictable; in particular when the Russia-Ukraine war continues to develop while China's airline market stays largely intangible.

This study also unveils that airports follow suggested guidelines published by WHO, IATA, and U.S. C.D.C. to construct their preventative and emergency response plans. Information sharing and transparent communication with the flying public can primarily help create public awareness and significantly reduce the risk of communicable diseases at the beginning stage. Other practices such as screening and identification, face masks and physical distancing, and sanitizing and cleaning programs are the top-used practices by airports and are proven relatively effective by the practitioners.

Future Study

There is no air cargo service provider included in this study. A future study on air cargo may be performed to fill the gaps. By the time of the study, China has imposed more strict pandemic policies against public health crises such as "Dynamic COVID Zero," "Stay-at-Home," and "Circuit Breaker" protocols. A future Case Study of the post-COVID pandemic achievement in China compared to other leading aviation countries like the U.S.A and Europe Union countries would be researchable. This study did not measure the effectiveness of the actions taken by the industry. A follow-up benefit-cost study assessing the result of all the efforts shall be performed.

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #3

3-28-2023

Identification, Evaluation, and Causal Factor Determination of Maintenance Errors Common to Major U.S. Certificated Air Carriers

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A mixed methods study was conducted to identify common errors, causal factors, and corrective actions related to maintenance errors that have occurred on aircraft operated by major U.S. air carriers. An initial review of FAA compliance action letters obtained via FOIA for American Airlines, Southwest Airlines, and United Airlines identified errors and causal elements for categorization and further study. Study participants were randomly selected from FAA listings of certificated mechanics and asked to complete a survey. Quantitative data was acquired from participants who completed the survey, and qualitative data was acquired by interviewing a selection of those who completed the initial survey. The study found common errors with the completion of maintenance entries, handling of maintenance documents, the content of maintenance instructions, installation of parts, deviations from maintenance procedures, and maintenance steps or tasks that were overlooked or not performed. Dominant causal factors were identified as a failure to follow instructions or procedural requirements and maintenance instructions that contained inaccurate information or lacked sufficient detail. Dominant human factors identified in the study were complacency and lack of attention. Repetitive or simple tasks were identified as a contributor to complacency and the failure to follow instructions. Demands on mechanics to quickly return aircraft to service also contributed to the performance of maintenance without the use of instructions. Corrective actions included rectification of the initial errors, counseling of employees, and correction of instructions and documentation.

Recommended Citation:
Harper, R. & Bliss, T. (2023). Identification, evaluation, and causal factor determination of maintenance errors common to major U.S. certificated air carriers. *Collegiate Aviation Review International*, 41(1), 56-74. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9419/8469

A publication of the University Aviation Association, © 2023, ISSN: 1523-5955

Introduction

The operation and maintenance of large commercial passenger aircraft are prone to errors that can have devastating consequences. These consequences can include the loss of aircraft, injuries, or even fatal outcomes to aircraft occupants or those on the ground. Errors committed by flight crews operating passenger aircraft tend to receive greater attention from the public and investigators. However, flight operations are just one operational segment wherein errors can be committed. Ground operations and aircraft maintenance comprise other operating segments that are prone to errors. Aircraft maintenance is susceptible to the commission of errors due to the multitude of maintenance tasks which typically require technicians to remove and replace parts in confined spaces and who are often under time constraints to return aircraft to service (Reason & Hobbs, 2003).

Aircraft maintenance is not only costly for air carriers, but errors committed by maintenance personnel can further impact airlines through operational delays or accidents (Kanki & Hobbs, 2008). Maintenance errors committed by aircraft maintenance personnel have been determined to be responsible for 12 to 15 percent of all aircraft accidents and incidents (Rashid et al., 2014). Human factors are recognized as causal factors that lead to the commission of errors, and they have been identified as the root cause of 80 to 90 percent of all aircraft accidents (Erjavac et al., 2018; Shanmugam & Robert, 2015). A 1997 study conducted by Alan Hobbs, who interviewed aircraft technicians, noted 86 safety-related incidents, of which over half were of a type that had previously occurred (Reason & Hobbs, 2003).

Previous studies focused on specific errors that can impact maintenance. A study on maintenance errors reviewed 1,182 Aviation Safety Reporting System (ASRS) reports and found that insufficient communication comprised eight percent of all the reports received, and of that eight percent, over one half were directly related to work turnover communication issues (Parke & Kanki, 2008). The repetitive and monotonous nature of maintenance tasks drove complacency leading to the failure to use or follow technical instructions (Liang et al., 2010). Environmental factors such as poor lighting, confined spaces, and weather conditions can hide defects that would normally be found during a visual inspection by a maintenance inspector (Marais & Robichaud, 2012).

Human factors play a key role in the commission of maintenance errors, but these studies do not identify repetitive maintenance errors shared in common by commercial passenger air carriers. The identification and categorization of these errors and their causal factors would help determine what proactive efforts are required to eliminate or reduce the occurrence of such errors, which in turn would enhance the safety of aircraft operated by air carriers.

Statement of the Problem

Research conducted on aircraft maintenance errors related to United States (U.S.) registered commercial aircraft has predominantly been reactively utilizing statistical data available from the NASA Aviation Safety Reporting System (ASRS) and reports published by the National Transportation Safety Board (NTSB) (Erjavac et al., 2018; Lattanzio et al., 2008). Proactive research such as that conducted by Liang et al. (2010) explored the use of maintenance instructions using an online maintenance assistance platform providing visual instructions as a supplement to traditional printed maintenance instructions. Both reactive and proactive research provides conclusive evidence that a variety of factors affect the commission of maintenance errors, but past studies have not identified the most common maintenance errors shared by U.S. air carriers or actions that could be collectively undertaken by the air carrier industry to prevent those errors. With few exceptions related to events that prompt media and public attention, the vast majority of errors identified by the Federal Aviation Administration (FAA) during their air carrier oversight activities are not made available to the public. In addition, errors discovered internally by air carriers are not shared with the public and are considered privileged information if voluntarily shared with the FAA. The lack of information specific to maintenance errors impacting aircraft operated by U.S. air carriers drove the need to perform this study and identify the most common types of maintenance errors shared by U.S. air carriers and the causal factors for these errors.

Purpose of the Study

This study was conducted to identify and analyze maintenance errors committed by major U.S. certificated air carriers with the intent of identifying and categorizing common errors, the causal factors that led to the commission of these errors, and corrective action measures that mitigated the errors.

Research Questions

Three research questions were proposed for this study:

1. What errors are common to maintenance performed on aircraft operated by major U.S. air carriers certificated under FAR Part 121?
2. Why are these maintenance errors committed?
3. What actions have been or could be instituted to prevent the commission of maintenance errors on aircraft operated by major U.S. air carriers?

Research Methodology

This study employed a mixed-methods research approach to provide initial confirmatory research using quantitative data gathered through the use of surveys followed sequentially by the performance of interviews to gather qualitative data (Patton, 2015). Creswell and Plano Clark (2018) describe the core characteristics of mixed method research as the means to acquire both qualitative and quantitative data allowing integration of the data to achieve results using a research design that is both logical and lies within established principles and theory. According to Patton (2015), "Qualitative data can put flesh on the bones of quantitative results, bringing the results to life through in-depth elaboration" (p.230).

Initial research was conducted by reviewing reports of compliance actions identified by the Federal Aviation Administration (FAA) during their inspections of the four largest US air carriers over the FAA's 2018 fiscal year. This information was requested in accordance with the provisions of the Freedom of Information Act (FOIA) for the four US air carriers that had the highest number of air seat miles (ASMs) for the twelve-month period ending on September 30th, 2018. The four air carriers were identified as American Airlines (247,763,901 ASMs), United Airlines (241,075,102 ASMs), Delta Air Lines (235,325,726 ASMs), and Southwest Airlines (157,317,793 ASMs). Each of the FOIA requests asked for copies of compliance action documents consisting of the compliance action letter sent to the air carriers and closure letters. The FAA Certificate Management Offices (CMOs) for American, United, and Southwest provided copies of documentation that allowed for the categorization of 11 types of errors along with six types of causal factors. Delta's FAA CMO declined to provide information claiming that all of its inspections were considered a component of Delta's voluntary disclosure program.

Analysis of the FAA's 2018 compliance action letters identified maintenance errors that fell into 11 categories. The most predominant maintenance errors are associated with maintenance record entries (93 instances), task deviations (58 instances), tasks not performed (44 instances), and errors noted with the content of maintenance instructions (28 instances). The remaining seven categories of errors are categorized as training or qualification issues (22 instances), missing documentation or tags (16 instances), tool calibration issues (14 instances), parts and material storage (11 instances), management control (10 instances), procedure not FAA approved (5 instances), and missing parts or equipment (3 instances).

Analysis of the FAA's compliance action closure letters noted causal factors that fell into six causal factor classifications. They are categorized as failure to follow instructions (92 instances), failure to make correct maintenance entries (89 instances), inaccurate or incorrect maintenance instructions (29 instances), inadequate administrative programs (20 instances), lack of training (14 instances), and ineffective maintenance process controls (10 instances). The FAA compliance action closure letters seldom mentioned human factors as causal factors. Of the few letters that referenced human factors, eight errors were attributed to lack of awareness by one or more employees, seven were attributed to complacency, three were attributed to lack of attention, and one was attributed to distraction.

The quantitative portion of this study was conducted using a survey containing a structured set of questions with a set of ordinal frequency-based responses. The survey was designed in four parts. The first contained 11 questions focused on the type of errors previously identified during the review of the FAA's compliance actions. The second section contained six questions focused on the causal factors identified during the analysis of the air carrier responses noted in the FAA compliance action closure letters. The third section contained four questions focused on the human factors noted in the closure letters as contributors. All the survey questions for the first three sections were based on the categories previously identified from the review of the FAA's compliance action letters. Designing the survey in this manner provides the ability to compare the results directly with the FAA data. The fourth section contained demographic questions to help identify respondents who were involved in maintaining air carrier passenger aircraft. Additional open-text questions were added to each of the first three sections to prompt participants for comments regarding errors, causal factors, and human factors.

The qualitative portion of the mixed methods study was based on a grounded theory design using interviews to gain deeper insight into the commission of errors, the causal factors, and corrective actions. The same set of open-ended questions was employed in a semi-structured format supplemented with additional unstructured questions to elicit personal stories to add validity and depth to the survey results.

Study Participants

Participants selected for this study were FAA-certificated mechanics involved with the performance of maintenance on passenger aircraft owned or operated by a U.S. air carrier and having more than 70 seats. The initial population consisted of certificated mechanics listed in the FAA's database that was downloaded from their website in January 2021. The FAA's database contained over 270,000 individuals who held airframe and/or powerplant mechanic certificates. The listing was sorted to identify individuals by United States Postal Service (USPS) zip code that reside within 15 miles of the major airport maintenance hubs belonging to American Airlines, United Airlines, Delta Air Lines, and Southwest Airlines. These locations were identified as Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and Houston, Texas.

The resultant listing of 12,064 individuals was subsequently sorted using a table of random digits generated by using a Microsoft Excel software command. From this randomly sorted list, the first 1000 individuals were selected to receive a request to participate in the study. The method used to identify the sample population for the first phase of this study is multistage cluster sampling. This method allows the selection of the sample to be conducted in several stages if the subject population is large and cannot be easily defined (Creswell & Guetterman, 2019). Of the 1000 survey requests that had been sent, 71 survey responses were received, of which 48 responses were completed by individuals that perform maintenance on airline-operated aircraft having more than 70 seats.

The second phase involved the selection of individuals from those who completed the survey and who indicated their willingness to be interviewed. Interview participants were randomly selected from survey respondents who indicated that they were involved with the performance of maintenance on aircraft operated by major U.S. airlines and had a minimum of two years of experience. Ten participants were randomly selected from those who had indicated their willingness to be interviewed and were mailed consent forms for review and signature. Nine of these individuals returned the consent forms and were subsequently interviewed by one of the researchers.

Validation Process

The reliability of the survey used for the initial quantitative phase of this mixed-method research study was measured to ensure that participant scores were consistent and meaningful with respect to the elements under study. The validity with respect to quantitative research is best described as how well an instrument measures what it is supposed to measure (Creswell & Guetterman, 2019). The questions in the survey were written so that they were clear to the participants. Pre-testing of the survey was accomplished by test subjects who were certificated mechanics with experience working for a major U.S. air carrier. They were asked to take the survey and provide their comments and recommendations. Their comments and recommendations were then used to further edit and improve the survey. These test participants were subsequently excluded from the sample of participants selected for the survey.

Once surveys were received from eligible participants, the internal consistency of the survey was subsequently measured using Cronbach's alpha. This test is applied to the survey results by comparing how the results for each survey question relate to each other and to the results of the entire survey. To support the internal consistency of a test or survey, the questions should be interrelated with each other and unidirectional. Cronbach's alpha values that range from 0.70 to 0.95 are considered acceptable values to indicate internal consistency, although values in excess of .90 may suggest that several of the questions on the survey measure identical items (Tavakol & Dennick, 2011). A low alpha value is undesirable as this indicates that the survey questions are not interrelated or that the survey lacks enough questions.

The survey contained 27 questions, of which 21 were designed as Likert-style questions using the same series of ordinal frequency-based responses. Cronbach's alpha was calculated on the entirety of the 21 questions and repeated using the data from the first 11 questions that focused on the frequency of specific error types and on the combination of 10 questions that focused on the causal and human factors and maintenance errors. The results of the measurements found that Cronbach's alpha for the 21 questions was .915, which indicates a high level of internal consistency. The measurement was repeated but limited to the 11 questions related to maintenance errors, and this resulted in a Cronbach's alpha of .869 which also demonstrates a high level of internal consistency. The remaining ten questions related to causal and human factors were also analyzed and were found to have a Cronbach's alpha of .839. Cronbach's alpha was also calculated to determine how internal consistency would change upon the removal of each question from the groupings that were measured. The removal of an individual question from each grouping resulted in a change to Cronbach's alpha of plus or minus .01 which does not impact the overall reliability of the survey.

Findings

Survey Results

The results from the first section of the survey were tabulated and displayed in Table 1. Descriptive statistics were used for analysis due to the limited number of survey responses received, which precluded analysis by variance. The descriptive statistics were calculated based on the number of responses received for each question and adjusted for instances where survey participants chose not to respond. The first six questions were found to have a higher mode of three, whereas the last five questions had a mode of two. A closer review of the frequencies attributed to the responses for these six questions found that over 50 percent of participants indicated they selected *Sometimes* for having seen errors concerning the handling of maintenance documents, records, tags, forms, or placards; errors with the installation of parts or equipment; and errors regarding the completion of maintenance entries. It was noted that in addition to the three errors that had mid-point frequency distributions of over 50 percent, a fourth error related to the content of maintenance instructions was observed to have high-frequency distributions at the far right of the frequency scale. This error was seen *Regularly* by 25.0 percent of the participants and *Often* by 8.3 percent.

Table 1
Frequency of Maintenance Errors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Have seen errors with respect to the storage of parts and materials	48	3	4.2%	27.1%	47.9%	12.5%	8.3%
Have seen errors with the content of maintenance instructions	48	3	0.0%	20.8%	45.8%	25.0%	8.3%
Have seen errors with the scheduling and/or control of the maintenance process	48	3	2.1%	33.3%	39.6%	18.8%	6.3%
Have seen errors with the handling of maintenance documents, records, tags, forms, or placards	48	3	0.0%	16.7%	50.0%	22.9%	10.4%
Have seen errors with the installation of parts or equipment	48	3	2.1%	39.6%	52.1%	4.2%	2.1%
Have seen errors with the completion of maintenance entries	47	3	0.0%	12.8%	51.1%	27.7%	8.5%
Have seen errors regarding maintenance steps or tasks performed using procedures that are not accepted or approved by the FAA	47	2	21.3%	46.8%	27.7%	4.3%	0.0%

Have seen errors regarding maintenance steps or tasks performed that deviate from written instructions or procedures	47	2	8.5%	42.6%	42.6%	6.4%	0.0%
Have seen errors regarding maintenance steps or tasks that were overlooked or not performed	47	2	12.8%	44.7%	31.9%	10.6%	0.0%
Have seen errors with the handling, usage, or control of calibrated tools and equipment	48	2	18.8%	52.1%	22.9%	6.3%	0.0%
Have seen errors with training requirements, recurrent training, or maintaining of qualifications for those assigned to perform maintenance	48	2	12.5%	43.8%	29.2%	10.4%	4.2%

The data gathered by the survey is considered ordinal non-parametric data, and as such, the precise interval between each of the responses is undefined. However, by calculating the total percentage of survey participants that answered each question with a selection of either *Sometimes*, *Regularly* or *Often*, the top three errors observed by the majority of participants become more apparent and were identified in order of percentages as follows:

- Errors observed with the completion of maintenance entries – *87.3 percent*
- Errors observed with the handling of maintenance documents, records, tags, forms, or placards – *83.3 percent*
- Errors observed with the content of maintenance instructions – *79.1 percent*

The results from the second section concerning causal factors were tabulated and are displayed in Table 2. Four of the six questions were found to have a mode of three, whereas the other two questions had a mode of two. However, an examination of the response frequencies for the two questions that had a mode of two found that one question received high-frequency responses of *Regularly* and *Often* when compared to similar response frequencies for the four that had a mode of three.

Table 2
Frequency of Maintenance Error Causal Factors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information cause maintenance errors	48	3	8.3%	37.5%	41.7%	10.4%	2.1%
Failure to follow instructions or procedural requirements causes maintenance errors	48	3	4.2%	39.6%	43.8%	10.4%	2.1%
Ineffective controls over the maintenance process or the lack of a measurement process cause maintenance errors	47	2	10.6%	55.3%	25.5%	6.4%	2.1%
Maintenance and process instructions that contain inaccurate information or lack sufficient detail cause maintenance errors	48	3	12.5%	35.4%	39.6%	2.1%	10.4%
Maintenance personnel lacking sufficient training or knowledge cause maintenance errors	48	2	8.3%	37.5%	31.3%	10.4%	12.5%
Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record-keeping documents causes maintenance errors	48	3	16.7%	33.3%	37.5%	8.3%	4.2%

Prioritization using the mode alone was insufficient to identify the primary cause of maintenance errors. Selecting the causal factor having the highest percentage calculated for the mid-point frequency selection of *Sometimes* would not take into consideration the high response percentages allocated to the greater frequency responses for *Regularly* and *Often*. Therefore, the six causal factors were ranked in order from high to low by totaling the frequency percentages allocated to the selections of *Sometimes*, *Regularly*, and *Often* by the participants in the survey.

- Failure to follow instructions or procedural requirements – *56.3 percent*
- Policies and procedures that are inadequate, lack sufficient detail, or do not contain current information – *54.2 percent*
- Maintenance personnel lacking sufficient training or knowledge – *54.2 percent*
- Maintenance and process instructions that contain inaccurate information or lack sufficient detail – *52.1 percent*
- Failure to make maintenance entries or omitting relevant information in logbooks, maintenance records, or other record-keeping documents – *50.0 percent*

- Ineffective controls over the maintenance process or the lack of a measurement process – *34.0 percent*

With the exception of the causal factor regarding ineffective controls over the maintenance process or the lack of a measurement process, the survey results found the remainder of the causal factors equally responsible for maintenance errors.

The results from the third section concerning the contribution of human factors as causal factors were tabulated and are displayed in Table 3. The descriptive statistics noted that all four listed human errors resulted in responses with a mode of three. There were variations in the frequency response rate percentages, particularly for the three higher response rates of *Sometimes, Regularly,* and *Often*.

Table 3

Frequency of Human Errors that Induce Maintenance Errors

Variable	n	Mode	Never	Rarely	Sometimes	Regularly	Often
			n %	n %	n %	n %	n %
Lack of awareness causes maintenance errors	48	3	2.1%	37.5%	52.1%	4.2%	4.2%
Complacency cause maintenance errors	48	3	2.1%	20.8%	45.8%	22.9%	8.3%
Distractions cause maintenance errors	47	3	0.0%	25.5%	59.6%	14.9%	0.0%
Lack of attention cause maintenance errors	47	3	0.0%	27.7%	57.4%	12.8%	2.1%

To provide some degree of prioritization between the four human factors addressed in the survey, they were ranked in order from high to low in accordance with the total of the response rate percentages allocated to participant selections of *Sometimes*, *Regularly,* and *Often.*

- Complacency cause maintenance errors – *77.0 percent*
- Lack of attention causes maintenance errors – *72.3 percent*
- Distractions cause maintenance errors – *64.5 percent*
- Lack of awareness causes maintenance errors – *60.5 percent*

Comparing the total percentage of participants who observed these human factors at higher frequencies of *Sometimes* or greater illustrates that complacency and lack of attention were identified by the survey participants as the two key factors that caused or contributed to maintenance errors. However, the remaining two human factors must be considered equally important given that over 50 percent of the respondents indicated that they also contribute to errors at frequencies of *Sometimes* or higher.

The survey questions in the third section of the survey were limited to human factors that had been identified from the review conducted by the FAA compliance action closure letters.

Although prior studies have identified additional human factors that affect aviation maintenance, this survey was constructed to query only those that were identified in the FAA closure letters. The survey included an open question that asked participants in the survey to identify additional human factors that they believe cause or contribute to maintenance errors. One participant cited physical and environmental factors such as fatigue, heat, and working too many hours as the cause of not following written instructions. Other participants identified the lack of morale, increased stress, or pressure to accomplish tasks as human factor-related contributors to errors.

Interview Results

The second phase of the study gathered qualitative data through interviews of survey participants selected from those participants that completed the survey. The interviews were performed using a semi-structured interview process where participants were asked a specific set of questions supplemented by additional non-structured questions to allow further exploration of responses provided to the structured questions (Merriam & Tisdell, 2016). Nine participants were interviewed for this study and provided information concerning maintenance errors and causal factors.

Maintenance Errors

Of the maintenance errors identified by the participants, eight were related to the installation of parts, and four were related to the storage and handling of parts. Other errors discussed included three instances where maintenance steps or tasks were performed that deviate from written instructions or procedures, three instances where maintenance steps or tasks were not preformed or overlooked, three errors regarding the content of maintenance instructions, two errors concerning the scheduling and/or control of the maintenance process, one error with the completion of maintenance entries, and two maintenance related errors that fell outside of the categories listed in the original survey.

Examples of errors related to the installation of parts included an instance where flight augmentation computers were not properly secured in the aircraft electronics compartment and had slid out of their mounting racks during flight. Another participant described an installation error involving a brake anti-skid module that had been installed on the aircraft with its two high-pressure hydraulic lines reversed. Installation of incorrect parts was reported with a hydraulic actuator that failed a pressure test due to an o-ring that had been installed incorrectly and another instance where an incorrect elevator/aileron control computer was installed on an aircraft that had already been modified for operation with a different version of the computer.

Incorrect storage of parts and materials was noted, with descriptions of serviceable and unserviceable parts comingled together in the same storage bins. Incorrect storage of hoses, lines, and other parts with openings that were not covered with protective caps or covers was also described. Errors related to the deviation from instructions or procedures included elevator free-play checks that were performed to airline instructions that deviated from those published by the manufacturer. Procedures were also not followed with two aircraft spoilers that had been placed into a maintenance configuration instead of an operational configuration as required by the maintenance instructions.

Examples of errors related to steps or tasks not preformed or overlooked included wing to body fairing fasteners that were not torqued upon installation as required by the aircraft maintenance instructions. Another example was described as a failure to release the main landing gear oleo strut pressure in accordance with instructions prior to removal and partial disassembly of the landing gear. Circuit breakers that had been pulled in addition to others specified by the maintenance instructions but were not reset following maintenance were also noted.

Errors with the content of maintenance instructions were identified by some of the participants. One participant described an issue with a lavatory door hinge pin that was discovered to have protruded through the top of the fuselage but had been overlooked due to maintenance instructions that limited visual inspection of the downward migration of the pin through the lower lavatory door hinge. Other examples included work cards that had editing errors when they were re-written into a different format recently adopted by the airline.

Examples of errors with the scheduling and control of maintenance included a scheduling issue with an aircraft that required repetitive inspections but had over-flown the dates or flight hours due to scheduling errors. A similar error was noted with the operation of an aircraft that was scheduled and flown on an Extended Twin-Engine Operations Performance Standards (ETOPS) over-water flight, even though it was not qualified for such operations. This error was compounded by another type of error involving the completion of maintenance entries where maintenance personnel had signed for the accomplishment of an ETOPS inspection in the logbook, even though the aircraft was clearly not an on-ETOPS aircraft.

Causal Factors

Causal factors were identified during the interviews with some of the participants noting errors that were caused by multiple factors. There were 11 reported instances where errors were attributed to maintenance and process instructions that contained inaccurate information or lacked sufficient detail. Nine instances were reported where the failure to follow instructions or procedural requirements caused the errors to occur. Five instances were identified where the lack of training or knowledge contributed to the maintenance errors. One instance was described where the lack of controls over the maintenance process was responsible for an error. No instances were reported for causal factors related to the omission or failure to make maintenance entries or causal factors related to the inadequacies of policies and procedures.

Human Factors

Human factors were identified as contributors to many of the errors discussed by the participants. The three most common human factors were identified as complacency, lack of attention, and lack of awareness. Distractions were not mentioned by the participants as factors related to the maintenance errors, although other factors, such as stress imposed by time constraints and management demands, were cited as reasons some technicians may resort to taking shortcuts while performing maintenance.

Complacency was identified as the most significant contributor to the commission of errors described by the interviewed participants. Several cited the repetitive nature and simplicity of various maintenance tasks that drive mechanics to accomplish maintenance without using maintenance instructions or proper tooling. Complacency is also driven by the content of the maintenance instructions and the complexity of part catalogs. One participant noted that the proliferation of modification programs on some aircraft had affected the installation eligibility of parts for those modified aircraft. Mechanics that look for replacement parts in the parts catalog are confronted with multiple notes that limit the installation of certain part numbers to different aircraft based on modification status. For an airline with a fleet of aircraft that includes one type of aircraft but at different modification levels, it can be difficult to determine the correct replacement part for each aircraft. A participant commented that mechanics are not “See Note A, See Note B, See Note C type people.” They can get “worn out from that, and they say, ‘yeah, yeah, yeah, It’s the right one. It’s the right one.’ and they’ll install that [incorrect] part, and that was happening a lot.”

Lack of attention was also cited as a major contributor to some of the errors. The error that resulted in the bursting of the vacuum bag surrounding a flight control in an autoclave was attributed to lack of attention by one of the participants who believed: “I think its lack of attention that you just didn’t pay enough attention to the stress points, the critical, I say critical points where the bag will fail if you don’t get it protected properly.” Lack of attention during the training process was cited as a contributor to the failure to release pressure from the main landing gear strut before it was disassembled and removed from the aircraft. In this instance, the maintenance card was described as having more than 200 pages and included a specific step to deplete the pressure. The participant stated, “The only thing I can think of is that either the person wasn’t properly trained, or when they were being trained, they didn’t pay attention carefully as to exactly what to do, or they did not read the aircraft maintenance manual very carefully.”

A mechanic’s lack of attention, together with complacency, can lead to the commission of significant errors. This was likely the combination that existed with an error regarding a non-ETOPS aircraft that was inspected and released for an over-water ETOPS flight. One participant noted that the process to release the aircraft required the completion of a pre-departure check where maintenance personnel must walk around the aircraft and perform inspections prior to releasing the aircraft for the over-water flight. The aircraft was inspected and found compliant despite the absence of emergency aircraft equipment, including life rafts and a hydraulic-driven generator.

Lack of awareness was identified as the third most common factor that contributes to the commission of errors. A participant noted that some mechanics become dependent on work cards and air carriers developed maintenance instructions for the work scope. As a result, they become unaware that they should be reviewing the aircraft maintenance manual (AMM) to retrieve additional information that supplements the work cards issued for the task. This was explained as a possible contributor to an error that was committed when a landing gear wheel and brake assembly were removed and caused impact damage to the axle. The cause of the damage was the failure to use the proper tool to protect the axle, but an additional error was made during the inspection of the axle after it was damaged. Rather than looking at the AMM for damage tolerance and repair instructions, the mechanics relied on the use of an inspection work card originally written for heat damage to the axle, not impact damage. The mechanics' reliance on the applicability of the work card was due in part to its title, which simply referred to axle damage. Lack of awareness regarding the need to review other manuals for specific instructions and perhaps lack of awareness on the part of the work card author, who used a generic title on a work card specific for one type of axle damage, were contributors to the error.

Several interview participants commented that there were additional human-related factors that contributed to some of the errors they had described. These factors include stress-related situations encountered by mechanics, physical issues, and working conditions affecting the mechanics while they were performing repairs. The stress placed upon the mechanic to quickly return the aircraft to service was one such factor shared by several participants. This was previously mentioned with errors that were associated with complacency, but in some instances, stress can be the root cause of errors.

Corrective Actions

Qualitative data gathered from the interview participants included corrective actions which had been taken by their respective air carriers to mitigate the errors and prevent them from re-occurring. The participants noted that air carriers took immediate action to correct the actual errors. Mechanics were counseled, maintenance instructions and work cards were revised, and newsletter articles and bulletins were issued. Participants were asked to provide information regarding what corrective actions they believe should have been taken to address the errors. Technological improvements were identified by several participants as a partial solution that will provide mechanics with easier access to maintenance instructions. Ease of access may drive a greater number of mechanics to review the manuals before performing maintenance tasks. It was also suggested that air carriers allow for collaboration between mechanics and the writers of work instructions to improve accuracy and eliminate errors.

Assumptions and Limitations

The study made the assumption that participants selected for completion of the survey and those selected for interviews provided a true account of their experiences relevant to the scope of this study. It was also assumed that insight gained from the experiences shared by the participants is representative of what other members of the population that maintain aircraft for major U.S. air carriers experience.

Limitations affecting this study include the narrow focus and analysis of data specific to maintenance on U.S. certificated air carriers that provide scheduled passenger services under Part 121 of the Federal Aviation Regulations and who operate aircraft with more than 70 seats. The selection of study participants was limited to those residing within 15 miles of key airports used as maintenance hubs by American Airlines, United Airlines, Delta Air Lines, and Southwest Airlines. These hub cities were identified as Tulsa, Oklahoma; Chicago, Illinois; Dallas, Texas; Ft. Worth, Texas; Atlanta, Georgia; and Houston, Texas. The scope of the study excluded non-maintenance operations, including but not limited to flight operations, ground operations, fueling, deicing, and cargo activities. Initial research of reported maintenance errors was limited to Federal Aviation Administration (FAA) air carrier inspection reports for the FAA's 2018 fiscal year from October 1st, 2017, through September 31st, 2018. These reports were obtained via FOIA from the FAA Certificate Management Offices for American Airlines, United Airlines, and Southwest Airlines. Although requested, no reports for Delta Air Lines were provided.

General limitations affecting this study include the small size of survey participants that responded to the survey requests. Those that did respond to the survey and who were interviewed may have induced limitations based on the relevancy of their experience with the subject matter, cultural differences, and varying backgrounds.

Conclusions

What errors are common to maintenance performed on aircraft operated by major U.S. air carriers certificated under FAR Part 121? The results of this study did not identify one category of error over another as the most common. However, certain error categories were reported by survey participants to have a higher frequency of occurrence than others. Survey data noted that frequent errors were observed with the completion of maintenance entries, the handling of maintenance documentation, and the content of maintenance instructions. Interviews with participants provided descriptions of errors related to the installation of parts, storage of parts, deviation from instructions, maintenance steps not performed, the content of maintenance instructions, scheduling errors, and errors related to the completion of maintenance entries.

Both the survey and interview data found commonality with three types of errors: completion of maintenance entries, deviation from instructions or procedures, and steps or tasks not performed or overlooked. This compares favorably with common errors identified from the examination of FAA compliance action letters that noted 86 errors related to maintenance entries, 37 errors involving deviation from maintenance instructions, and 31 errors related to tasks that were not performed. The high number of errors related to incorrect maintenance entries noted by the FAA agrees with the higher frequency of similar errors reported by the survey participants. Similarly, the high number of errors noted by the FAA regarding deviations from maintenance instructions, along with errors related to tasks not performed, agree with the higher incidence of errors reported by the interview participants. In contrast, the category related to errors observed with the handling of maintenance documents, records tags, forms, or placards was not mentioned as a common problem by the interview participants. Although such errors were frequently noted in the FAA data and survey results, this type of error may not be viewed as significant by the interview participants.

Why are these maintenance errors committed? The survey data noted that five of the six causal factors were highly considered responsible for maintenance errors, written comments included in the survey, together with the results from the interviews, identified two causal factors which were predominant. These were failure to follow instructions or procedural requirements and maintenance and process instructions that contained inaccurate information or lacked sufficient detail. The results from the survey correlate with the qualitative data obtained from the participants who were interviewed. A comparison of these causal factors with those identified during the initial research that examined FAA compliance action documents found that there is also a correlation. The FAA compliance action closure letters found that failure to follow instructions and instructions that contained inaccurate or incomplete information were primary causal factors. However, the FAA data also identified the failure to make maintenance entries or omission of entries as a significant causal factor. The survey results and interview data do not suggest that this is a predominant causal factor. It is possible that the FAA may identify this more frequently during their inspections of air carrier maintenance records than the participants, who may spend the majority of their time physically working on aircraft.

The identification of common causal factors also included an analysis of human factors that cause maintenance errors. Four human factors were included in the survey, and the responses verified that all four were causal factors for maintenance errors. However, two of the human factors were observed by the survey participants at a higher frequency. These were identified as complacency and lack of attention. Qualitative data from both the survey comments and the interviews found that these two human factors were also of great significance. Of the two, complacency was established as the leading human factor that contributed to the commission of errors. This agrees with another study conducted by an airline over a two-year period that identified complacency as the cause of maintenance errors (Liang et al., 2010).

A causal factor that was not anticipated by this study was the impact of stress on complacency. As explained by several participants, the demand to return aircraft to service quickly, either implied or directed by supervision, can drive mechanics to take shortcuts and avoid using maintenance manuals. This happens frequently with simple or repetitive tasks that are familiar to mechanics who believe that they can complete the tasks without the need to retrieve the manuals instructions. Coupled with the perception that anyone looking up maintenance instructions may be doing so to slow the repair process, mechanics may purposely avoid using the maintenance manuals. Of the causal factors identified by this study, failure to follow instructions or procedural requirements due to complacency and the need to return the aircraft to service is of the deepest concern.

What actions have been or could be instituted to prevent the commission of maintenance errors on aircraft operated by major U.S. air carriers? Participants who were interviewed were asked to identify successful and unsuccessful corrective action measures that had been taken to mitigate errors. Most noted that corrective actions taken by the air carriers were limited to mitigation of the specific errors that had been identified. These included counseling mechanics who made the errors, correcting the errors by replacing components or repairing damage, issuing training bulletins, and in some instances, revising maintenance instructions to either clarify existing instructions or add wording to qualify any deviations that may have been taken. With few exceptions, most corrective actions taken by the air carriers were localized to that error and not universal in coverage.

Study Beneficiaries

Air carriers and maintenance providers are principal beneficiaries of this study as it provides information that helps identify the most common types of maintenance errors and causal factors that are shared by U.S. air carriers. The information from the study adds to existing research and may help future studies that look at errors and causal factors by category and which impact air carriers at higher frequencies.

Recommendations for Further Research

One of the key findings of this study identified errors where mechanics failed to follow instructions or procedural requirements. Participants noted that this could happen if the tasks are considered simple or repetitive. This study did not delve into the simplicity of these tasks or if the performance of those tasks would be considered acceptable without the need for specific maintenance instructions. While it is recognized that certificated aircraft mechanics received extensive training, at what level should maintenance instructions cover certain tasks or steps that could be considered generic, thus negating the need for describing simple actions?

This study also highlighted issues where maintenance instructions contained inaccurate information or lacked detail. Participants commented that such errors frequently appear on work cards published by the air carriers and attributed the causal factors to the lack of knowledge and experience of the work card authors. Corrective action suggestions included the pairing of mechanics with engineers and other work card authors to validate the instructions prior to publication. While this suggestion has merit, further study is recommended to determine if this would reduce or eliminate many of the errors currently associated with the accuracy of maintenance instructions.

Responses to the initial 1000 survey requests produced just 71 responses, of which only 48 could be used for this study, thus limiting the application of statistical analysis. One anomaly that limited the distribution of the survey requests was attributed to FAA-managed data. Of the 1000 survey requests that were sent to selected mechanics who appeared in the FAA's database, 128 survey request letters were returned as undeliverable. This represents an error of 12.8 percent which was not expected. Further research is recommended to identify the extent of erroneous information contained in the FAA's database, the causal factors that drove these errors, and identify what actions can be taken to ensure that the database reflects the current mailing addresses for FAA certificate holders.

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #4

4-1-2023

Exploring the State of SMS Implementation at Airports

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Safety Management Systems (SMS) in the aviation industry are an increasingly important aspect of identifying hazards and managing the associated risks. While SMS has become commonplace and is often a regulatory requirement for air carriers, it remains voluntary for many other aviation service providers, such as airports. Over the past decade, commercial Unmanned Aircraft System (UAS) operations near airports have significantly increased along with the development of Advanced Air Mobility operations. Airports face new and emerging safety challenges. However, safety is a precursor for public acceptance and proliferation of these next-generation aviation technologies. Safety practitioners consider SMS a key enabler in ensuring the safety of the National Airspace System and may assist airports in addressing these emerging hazards and risks. This research explored the current state of SMS at airports and their incorporation of UAS hazards and risks. This research utilized a mix of quantitative and qualitative methods, which included an extensive literature review and a survey of airport stakeholders. Research results suggest a need for further development and adoption of SMS at airports, including further maturation of UAS safety practices along with education and training. This study may assist airport stakeholders and regulators with further developing robust safety and risk management practices that support the safety of the next generation of aviation operations.

Recommended Citation:
Jadhav, P., Lercel, D., Hubbard, S. & Schreckengast, S. (2023). Exploring the state of SMS implementation at airports. *Collegiate Aviation Review International*, 41(1), 75-93. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9421/8470

Introduction

A safety management system (SMS) for airports is known as a “formal, top-down, business-like approach to manage safety risks” (Federal Aviation Administration (FAA), 2007, p. 1) that is attributed to the airport. An SMS helps the airport identify personnel in charge of airport safety, identify hazards, manage risk, assure safety, and promote safety at the airport. Implementing an SMS is part of the safety management principles as designated by the International Civil Aviation Organization (International Civil Aviation Organization (ICAO), 2018).

Over the past decade, Unmanned Aircraft Systems (UAS) have rapidly evolved into an established and growing commercial segment of the aviation industry. UAS are becoming an increasingly integrated and essential component of the National Airspace System (NAS). The Teal Group’s 2022/2023 World Civil UAS Market Profile and Forecast predicts that civil UAS production will grow from $7.2 billion annually to $19.8 billion by 2031 (Teal, 2022). Advanced Air Mobility (AAM) is the next progression of UAS and is expected to further increase the volume of air traffic. Morgan Stanley Research predicts the AAM market value nearing $1.5 trillion by 2040 (Jonas, 2019).

Consequently, there has been an exponential increase in UAS operations across a diverse population of users and applications. As of May 2022, there were about 865,000 registered UAS in the United States (U.S.) (FAA, 2022a), which far exceeds the approximate 250,000 registered manned aircraft (FAA, 2022b). The commercial UAS market is estimated to be about $63.6 billion by 2025 (Insider Intelligencer, 2022), enabling various opportunities for businesses, governments, and hobbyists, which also suggests an increase in the overall UAS air traffic within the NAS. Additionally, the U.S. Department of Transportation (DOT) continues to expand its use of UAS technologies and recently selected Alphabet, AT&T, Intel, and Apple to conduct further research in UAS applications (Reuters, 2018).

The research suggests UAS operations on or near airports are increasing along with an increase of UAS in close proximity to manned aircraft. In 2015, Ettinger et al. (2015) completed one of the first detailed analyses of incidents involving UAS and manned aircraft in the U.S. NAS. Their research found that most events occurred in close proximity to airports, with 158 incidents of UAS coming within 200 feet or less of a manned aircraft (Ettinger et al., 2015). The Federal Aviation Administration (FAA) established the Low Altitude Authorization and Notification Capability (LAANC) in 2017, which provides UAS operators with automated airspace authorizations near airports (FAA, 2022c). Since LAANCs inception, the FAA has issued over a million airspace authorizations (FAA, 2022c). Wallace et al. (2022) collected data regarding UAS airspace operations from July 1, 2021 through January 31, 2022. During this time, the research team detected 470,902 small UAS flights at 64 separate sampling locations across the United States. Approximately 30% of these flights were in controlled airspace, which further indicates the number of UAS operations near airports is increasing (Wallace et al., 2022).

Research Problem

Due to the rapid proliferation of UAS and their operation at or near airports, safety practitioners are challenged to keep pace with developing robust SMS practices that ensure an acceptable level of safety. Aviation authorities increasingly receive UAS sighting reports from manned pilots and air traffic controllers – creating a rising concern about a collision between manned and unmanned aircraft (FAA, 2022d; Pyrgies, 2019). In addition, the increase of commercial UAS operations in the airport operating area (AOA) adds to this collision risk, making safety management processes specific to UAS operations of increasing importance. As such, this research attempts to gain perspective on what is the current state of SMS at airports and their incorporation of policies that address UAS hazards and risks.

Background

Important considerations for this study include research related to UAS at airports and research related to the implementation of safety management systems (SMS) at airports.

UAS at Airports

Manned aircraft are usually flown in accordance with visual flight rules (VFR) or instrument flight rules (IFR), which are most often dissimilar to UAS flight plans (Wilson, 2018). These differences create complications in the air traffic system, which may prove to be dangerous. UAS flights may also result in disastrous collisions with manned aircraft due to the UAS lacking traditional aviation communication, navigation, and safety-related technologies. Overall, the number of close encounters between UAS and manned aircraft is on the rise. Pyrgies (2019) conducted a quantitative analysis of 139 UAS incidents and categorized 24 of these incidents to be a near mid-air collision with manned aircraft, two UAS resulted in a mid-air collision, ten UAS resulted in airport closure, and one UAS was sighted inside the airport premises. Since the FAA first started collecting UAS sightings reports in 2016, there has been a steady rise in the number of sightings. For example, a review of this data found that during the period from April through June 2021, there were 958 sightings, an increase of 79% over the same 3-month period in 2016 (FAA, 2022d).

The use of a UAS-based platform was also found to be more cost-effective for conducting basic inspections in and around the airport. Airports have increasingly started to use UAS to assist with tasks such as security, mapping, surveying, and inspections (Hubbard et al.; Mackie & Lawrence, 2019). Regulators have struggled to keep pace with this ever-changing ecosystem. Guidelines and policies that effectively address safety-related hazards and subsequent risk management of UAS have lagged behind the advancing marketplace. The projected increases in commercial air traffic will further exacerbate the demand for FAA’s Air Traffic Control (ATC) resources (Chauhan et al., 2021; Hubbard et al., 2017; Kamienski et al., 2015; Parker et al., 2018). The continued increase in air traffic, coupled with the incorporation of next-generation technologies, further signifies the importance of robust safety management practices.

An increasing number of UAS in the NAS and the lack of a mature regulatory framework have led to concerning events around the AOA. The drone events at the London-Gatwick (Wendt et al., 2020) and Dubai airports halted airport operations for a significant time and exemplify the potential hazards small UAS (below 55 lbs.) pose to airports. While the owners of the UAS being flown at London and Dubai remain unidentified, these events further demonstrate the need for an SMS to manage UAS operations inside the AOA. Airport boundary intrusions, airport threats, airspace disruption, air traffic controllers' increased workload, and runway incursions are just some of the hazards presented by small UAS. Such issues highlight the need for a structured SMS to better manage commercial UAS operations. ICAO (2018) has recommended SMS for all aviation entities. However, there may be a gap in the current SMS processes to adequately manage the associated UAS safety risks at airports.

The Gatwick airport drone incident (2018) is a prime example where a UAS was spotted particularly close to the airport multiple times (Rowlatt, 2019). This incident highlighted the need for stringent UAS mitigation techniques to combat these types of events. This incident resulted in immense financial losses, and close to a thousand flights were affected (Rowlatt, 2019). A similar incident occurred in the UAE in 2016, when Dubai International Airport was compelled to close for three times due to unauthorized drone activities for about 3 hours, leading to cumulative losses of close to $16.62 million (The National, 2016).

SMS at Airports

Current FAA UAS regulations primarily focus on UAS operations in uncontrolled airspace or within a limited area of the controlled airspace around an airport (14 CFR § 107, 2021). Airports may better prepare for these types of advanced UAS operations by proactively developing related SMS processes. ICAO started introducing elements of SMS in 1997 with the Global Aviation Safety Plan (GASP) (ICAO, 2007). This plan was a safety guide for organizations and was regularly updated until 2005. In 2006, ICAO published a Safety Management Manual (SMM) Doc 9859 (ICAO, 2018), which was the first crucial step for the development and implementation of SMS for airports, aircraft manufacturers, airlines, and many other lower-tier industries related to aviation. To encourage the adoption of SMS, ICAO launched a series of educational initiatives to familiarize aviation stakeholders with SMS.

In 2006, the FAA (2015) first started exploring SMS for aviation service providers, which included airlines, airports, MRO facilities, and manufacturers. The FAA initiated an Airport SMS Pilot Study in 2007 with 22 airports participating (FAA, 2022e). The purpose of the study was to evaluate the implementation of SMS at airports. As part of this study, each participant conducted a gap analysis to see what elements of an SMS may already exist in their organization. These analyses found only 1 participant had an existing SMS, and none had a formal process for safety risk management (SRM) (FAA, 2022e). The study found a lack of information related to smaller airports and recommended additional guidance. In addition, the study found that compliance with regulatory requirements fell short of the requirements for a functioning SMS (FAA, 2022e). In 2008, the FAA initiated a second Airport SMS Pilot Study to gather information on the scalability of SMS and how smaller airports might implement SMS (FAA, 2022f). Overall, participating airports found that meeting the SMS requirements was achievable, but the study found a wide variation in interpreting these standards, largely undefined best practices, with an unknown return on investment (FAA, 2022g).

Subsequently, Canada and Australia began the implementation of SMS in aviation, which many consider as the benchmarks for SMS. In 2015, the FAA established a rule requiring all part 121 air carriers to establish an SMS by 2018 (FAA, 2015). However, airports are currently not mandated to have an SMS. The FAA encourages airports to establish an SMS through its voluntary SMS program and provides guidance regarding SMS development. In addition, the FAA is also developing a Part 139 policy that incorporates elements of SMS that may apply to these certificated airports (FAA, 2022i). With the introduction of FAA Order 8000.369C, the FAA discusses UAS as a hazard in the aerospace system that requires the application of SRM processes (FAA, 2020).

In response to the increase in UAS operations at airports, the Transportation Research Board published a series of guidebooks on UAS operations at airports. Volume 1 describes the current regulatory framework to help airports better interact and guide UAS users who fly in their vicinity. This volume also discusses UAS considerations for an airport's SMS and provides examples of UAS contingency events (NASEM, 2020a). Volume 2 presents processes and methods to incorporate UAS into airport infrastructure planning, such as vertiport design, ground support considerations, and public policy (NASEM, 2020b). Volume 3 discusses the use of UAS to support airport operations, such as pavement inspections, wildlife surveys, and perimeter security. Similar to Volume 1, this volume also describes the incorporation of such activities into an airport's SMS (NASEM, 2020c).

The literature suggests effective SMS practices provide enhanced safety benefits to airports by helping to better manage risks and reduce the number of adverse incidents (NASEM, 2009; Mendonca et al., 2017). SMS includes formal processes for stakeholders to report hazards or incidents and a means to assess the effectiveness of any safety mitigations (NASEM, 2009). These processes are especially important when new technologies, such as UAS, are introduced as new operating and emergency procedures are required (NASEM, 2020c). In addition, SMS is complementary and may enhance similar safety programs, such as wildlife hazard or quality management (NASEM, 2015; Lercel, 2013). With future AAM operations, which include on airport operations such as cargo delivery and air taxi, the complexity of unmanned aviation operations will only further increase along with the need for robust safety management (Jadhav, 2021; Jonas, 2019).

From the literature review, researchers found that there is a lack of SMS guidance for commercial UAS operations in the AOA and the NAS as a whole. This, coupled with the increasing number of commercial UAS applications, suggests the need for robust UAS safety management processes. Additionally, the growing number of UAS sightings near airports is a concern for airport stakeholders. Advancement and investments in AAM technology have further led researchers to study conceptual workflows of manned-unmanned operations inside the AOA (Jadhav et al., 2021). Such issues highlight the need for innovative safety risk management strategies to better manage commercial UAS operations. The unique and non-traditional operation of UAS further reinforces the need for a documented SMS that assists airport stakeholders with moving from a reactive to a proactive state of managing these next-generation aviation operations.

Methodology

Researchers conducted a content analysis of UAS guidelines, regulations, and the published SMS standards of various national and international aviation regulatory bodies were analyzed as a part of the content analysis process. The content analysis enabled a chronological explanation of the current state of SMS. Table 1 below summarizes the documents that the researchers reviewed along with their regulatory area. These documents assisted researchers in understanding existing SMS practices and regulatory preparedness for next-generation aviation operations in the AOA.

Table 1

Guidance Documents from National and International Agencies

Document Name	Publisher (Date)	Applicable Region
Introduction to SMS for Airport Operators	Federal Aviation Administration (2007)	USA
Unmanned Aircraft Systems (UAS) at Airports: A Premier	Transportation Review Board (2015)	USA
Airports and UAS, Vol. 1: Managing and Engaging Stakeholders on UAS in the Vicinity of Airports	National Academies of Sciences, Engineering, and Medicine (2020)	USA
Document 9859 – Safety Management Manual (4th Edition)	International Civil Aviation Organization (2018)	International
Drones in the Airport Environment	Airports Council International (ACI, 2016)	International
CAR - UAC	General Civil Aviation Authority (2019)	UAE
Easy Access Rules for UAS	European Union Aviation Safety Agency	Europe

The analysis of SMS for airport operators by the FAA (2007) is a primary publication used in the content review phase. Some publications are based on the topic "SMS for airports." In contrast, others are just "regulations for UAS," indicating a lack of guidance relating to a comprehensive SMS for airports to mitigate risks due to commercial UAS. Safety guidance provided by FAA (2007) and ICAO (2018) was reviewed and referenced. The research then explored regulations and advisories pertaining to UAS in the AOA. This study employed a two-step content review process to 1) acknowledge current SMS practices at airports and 2) consider the airport's integration of UAS risks into their SMS.

A survey was developed to obtain information about airport SMS, including knowledge and practices, as well as airport demographic information, such as airport size and category. This survey was developed based on the information gained during the content analysis of UAS and

SMS regulations and practices. The initial survey instrument was reviewed by aviation management professors at an R1 university with subject matter expertise in airport management and SMS and was beta tested by airport personnel and external aviation experts. Experts were selected for review and beta testing based on personal contacts of the research team as well as the faculty and staff of the university aviation program (there are over 50 faculty and staff members in the university aviation program); experts were selected based on their knowledge of airport activities, UAS, and SMS. These experts reviewed the survey questionnaire and provided inputs to validate the study further, which helped demonstrate face validity. Once face validity was established, the researchers sent out the survey questionnaire to a sample of aviation experts for feedback. Once the survey was developed and reviewed, researchers sent the survey to 1,720 airport personnel via email; these airport personnel worked at some of the 5,000 public-use airports in the U.S. (FAA, 2021a). Emails were collected from publicly available databases such as airport directories, and the survey was distributed using the Qualtrics survey tool. The survey consisted of multiple-choice questions and one open-ended question and is shown in the Appendix.

The survey was kept active for a period of 33 days to allow an appropriate time for survey submissions. Survey data was then initially analyzed using descriptive statistics, where cross-tabulations were created to compare individual variables. Based on survey responses, a statistical and graphical analysis was performed to interpret the survey data obtained.

Results

The survey returned 146 responses. A total of 111 surveys were retained after data cleaning efforts.

Demographics

Data collected from the survey were analyzed to examine demographic data such as airport categories, airspace classification, and FAA region. Below is a description of these demographic data,

- Type of Organization: 97.3% (N=108) of the 111 survey respondents indicated they were associated with an *airport*, whereas 2.7% (n=3) of respondents were associated with a “fixed-base operator” or “other.”
- Airport Category (FAA, 2021a): 76.58% (n=86) of the responses were *general aviation* airports, 10.81% (n=12) were *reliever*, 6.31% (n=7) were *commercial service – non-hub*, 4.50% (n=5) were *commercial service – small-hub* and 0.9% (n=1) were *commercial service – large-hub* and *non-primary commercial service*.
- Airspace Distribution of airports is shown in Figure 1
- FAA Region (FAA, 2021b): 32% (n=35) of the responses were from the *Great Lakes Region*, 21% (n=23) were from *Southern Region*, 14% (n=16) were from both *Southwest* and *Eastern Regions*, 13% (n=14) were from the *Central Region*, 4% (n=4) were from *Western-Pacific Region*, and 2% (n=2) were from *Northwest Mountain Region*. All regions were represented in the survey except the *Alaskan Region*.
- Control Tower: 75.68% (n=84) of the responses were from *non-towered airports*, whereas the remaining 24.32% (n=27) were from *towered airports*.

State of SMS at Airports

While examining the state of SMS implementation and adoption at airports (SMS at Airports) (n=108), survey results found 15.7% (n=17) of the airports indicated they have a documented SMS. In comparison, another 13.9% (n=15) of the airports indicated they were currently developing an SMS. In addition, a greater number of non-towered airports (n=10) indicated they have an SMS versus towered airports (n=7).

Researchers compared the current state of SMS implementation at airports based on airspace classification (n=108), which is illustrated in Figure 1. The comparison found that 33.3% (n=1) of airports in Class B, 18.2% (n=2) in Class C, and 24% (n=6) of airports in Class D airspace indicated they have a documented SMS. As most survey responses were obtained from airports situated in Class E and Class G airspace, SMS adoption at airports in these classes of airspace was 14.3% (n=5) and 9.0% (n=3), respectively. While several airports acknowledged they had a documented SMS, overall, 84.3% (n=91) of the respondents acknowledged a lack of SMS at their airports.

Researchers then included a follow-up question to *SMS at Airports* that explored if their documented SMS included elements to address UAS-related safety risks. While studying these responses, researchers found that only 4.6% (5 of 108) of the total airports indicated that their SMS addressed UAS-related hazards and risks. Comparisons based on airspace revealed that no airports in Class B, C, or E airspace indicated their SMS addresses UAS safety. Only 12% of airports in Class D and 6.1% of airports in Class G included UAS safety in their SMS. This data is graphically represented in Figure 1.

Familiarity and Guidance

The survey then explored the respondents' familiarity with FAA regulations related to UAS. *Levels of familiarity* were defined on a Likert-type scale as "not at all," "to a little extent," "to some extent," "to a moderate extent," and "to a large extent." To further explore the area of familiarity, researchers asked participants if they would like *additional guidance regarding UAS safety and risk management* (SRM), which the respondents defined by using one of the following options, "strongly disagree," "disagree," "neither agree nor disagree," "agree," and "strongly agree."

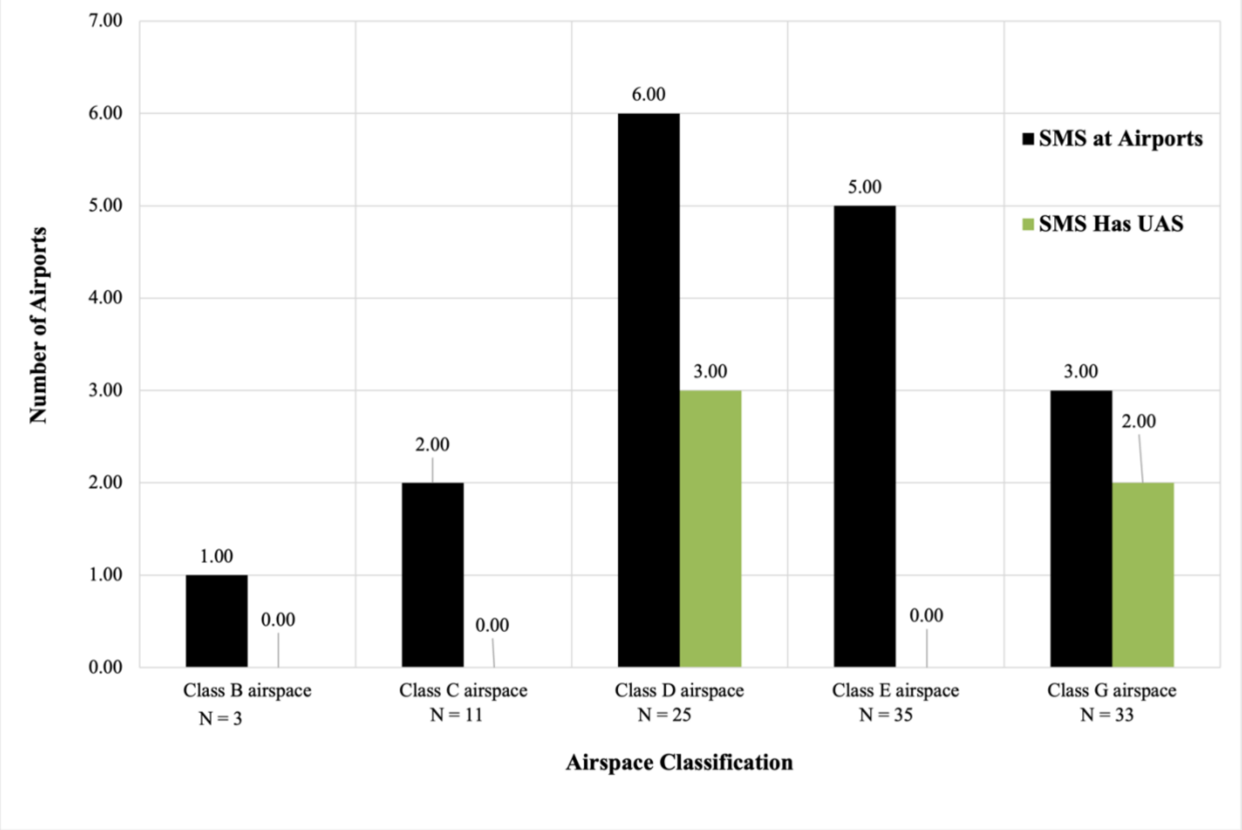
Level of Familiarity

Examining the *level of familiarity* of the 107 respondents that responded to this question, researchers found that 51.4% (n=55) said their level is "to a moderate extent" or "to a large extent." On the other hand, only 15.9% (n=17) indicated familiarity levels "to a little extent" or lower. It is important to note that for the responses about the level of familiarity, the following factors may affect the scoring

- *The level of familiarity* was purely based on the respondent self-assessing its organization's knowledge regarding regulations related to UAS.

- The researchers did not conduct any assessment to determine the respondent’s level of familiarity.

Figure 1
SMS Adoption at Airports and those whose SMS includes UAS by Airspace Classification



Additional Guidance regarding UAS SRM

Further reviewing the complementing variable of *additional guidance regarding UAS SRM*, 64.5% (n=69) of respondents agreed or strongly agreed, whereas only 7.5% of the respondents disagreed or strongly disagreed with the need for additional guidance, which may suggest a gap in the participants’ knowledge of UAS SRM as it applies to the AOA.

Level of Familiarity and Additional Guidance regarding UAS SRM

Researchers then cross-tabulated *familiarity with FAA regulations* and *additional guidance regarding UAS SRM* to explore inferences (see Table 2). When looking at familiarity, 90 respondents (84.1%) suggested that their familiarity levels ranged from “to some extent” to “to a large extent.” Further investigating the familiarity and guidance crosstabulation, it was observed that 48.6% (n=52) of the respondents that felt their *familiarity with FAA regulations* was “to a moderate extent” or “to a large extent” also indicated a desire for additional guidance (“neither agree nor disagree”, “agree”, or “strongly agree”). Analyses of the cross-tabulated results found that stakeholders wanted additional guidance irrespective of their level of familiarity.

Table 2

Crosstabulation of Familiarity with Regulations and Need for Additional Guidance

	Level of Familiarity					
Additional Guidance	Not at all	To a little extent	To some extent	To a moderate extent	To a large extent	Total
Total	4	13	35	39	16	107
Strongly Disagree	0	0	1	1	0	2
Disagree	2	0	2	2	0	6
Neither Agree nor Disagree	0	6	8	11	5	30
Agree	2	6	19	18	7	52
Strongly Agree	0	1	5	7	4	17

Additional Education or Training regarding UAS Safety and Regulations

Researchers included a supplementary question in the survey to further explore the participant's desire for additional UAS/SMS guidance across different subject areas, such as regulations, airspace waivers and authorizations (LAANC), unmanned traffic management (UTM) (NASA, 2022), safety and risk management, and counter UAS technology. Survey respondents could choose multiple items. Even though 84.11% (n=90) of the respondents indicated their level of familiarity with UAS regulations was equal to or greater than "to some extent", a majority (87 of the 108 respondents) still indicated a desire for some type of "additional education or training" regarding UAS safety and regulations. Specifically, the results by category were 58.88% (n=63), indicating a need for more regulatory education and training, 49.53% (n=53) for airspace waivers and authorization, and 61.68% (n=66) for safety and risk management. The cross-tabulated distribution between "familiarity with UAS FAA regulations" and "additional guidance and training" is given in Table 3.

Furthermore, researchers found that with the increase in the number of off-the-shelf consumer UAS, large commercial airports were also experiencing an increase in UAS intrusions. These types of intrusions may have led many regulators to begin the adoption of UAS safety and risk management procedures as part of their SMS(ACI, 2016; FAA, 2007; FAA, 2015; FAA, 2022i; ICAO, 2007). Unauthorized UAS intrusions have resulted in major flight delays and financial losses, which in turn led to the realization of a need for more robust UAS SMS practices at airports (Rowlatt, 2019; The National Staff, 2016; Wendt et al., 2018). Similarly, two survey respondents indicated having experienced a hazardous UAS event and a high number of unauthorized UAS flights within their controlled airspace.

Table 3
Crosstabulation of Familiarity with FAA regulations and Additional Education and Training

	Level of Familiarity					
Additional Education and Training	Not at all	To a little extent	To some extent	To a moderate extent	To a large extent	Total
Regulations	2.0	10.0	22.0	20.0	9.0	63.0
Airspace waivers and authorization (LAANC)	1.0	5.0	19.0	18.0	10.0	53.0
Unmanned Traffic Management (UTM)	2.0	5.0	17.0	19.0	9.0	52.0
Safety and Risk Management	1.0	9.0	21.0	26.0	9.0	66.0
Counter UAS Technology	1.0	2.0	14.0	12.0	9.0	38.0
My organization is sufficiently trained	1.0	0.0	2.0	3.0	7.0	13.0
Other	1.0	0.0	2.0	1.0	0.0	4.0

Open-ended question responses

The survey included one open-ended question, which asked respondents if they had any other comments regarding SMS or UAS operations on or near airports. Overall, 14 people provided additional comments. Two of the respondents indicated their airport had experienced a hazardous event involving a UAS operating within the manned aircraft traffic pattern. One of these airports indicated they are using a UAS monitoring system and have recorded “an alarming number of illegal UAS flights” in their Class D airspace. Four respondents indicated a need for better UAS safety guidance and training that is tailored toward airports. Two respondents also expressed a need for better communication across the air traffic control community and frustration over the constant change in UAS policy. Three respondents from smaller airports located in Class G airspace voiced concern that an SMS regulation may be overly burdensome and must be scaled to smaller airports. Two respondents described a positive experience with UAS, having on occasion used UAS to conduct airport infrastructure inspections.

Discussion

This study’s main research purpose was to gain perspective on the state of SMS at airports. Initial inferences were derived from the review of the literature regarding SMS at airports. Further on, this study found a significant contrast between the implementation of SMS at airports, especially with regard to elements of SRM for UAS, given the increase in UAS operations in the NAS.

The following assertions may be derived from the literature and developed results,

- Documented SMS for airports is continuously being updated by aviation entities (organizations and regulatory agencies) as proactive safety practices evolve (ACI, 2016; FAA, 2007; FAA, 2015; FAA, 2022i; ICAO, 2007). The analyzed results gathered from the survey further suggest the need for additional guidance for SMS at airports as a lower percentage (15.3%) of airports had an SMS. Participant responses to the open-ended survey question further support this finding.
- Even though there has been an increase in commercial UAS operations in the AOA (FAA. 2022c; Pyrgies, 2019), survey results suggest SMS implementation at airports is behind. Initially, from the literature review of national and international regulatory guidance, researchers found that SMS for UAS was quite uncommon nor widely adopted. To further support findings from the literature review, results evaluated from survey responses found only 4.9% of airports include UAS elements in their SMS. The cumulative study of literature and results suggests a lack of guidance or understanding regarding commercial UAS operations in the AOA. This finding is further supported by the participant's responses, where a majority indicated the need for more education, training, and guidance regarding commercial UAS operations inside the AOA. Participant survey comments suggest a need for clearer policy guidance and education.
- A major component of any SMS is safety promotion (FAA, 2022d; ICAO, 2007). Communication of new and updated guidelines is an integral part of ensuring the latest safety practices in aviation are conveyed to all concerned aviation entities. Analysis of open-ended responses in the survey found that there may be a shortfall of communication that exists between the regulatory bodies and airport stakeholders.

Future Research

This research provides a perspective on the current state of SMS for airports. Based on the results, it is necessary for regulatory agencies to further develop guidance that assists airport stakeholders with safely addressing UAS and AAM operations. Additional regulatory guidance also requires effective education and communication between the regulatory body and airports. Future research may include comparing the airports' state of SMS from this research with the level of UAS activity within the airport's operating area.

Limitations

Many of the limitations of this study are related to sampling issues inherent to a convenience sample and by the timing of this study, which coincided with the COVID-19 pandemic. In terms of sampling issues, the survey was distributed widely via email to airport personnel for whom the researcher had contact information. The resulting responses (over 100) provide some insight into the perspective of airport operators but should not be considered representative of all airport personnel due to limitations inherent in non-probability sampling methods. The COVID-19 pandemic limited responses since researchers were unable to attend conferences to promote the research and limited the scope of the study since it was not practical to conduct in-person interviews or observations. COVID may also have impacted participation due to reduced staffing levels at many airport facilities, including larger and busier airports, such as those in Class A and B airspace. There may also be issues with self-selection since airport personnel who are not familiar with SMS and UAS topics may have been less likely to complete the survey. A final limitation is the use of email for the survey distribution; this methodology requires a strong database of current emails for airport personnel, it requires that the survey request make it through spam filters, it requires that the airport personnel click on a link, which some people are hesitant to do for security reasons.

Conclusion

With the advent of UAS commercial applications, the importance of SMS practices at airports is increasing. To ensure safety in the AOA as UAS operations further evolve, a formal SMS helps airports remain vigilant and proactive in addressing not only current threats but those that are not yet identified. As this study suggests, with the increase in commercial UAS operations in the AOA, there will arise an even greater need for airports to further develop robust safety practices. While many UAS opponents and media outlets or often of the opinion that UAS must remain clear of the AOA, UAS is slowly becoming an essential tool to assist airports in effectively managing operations, inspections, and maintenance practices (Hubbard et al., 2017; Mackie et al., 2019). Furthermore, UAS may improve efficiency at airports, aid organizations in safely conducting hazardous inspections, and reduce the completion time of various commercial applications as compared to traditional methods (Hubbard et al., 2017; Mackie et al., 2019). Looking ahead, the emergence of advanced air mobility, air taxis, and unmanned traffic management (UTM) (NASA, 2022) further supports the need for robust SMS at airports. Ultimately, this research suggests the importance of airports developing an SMS that addresses threats associated with commercial UAS operations. While this research describes the airport's current state of SMS processes related to commercial UAS operations, it highlights the need for further research into developing effective SMS processes that keep pace with emerging UAS technologies and use cases. This study may assist airport stakeholders, UAS operators, and regulators to further develop robust safety and risk management practices that support safe UAS operations within the airport operating area.

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Appendix

1. Please select the best description of your type of organization.
    - o Airport
    - o Fixed Base Operator at an airport
    - o Airport Air Traffic Control
    - o Air Passenger or Air Cargo Service
    - o Other____
2. Please select the FAA region associated with your airport.
    - o Alaskan Region
    - o Central Region
    - o Eastern Region
    - o Great Lakes Region
    - o Northwest Mountain Region
    - o Southern Region
    - o Southwest Region
    - o Western-Pacific Region
3. Which of the following categories best describes your airport's activity?
    - o Commercial Service - Large Hub
    - o Commercial Service - Medium Hub
    - o Commercial Service - Small Hub
    - o Commercial Service - Nonhub
    - o Non-Primary Commercial Service
    - o Reliever
    - o General Aviation
4. Which of the following airspace classifications is your airport located in?
    - o Class B airspace
    - o Class C airspace
    - o Class D airspace
    - o Class E airspace
    - o Class G airspace
    - o Special-use airspace (Restricted areas, military areas, etc.)
5. What is your position at the airport?
    - o CEO
    - o President
    - o Director
    - o Manager
    - o Assistant Manager
    - o Supervisor
    - o Other, please specify ____
6. Does your airport have a control tower?
    - o Yes
    - o No
    - o Don't know

7. Does your airport have a documented Safety Management System (SMS)?
   - o Yes
   - o No
   - o My airport is currently developing an SMS
   - o Don't know

If the answer to question 7 is Yes, then display this question:

8. Are UAS-related safety risks also a part of the Safety Management System (SMS)?
   - o Yes
   - o No
   - o Don't know

9. Does your airport have a UAS response plan?
   - o Yes
   - o No
   - o Don't know

10. What is the airport's level of familiarity with FAA regulations related to UAS?
   - o Not at all
   - o To a little extent
   - o To some extent
   - o To a moderate extent
   - o To a large extent

11. My airport would benefit from additional guidance regarding the Safety and Risk Management of UAS.
   - o Strongly Disagree
   - o Disagree
   - o Neither Agree nor Disagree
   - o Agree
   - o Strongly Agree

12. Do you feel your airport would benefit from additional education and training regarding UAS in the following subject areas (click all that apply)?
   - ☐ Regulations
   - ☐ Airspace waivers and authorization (LAANC)
   - ☐ Unmanned Traffic Management (UTM)
   - ☐ Safety and Risk Management
   - ☐ Counter UAS Technology
   - ☐ My organization is sufficiently trained
   - ☐ Other ____

13. Do you have any other comments regarding SMS or UAS operations on or near airports?____

Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #5

4-9-2023

Technical and Regulatory Factors of Adopting Electric Training Aircraft in a Collegiate Aviation Setting

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Electric-powered aircraft have entered the market. The arrival of the Pipistrel Velis Electro and other developmental efforts by companies such as Bye Aerospace, Piper, and eViation, have signaled to the aviation community that more electric-powered aircraft can be expected in the coming years. But how useful are they for training pilots in a Federal Aviation Administration (FAA) approved Part 141 collegiate aviation environment? To identify candidate flight courses and lessons, the authors examine flight hour distributions of a one-year window of invoiced flights (N = 52,728), including flight hour data cut-points at 60 minutes (n = 6,050) and 90 minutes (n = 25,439). The data distribution suggests that approximately 11.5% of the candidate flights would fall within a 60-minute expected flight duration, whereas 48% of flights would fall within a 90-minute flight duration. These calculations provide realistic targets for designed minimum flight duration (plus the inclusion of required FAA reserve) in order to be determined a feasible trainer in many high-volume FAA Part 141 training environments. Detailed course-level analysis suggests the Instrument Flight Instructor (CFII) flight course as a potential launch point for electric flight due to the relatively lower flight hour per lesson. In addition to minimum flight duration, other feasibility questions are included in this analysis, such as regulatory requirements, battery duration, aircraft turnaround time, multiple charge-discharge cycles per day, environmental factors, airport charging infrastructure, and maintenance factors. Additional research will benefit this developing area of electric aircraft in flight training environments.

Recommended Citation:
Wilson, N., Archer, L, Guthridge, R., Roesler, J. & Lents, M. (2023). Technical and regulatory factors of adopting electric training aircraft in a collegiate aviation setting. *Collegiate Aviation Review International,* 41(1), 94-114. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9468/8471

At the time of this writing, significant domestic and global events were and are expected to continue to influence the course of travel and technology. Public education on the relationship between carbon emissions and climate change has contributed to a growing awareness of the risks. According to one survey, well over 90% of adults in Europe and North America were aware of the problems associated with climate change (McSweeney, 2015). Unfortunately, the awareness of the risks of climate change is not uniform around the globe, yet it can be argued that the benefits of decarbonization may be felt by everyone.

In addition to the risks of climate change, the world has significant geopolitical and economic challenges. The war between Russia and Ukraine that began in 2022 has disrupted normal energy markets and contributed to energy and food instability in many parts of the globe (Economist, 2022a). The COVID-19 pandemic continues in selected regions (namely China and certain developing nations), whereas other regions have returned to near pre-pandemic levels, including air travel in the United States. Finally, the combined factors of post-pandemic increase in demand and disrupted supply chains have triggered inflationary pressures in many countries (Economist, 2022a).

One might ask how geopolitical and economic pressures relate to sustainable practices. Well, the uncertainties surrounding energy (oil) markets appear to have strengthened the focus on finding alternative sources of energy, including solar, nuclear, and hydroelectric power. As evidence of growing popularity and ostensibly impacted by this energy uncertainty, battery-powered vehicle availability has continued to grow in many countries, including the availability of electric trucks, such as the Ford F-150 Lightning and Tesla’s Cybertruck (Economist, 2022b). According to the Economist (2022b), electric vehicle sales account for one in five cars sold in Europe and one in four vehicles in China.

What about aviation? In summary, the availability of electric-powered aircraft is growing, particularly with the arrival of the European Aviation Safety Agency (EASA)-certified Pipistrel Velis Electro, now owned by Textron (Moore, 2022). Yet, similar to electric cars, battery-powered aircraft will have similar concerns relating to battery endurance and infrastructure. So, what does that mean for potential adopters of this new technology? This research will investigate several considerations for adopting electric-powered aircraft within collegiate aviation.

Literature Review

State of Sustainability in Aviation/Aerospace

The pace of hybrid and electrified aircraft development has accelerated in recent years. Beginning as early as 2010, Airbus, one of the two largest aircraft manufacturers, began the development of the electric aircraft ‘Cri-Cri’(Airbus, 2021). From that point, the company embarked upon a series of electric and hybrid aircraft demonstrators, including the E-Fan X, E-Fan 1.0, E-Fan 1.1, and the Airbus City Demonstrator. Solidifying the company's commitment to zero-emission aviation, the company opened the E-Aircraft System House in Germany to serve as a central point for the testing and development of alternative propulsion systems (Airbus, 2021).

In the airline environment, United Airlines recently partnered with Heart Aerospace to bring electric aircraft into U.S. domestic airline operations by 2030 (Thomas, 2022). Heart Aerospace's ES-30 is expected to come to the market in the late 2020s and has also garnered orders from other prominent companies such as Air Canada, Mesa, and Icelandair. The expected range of the ES-30 is expected to be approximately 120 miles (battery-only) to 240 miles (with gas-electric hybrid reserve). Given the expected range of this aircraft, it is expected to fill a short-haul sub-regional type aircraft intended to move passengers from outside metropolitan areas into hub airports.

In the general aviation domain, several aircraft manufacturers are working towards electric-powered aircraft, including Bye Aerospace, Pipistrel, and Diamond Aircraft (Boatman, 2022; Diamond Aircraft, 2022; Moore, 2022). At the time this article was written, the only aircraft with any type of certification from this set of manufacturers was Pipistrel. However, Pipistrel's Velis Electro only held type certification in Europe and currently operates under the experimental category in the United States.

In the light trainer marketspace, other pathways toward electric-powered aircraft exist. In July 2022, Vero Beach, Florida-based aircraft manufacturer Piper, announced it was partnering with the Canadian aerospace firm, Canadian Aviation Electronics (CAE), to generate a retrofit eArcher (Professional Pilot Magazine, 2022). This partnership was expected to produce a supplemental type certificate (STC) to convert existing Piper Archer airframes to electric power with the goal of reducing carbon emissions. The basic airframe, control surfaces, and flight characteristics would remain relatively unchanged; however, the fuel system and powerplant would undergo a renovation, requiring an STC. The STC approval route may be a shorter development and approval timeline compared to the certification of a new electric aircraft. Similar to other electric aircraft developmental efforts, the timeline associated with this effort is currently unclear.

Training Using Experimental Aircraft in the United States

Until recently, pilot training in experimental aircraft in the United States under Part 61 required a Letter of Deviation Authority (LODA) which was required for the individual aircraft and by the instructor (CFI) performing the training (Geil, 2022). The LODA process was recently removed under the FY 2023 National Defense Authorization Act. However, this change for Part 61 operators does not change existing regulations required under Part 141. The regulation 14 CFR Part 141.39(a)(2) precludes the use of experimental aircraft in flight training provided by a Part 141 flight school. Without further FAA airworthiness certification of an aircraft such as the Pipistrel Velis Electro and similar experimental aircraft, the expected utility in high-volume Part 141 training markets is limited. Given the lengthy processes the FAA requires for airworthiness certification and this technology representing a sea-change of sorts, it may be expected that any U.S. operator of new electric aircraft (certified as experimental) may be limited to Part 61 operations. Expansion into Part 141 flight schools will require a newly certified aircraft with a standard airworthiness certificate, a previously certified aircraft operating with a supplemental type certificate (STC), or as per the requirements of 141.39(a)(2).

Electric Training Aircraft Limitations and Operating Considerations

Electric aircraft powered by battery power is subject to the capacity limitations of current battery technology. In effect, this translates to “approximately an hour" (60 minutes) of potential flight duration (plus required reserve) based on current public statements or estimates provided by various manufacturers (CNN, 2017). Additionally, more analysis is required related to charge-discharge cycles, operational considerations of charging, and environmental considerations such as temperature, humidity, and atmospheric salinity (known to accelerate certain types of corrosion). A specific consideration yet to be fully investigated includes the contextual use of battery-powered aircraft within the flight training regime. For example, cycling lithium batteries at high currents, as anticipated in a high-volume flight training environment, combined with very high and very low ambient temperatures, may lead to yet unknown impacts on battery performance and longevity.

The internal combustion engine (ICE) powered training aircraft we fly today emphasize structural integrity, aerodynamic stability, and include more than adequate fuel reserves to complete the typical flight lesson at most any power setting. The electric aircraft we expect to see in the near future must meet the same design safety standards as their ICE predecessors yet, have a substantially new weight (battery) system to consider in place of traditional fuel storage systems. One solution to extend flight lesson duration is to fly these battery-powered aircraft at slower airspeeds (reduced amperage draw). Rarely, however, are training flights designed around these slower, maximum-efficiency flight regimes. Maneuvering lessons often require greater buffer from low-speed flight hazards, such as aerodynamic stall. Lessons focused on runway operation, such as take-off and landing, may place greater strain on battery storage systems due to the fluctuating power demands, including maximum power bursts while initiating the take-off roll or performing a go-around maneuver. Additional research questions and regulatory considerations are explored below.

Regulatory Requirements of Pilot Certification

Flight training in the United States may occur entirely within the realm of 14 CFR Part 61 or within the supplementary context of 14 CFR Part 141. Operations within Part 141, while subject to strict regulatory oversight by the FAA, provides benefits such as reduced aeronautical experience requirements to earn certificates and/or ratings. In both cases, the present technological state of electric aircraft may integrate well within selected aspects of flight training but not others. Within the next section, the focus will be on the following most common airplane single-engine certificates and ratings acquired in a collegiate flight training environment: private pilot certificate – airplane single engine land, instrument rating – airplane, commercial pilot – airplane single engine land, flight instructor – airplane single engine, flight instructor – instrument airplane.

As noted above, two primary limiting factors in the widespread adoption of electric aircraft in the flight training environment are battery endurance and charging infrastructure. While endurance and range have separate definitions, the concepts are closely related. Therefore, the advertised endurance values of electric aircraft can be used to draw basic conclusions about the potential range of the aircraft (assuming a no-wind condition). Range becomes a limiting factor for electric aircraft adoption due to the various cross-country aeronautical experience requirements necessary to obtain certain certificates and ratings. Per 14 CFR 61.1, cross-country time is defined as "a point of landing that was at least a straight-line distance of more than 50 nautical miles from the original point of departure," although, notably, this definition changes to "more than 25 nautical miles" for a sport pilot certificate and "a straight-line distance of more than 50 nautical miles" (without requiring a landing) for an airline transport pilot certificate. Assuming a groundspeed between 100 to 150 knots, a flight of approximately 50 nautical miles would require between 20 to 30 minutes of endurance, well within the advertised capability of existing electric aircraft solutions. Considering a roundtrip will generally be necessary for logistical purposes, the endurance requirements increase to 40 to 60 minutes, approaching or reaching the limit for current battery technology. These assumptions are predicated on the pilot conducting a cross-country flight at the regulatory-minimum distance, eliminating the flexibility to travel further, which may be necessary due to geographic isolation.

Private Pilot Training Considerations

Furthermore, certain certificates and ratings require cross-country flights of greater minimum distances. For a private pilot certificate with an airplane single-engine rating, 14 CFR 61.109(a)(2)(i) requires a night cross-country flight of over 100 nautical miles total distance, similar to the roundtrip demands of the "more than 50 nautical miles" cross-country. However, electric aircraft endurance may be more significantly impacted at night due to exterior and interior electric lighting requirements. Per 14 CFR 61.109(a)(5)(ii), the pilot must conduct a solo cross-country flight with a total distance of 150 nautical miles, equivalent to approximately 60 to 90 minutes of endurance at 100 to 150 knots groundspeed.

Commercial Pilot Training Considerations

For the commercial pilot certificate with an airplane single-engine rating, 14 CFR 61.129(a)(3)(iii) and (a)(3)(iv) both require a "2-hour cross country flight", which must include "a total straight-line distance of more than 100 nautical miles from the original point of departure". Furthermore, 14 CFR 61.129(a)(4)(i) requires a cross-country flight of "not less than 300 nautical miles total distance" with at least one segment consisting of a "straight-line distance of at least 250 nautical miles from the original departure point". If the training is conducted in accordance with Part 141, 14 CFR 141, Appendix D requires a more restrictive cross-country flight consisting of a flight segment of "a straight-line distance of at least 250 nautical miles".

Instrument Rating Training Considerations

The instrument rating is applied to either a private pilot certificate or commercial pilot certificate, granting a pilot the privilege of operating an aircraft under instrument flight rules (IFR), permitting operations such as flight in instrument meteorological conditions (IMC) or flight in Class A airspace. Among other requirements, 14 CFR 61.65(d) requires 50 hours of cross-country flight time as pilot-in-command, 40 hours of actual or simulated instrument time, and an IFR cross-country flight of 250 nautical miles. Per 14 CFR 61.1, the provision requiring a landing of more than 50 nautical miles from the original point of departure applies to the 50 hours of cross-country time for the instrument rating, suggesting the same limitations (and potential solutions) for most of the cross-country aeronautical experience required for other certificates and ratings.

While the 40 hours of instrument time is not required to be paired with the 50 hours of cross-country pilot-in-command time, an instructor and student may choose to design the training in this manner to produce maximum efficiency and lowest cost, impacting the ability to integrate an electric aircraft into this training. Additionally, the 250 nautical mile cross-country flight poses a substantial challenge for an electric aircraft to achieve within existing capabilities, although multiple stops to allow for recharging could mitigate this.

Appendix C of 14 CFR Part 141 outlines the requirements for an instrument rating course at a pilot school (14 CFR 141). A significant difference is the exclusion of any cross-country flight time requirement, requiring only 35 hours of actual or simulated instrument time. However, the 250 nautical mile cross-country remains a requirement, with a more restrictive element of one segment of at least 100 nautical miles between airports. While the incorporation of an electric aircraft in a 14 CFR 141 instrument rating course may be simpler than incorporating it in instrument training outside the provisions of 14 CFR 141, the 250 nautical mile cross-country continues to pose a significant hurdle.

Electric Aircraft – Airport Charging Infrastructure

The installation of charging infrastructure at designated cross-country “outstations” could mitigate endurance concerns for most cross-country requirements. Of course, this would require significant investment to provide the infrastructure, especially if “fast charging” is desired. Additionally, airports and fixed base operators would likely need to reconsider their service fee model to account for electrical utility usage and potential reduction of fuel distribution revenue. Even if those barriers were overcome, this solution would currently be insufficient to achieve a single 250 nautical mile cross-country flight segment; a groundspeed of 100 to 150 knots would require approximately 1 hour 40 minutes to 2 hours 30 minutes of endurance, well beyond the current advertised capabilities of electric training aircraft operating on a single charge.

Precedents to overcome these minimum distance (endurance) hurdles may exist within the context of flight training on small islands. Due to the geographic limitations of locations such as Hawaii, many of the cross-country requirements for various certificates and ratings are impractical or impossible to achieve. 14 CFR 61.111 allows for a waiver of the cross-country distance provisions of 14 CFR 61.109 (aeronautical experience for a private pilot certificate) for applicants located on islands in which the cross-country requirements would necessitate flying over water more than ten nautical miles from the nearest shoreline. Conducting training using the provisions of 14 CFR 61.111 mandates the issuance of a limitation on the pilot certificate prohibiting the carrying of passengers on flights of more than ten nautical miles from the respective island (and all other islands) in which the training was conducted. The limitation may be removed upon meeting the cross-country requirements of 14 CFR 61.109.

For the commercial pilot certificate, 14 CFR 61.129(a)(4)(i), requiring a 300 nautical mile cross-country flight (with one segment of at least 250 nautical miles), permits a reduction for applicants conducting the training in Hawaii. These applicants can instead conduct the longest segment at only 150 nautical miles rather than 250 nautical miles. The same substitution is permitted in 14 CFR Appendix D (Commercial Pilot Certification Course) (5)(a)(1).

Flight Instructor (CFI) Training Considerations

Notably, per 14 CFR 61 Subpart H, the flight instructor certificate has no explicit aeronautical experience requirements beyond 15 hours of pilot in command time in the category and class of aircraft for the rating sought, which the trainee is likely to already possess upon commencement of their flight instructor training. The same subpart also governs the requirements to earn an instrument rating for the flight instructor certificate, again with no explicit aeronautical experience requirements. Flight instructor training under 14 CFR 141 is arguably more stringent. 14 CFR 141 Appendix F requires 25 hours of total aeronautical experience in an approved flight instructor training course with no specific requirements regarding the type of flying (ex., cross-country flights). Similarly, 14 CFR 141 Appendix G simply requires 15 hours of total aeronautical experience in an approved flight instructor instrument course. Additional flight-hour/flight-course analysis and adoption considerations are explored below.

Purpose of the Study

The purpose of this study is to address questions related to the technical and regulatory factors of using electric-powered general aviation training aircraft in a collegiate flight training environment. The first two questions intend to identify how many potential flights would fall within the expected flight duration of an example electric-powered aircraft at two different potential battery capacities; 60 minutes and 90 minutes (plus required reserve). Another purpose of the study was to perform an analysis of the flight lesson curricula by flight course to identify flight courses that may serve as suitable launch points for electric aircraft based on their composition of flight lessons and average flight lesson durations. The final purpose of this study was to identify sets of additional technical and operational factors which may need to be considered if a collegiate aviation institution were to adopt electric training aircraft.

Research Questions

RQ1.Assuming no changes to the current FAA-approved Part-141 training curriculum, what percentage of the flights would be considered candidate flights for electric-powered aircraft with a 60-minute flight hour duration plus reserve?

RQ2. Assuming no changes to the current FAA-approved Part-141 training curriculum, what percentage of the flights would be considered candidate flights for electric-powered aircraft with a 90-minute flight hour duration plus reserve?

RQ3. What are the mean flight hours by flight course, and what percentage of each flight course's training flights would be covered by aircraft flight durations of 60 minutes (1.0 Hobbs meter) and 90 minutes (1.5 Hobbs meter)?

Method

Sample

The master dataset includes invoiced training flights (*N* = 52,728) from all flight courses at a collegiate aviation institution during the fiscal year 2022 (FY22) (July 1, 2021, through June 30, 2022). For the purposes of the study, only invoices generated through the use of internal combustion engine (ICE) powered single-engine aircraft (e.g., the Piper Archer) were included in the study. To facilitate a more detailed analysis relevant to the study purpose, two subsets of the master dataset were created; a dataset with flight lessons of 1.5 hours Hobbs meter or less (*n* = 25,439) and a dataset with flight records of 1.0 hours Hobbs meter or less (*n* = 6,050). To determine invoiced flight lessons that may not represent "normal" training flights, the researchers also identified lessons with an invoice of 0.4 or fewer hours. These low-time lessons were limited to 316 flights and represented only a small fraction of the operation (0.59%) and, as such, did not represent a meaningful portion of the training requirements of a pilot candidate. Finally, a small number of flight records (*n* = 29) were removed from the analysis as they represented *legacy* courses of the approved Part 141 (*n* = 23) curriculum or were non-standard database entries (*n* = 6).

Data Collection

After each training flight, the student and/or flight instructor completes an invoice and submits it for processing into the flight records system. Included on the invoice are pertinent details about the flight, including the date, flight course, flight lesson, and billable flight hours. The billable flight hours are recorded from an analog gauge in the aircraft (referred to as the Hobbs meter). A report was generated from this dataset for FY22, and the data was cleaned of any identifiable student information and non-pertinent records. Additionally, the dataset included a small number of records (<1%), which represented flight courses either no longer a part of active training course outlines (TCOs) or non-standard database entries. Those records were also removed from the dataset. After cleaning the data, researchers rank-ordered the flight records by the duration of the flight (0.1 to 8.0 hours) and compiled a master (all flight records) and two subset (nested) datasets representing flight records 60 minutes and less (≤1.0 Hobbs meter) and 90 minutes (≤1.5 Hobbs meter). As the study focused only on flight duration analysis without any identifiable student information, no IRB approval was sought for the study.

Results

Using the master and two nested datasets, researchers first noted the record count within each dataset and calculated the lesson mean flight hour durations for each of the three related datasets using the =*average(cellrange)* function within Microsoft Excel. The result of this initial analysis of the master and two subset datasets is included in Table 1. To aid in the feasibility analysis of battery-powered flight, additional analyses were performed using the two nested datasets with lesson durations up to and including 60 minutes (1.0 Hobbs meter) and up to and including 90 minutes (1.5 Hobbs meter). These values were chosen as they represent the currently forecasted flight durations of electric aircraft in-service or proposed for development at the time of this writing.

Using these datasets, researchers then created pivot tables to assess the data by flight hour duration using incremental Hobbs hour records (0.1, 0.2, 0.3, etc.) and, separately, by flight course. The pivot table of the flight hour records was used to create the distribution shown in Figure 1. Flight lessons of 60 minutes or less represented 11.5% of the dataset, whereas a notable increase in candidate flights was noted when expanding the analysis to include 90-minute (1.5 Hobbs meter) flight durations, representing 48.2% of the dataset. The pivot table of the flight course records was used to calculate mean flight hours per flight course, as shown in Table 2.

Table 1

Master Dataset and Nested Datasets, Flight Record Counts and Means

Datasets	**Flight Count (N/n)**	**% of Master Dataset**	**Lesson Duration Mean (hrs)**
All Training Flights (Master)	52728	100.0	1.68
Flights ≤ 90 min (0.1-1.5)	25439	48.2	1.22
Flights ≤60 min (0.1-1.0))	6050	11.5	0.79
Flights ≤ 0.4 (≤ 24 min)	316	0.6	0.36

Note. The master dataset includes all flight records within the assessment period, whereas the 90- and 60-minute datasets are proportionately smaller. Flight records less than or equal to 0.4 hours Hobbs were included in the Master, 60-min, and 90-min datasets but had negligible impact on analysis.

In addition to the 60- and 90-minute subset analysis, the researchers analyzed the individual flight courses which currently employ ICE-powered aircraft and which may use electric aircraft in the future. Six (6) flight courses included in the FAA Part 141 curriculum using a single-engine aircraft (e.g., the Piper Archer) were analyzed. The results of the flight lesson count, mean flight lesson length, standard deviation (SD), and percentage of flight lessons within each flight course at and below the 60- and 90-minute cut points are included in Table 2. The first commercial “time-building” course (CP1) and instrument training (IR) courses include several longer cross-country flights, which increases the lesson mean above other courses such as Private Pilot (PVT) and the two fixed-wing airplane instructor courses (CFI and CFII). For consideration purposes, only 8.5% of flights would be covered within the existing CP1 curriculum with battery durations of 60 minutes, whereas over 80% of the flights in the CFII course would be covered at a battery duration of 90 minutes.

Table 2

Course Flight Counts, Means, SD, and Percentage of Lessons at or Below 60 and 90 Mins

Course	Flight Count (*n*)	Lesson Duration Mean (hrs)	SD	% Flight ≤ 60 min	% Flight ≤ 90 min
Private (PVT)	18,732	1.54	0.49	14.2	48.9
Commercial – Basic (CP1)	10,058	1.97	1.07	8.5	38.6
Instrument (IR)	8,035	1.89	0.97	10.6	49.2
Commercial - Advanced (CP2)	7,388	1.68	0.88	11.5	43.4
Flight Instructor (CFI)	5,480	1.48	0.35	15.5	50.9
Instrument Flight Instructor (CFII)	3,035	1.42	0.47	28.1	80.2
Total	**52,728**				

Note. Invoices from students who entered the university with an FAA private pilot certificate were grouped under the PVT course, along with traditional student pilots enrolled in the FAA PVT course.

Tables 3 through 8 below represent a summarized format of the current FAA Part 141 curriculum at the collegiate aviation institution separated by flight course. The tables are presented to allow the reader to further understand what portion of the curriculum would be covered by electric-powered aircraft of varying battery durations, assuming (1) no changes in the curriculum, and (2) assuming improvements to the battery longevity as technology improves. It is acknowledged that both of these factors – curriculum design and battery duration – will change over time, so a nearly infinite combination of curriculum designs would not be prudent to include in this manuscript. Collegiate aviation institutions have the option to include ground training devices (FTDs/ATDs/simulators) in their flight courses and determine to what scale they are used. Training time in the ground training devices does count towards pilot training requirements. The tables below do not include the TCO-approved use of ground training devices and focus primarily on single-engine airplane training time. These tables do include the additional practice and training typically observed at the collegiate aviation institutions dataset and not just the training required to meet FAA pilot training minimums.

Table 3

Part 141 PVT Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	30
Local Solo	1.3	2
X Country Dual	3	2
X Country Solo	3	1

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 4
Part 141 CP1 Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	15
Local Solo	1.5	5
X Country Dual	3	5
X Country Solo	3	5

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 5
Part 141 IR Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	13
Local Solo	NA	NA
X Country Dual	3	3
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 6
Part 141 CP2 Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	17
Local Solo	NA	NA
X Country Dual	NA	NA
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 7

Part 141 CFI Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	20
Local Solo	NA	NA
X Country Dual	NA	NA
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

Table 8

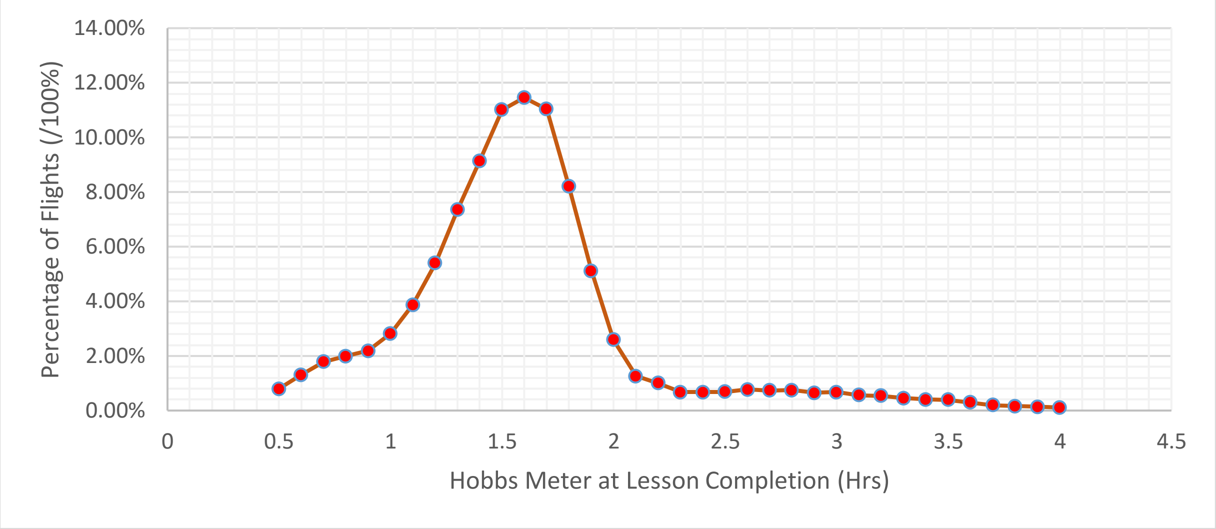
Part 141 CFII Curriculum – Breakdown by Expected Flight Lesson Duration and Count

Flight Lesson Type	Flight Lesson Duration - in TCO	Expected Lesson Count
Local Dual	1.5	9
Local Solo	NA	NA
X Country Dual	2.5	1
X Country Solo	NA	NA

Note. Students may witness differences in lesson times and numbers of lessons due to a variety of factors, including practice, weather, proficiency, prior experience, and others.

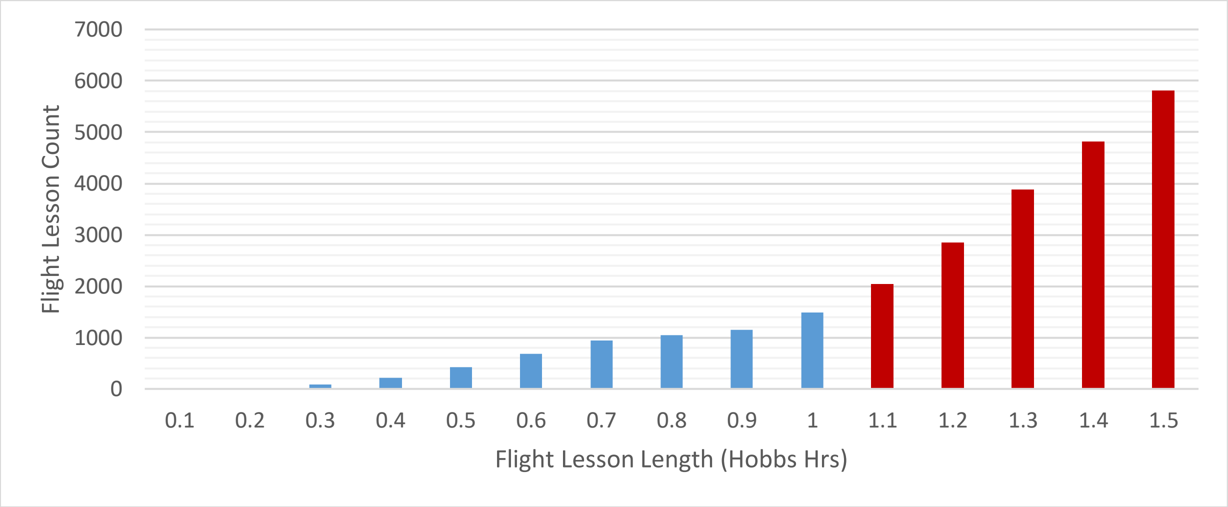
Additional graphical analyses of candidate flight lessons are included in Figure 1 and Figure 2 below. Figure 1 shows invoiced flight lessons between 0.5 and 4.0 flight hours and a concentration of candidate flight lessons between 1.0 and 2.0 hours, with fewer flights occurring above and below those values. Figure 2 shows greater detail on flight lesson counts, specifically focusing on flights that could be substituted from an internal combustion engine (ICE) powered aircraft to an electric-powered aircraft given current electric aircraft capabilities. The data in Figure 2 is color-coded by the flight hour duration with data up to 60 minutes (1.0 Hobbs meter) (blue) and data greater than 60 minutes and less than or equal to 90 minutes (between 1.1 and 1.5 Hobbs meter) (red). The data is colored to emphasize the difference in the nominal count of candidate flights which could benefit from an aircraft with a 60-minute flight duration plus reserve or an aircraft with a 90-minute flight duration plus reserve battery. Considering the data in Figure 2, flight lessons with a Hobbs reading of 0.1 to 0.4 total of 316 flights, lessons with a length of 0.5 to 1.0 hours total of 5,734 flights, and the records ranging from 1.1 to 1.5 represent *an additional* 19,073 flights.

Figure 1.
Fixed-Wing Flight Lesson Distribution by Percentage of Flights 0.5 – 4.0 Hours FY22 (n = 51,243)



Note. Training flights under 0.4 or over 4.0 recorded Hobbs time were excluded from the graph above to simplify graph interpretation. Flights over 4.0 recorded duration represent a small portion of cross-country training and will ostensibly require aircraft with internal combustion engines until battery technology continues to mature.

Figure 2.
Piper Archer Flight Lesson Count by Hobbs Meter Subset Data (≤60 and ≤90 Mins) – FY22 (n = 25,439)



The next portion of this research effort was to identify a set of additional factors flight schools must consider when assessing technical and operational considerations of electric aircraft. The research team generated this list through their extensive experience in Part 141 training environments and as a natural consequence of considering the logistical requirements of adopting electric aircraft into the training environment. It should be noted that the research team is all Federal Aviation Administration (FAA) certified pilots and flight instructors, each with extensive management, instructional experience, or both. Although this dataset includes many important factors, additional research and analysis by other teams may generate additional regulatory, infrastructure, or human factors considerations not included below. The factors and proposed research, training, or operational questions are listed below in Table 9.

Table 9

Operational and Training Factors of Electric Aircraft for Further Research

Factor	Operational Impact	Proposed Question(s)
Battery duration	If flight time available per charge is less than what is expected today using fuel, curriculum, training schedules, and/or flight lesson content must be modified.	What is the expected or typical amount of flight time available per charge? What is the projected development timeline for battery capacity increases?
Battery charging – Aircraft Turnaround Time	Fueling a general aviation airplane takes minutes. Longer times to charge the battery may extend the time between flights and may result in less aircraft utilization and/or increased operational costs.	What is the expected or typical time to charge the battery? What R&D is being done today to reduce this factor?
Battery charging – Multiple Cycles per Day	Airplanes used for flight training are used multiple times per day. The time needed to cool the battery after charging may extend the time between flights.	Will the battery need cooling time when charged multiple times per day? Does the frequency of the charge cycle impact battery health/longevity?
Battery Charging – Environmental Factors	Ambient temperature. Atmospheric Salinity (corrosion). Effects on airplane turnaround times and utilization.	What effects does ambient temperature (high or low) have on battery charging and the time to reach a full charge? Does atmospheric salinity increase the risk of corrosion on power components?
Base Airport Infrastructure – Charging Stations	The number of charging stations available will impact aircraft turnaround times. Large fleets may require dozens of available charging stations. Smaller operators may be able to operate with a single charging station.	Are airports prepared to construct and provide multiple charging stations? In ground installation? Above ground installation? What other power storage solutions can facilitate charging requirements?

Charging Station Availability at Other Airports	Flight training requires cross-country training. Charging station availability affects route selection. When paired with weather conditions, cross-country training could result in extended training timelines or limited route selection.	Are airports prepared to construct and provide multiple charging stations? In ground installation? Above ground installation? In the event of a diversion to an airport not equipped with charge, what solutions exist to recharge that aircraft after landing?
Aircraft Systems	The aircraft systems in an electric airplane are different from a standard combustion engine (E.g., fuel level vs. battery capacity, engine start/stop controls, emergency procedures, environmental system usage, etc.).	Will pilots in training be required to train in both electric and internal combustion engines, or will there be separate training similar to what is expected for complex, high-performance, and tailwheel airplanes?
Emergency and Operating Procedures	The aircraft systems and operating procedures in an electric airplane are different from an aircraft with a standard combustion engine.	Will pilots in training be required to train in both electric and combustion engines, or will there be separate training similar to what is expected for complex, high-performance, and tailwheel airplanes?
Insurance	Do insurers have adequate data to make informed decisions related to insurance rates? Aircraft with a standard combustion engine typically have fuel endurance of 4 to 6 hours.	Will individual aircraft or fleet insurance be higher or lower than ICE-powered aircraft? Will less flight time available because of lower battery endurance increase the per-hour cost of insurance?
Aircraft maintenance	The differences between electric and internal combustion engines.	Will aircraft mechanics be required to have additional training to be authorized to work on electric aircraft engines and systems in an environment where there is already a mechanic shortage?
Airport Rescue Fire Fighting (ARFF) Training and Capability	Electric batteries and liquid fuel tanks are different methods of storing chemical energy. They also present different challenges with respect to the containment of any reactions.	Do local ARFF teams need new equipment or training to support battery-powered aircraft?

Human Factors Decision Making	Pilots of common ICE-powered training aircraft can expect several hours of flight duration.	How does pilot decision-making change with different battery durations or remaining capacity display representations?

Discussion

Flight Course/Lesson Candidates – Course Type and Lesson Duration

Numerous factors influence the feasibility of adopting electric aircraft, given their current operating considerations and limitations. First, if we consider the nominal flight time for any set of candidate flight lessons (without respect to flight course, flight lesson content, or regulatory requirements), approximately 11.5% of the flights would be considered candidates at 60 minutes or less duration (plus reserve). If battery technology increases to allow for up to 90-minute battery duration (plus reserve), the amount of candidate flight lessons increases substantially to around 48.2% of possible flights. Most providers of flight training understand that sequential flight lessons may be of varying lengths. For example, a normal maneuvers lesson (~1.2-1.5 hours) may be followed by a night-cross country (~2.5 hours). Should students and instructors be expected to routinely switch aircraft types (or, at minimum, engine types) from one lesson to the next on a regular basis? On an isolated basis or if the aircraft type remains constant, it may not have a substantial negative impact assuming the instructors are adequately proficient in both aircraft types (electric or ICE). However, switching regularly between ICE and electric-powered aircraft simply to maximize utilization of electric aircraft may have secondary effects on student progress, human factors, and/or proficiency with normal and emergency procedures. These questions are not yet fully understood. Yet, we know that as battery technology improves to allow longer flights with operationally necessary payloads, the amount of *switching* between ICE and electric-powered aircraft is expected to diminish.

If we consider the alignment between the flight course curriculum and current electric aircraft capabilities, more specific solutions become evident. Considering Table 2, the flight instructor courses (CFI and CFII) and instrument training (IR) courses may be candidates for early adoption of electric flight. The instrument flight instructor course (CFII) with lower average flight times and no cross-country requirements may yield up to 80% of flight lessons as candidates for electric aircraft, assuming a 90-minute plus reserve capacity. Follow-on conditions may be placed on lessons such as “simulated instrument conditions only” to ensure compliance with regulatory factors such as filing of the alternate airport(s), etc. An additional breakdown of individual flight course curriculum structures was presented in Tables 3 – 8.

Flight Course/Lesson Candidates - Regulatory Considerations

For rapid adoption of electric aircraft in flight training, governing agencies must consider either regulatory exceptions or a review of existing regulations to better accommodate electric aviation. Regulatory carveouts similar in style to the carveouts provided for flight training on small islands could provide precedent. For the private pilot certificate, a new regulation could permit a waiver of the minimum cross-country distance requirements when training is conducted in an electric aircraft, with a limitation prohibiting passengers carrying on flights more than 50 nautical miles from the original point of departure. For the commercial pilot certificate, 14 CFR 141 Appendix D (5)(a)(1) should also apply to electric aircraft, allowing the "straight-line distance of at least 250 nautical miles" to be substituted for a "straight-line distance of at least 150 nautical miles". For commercial pilot training conducted under Part 61, the "Hawaii carveout" within 14 CFR 61.129(a)(4)(i) should also apply to electric aircraft, permitting a straight-line distance from the original point of departure of 150 nautical miles versus 250 nautical miles. There currently exists no "Hawaii carveout" for the 2-hour cross-country requirements, requiring a new, unprecedented regulation, perhaps reducing the requirement to 1-hour for electric aircraft.

There currently exists no regulatory exception for instrument training on small islands, providing no precedent to overcome the 250 nautical mile cross-country flight requirement for the instrument rating. The 40 hours (or 35 hours under 14 CFR 141) of instrument experience could be more achievable with the current state of electric aircraft technology, assuming these hours are acquired during local flights. Summarily, an electric aircraft (assuming current technology) could only be utilized to earn an instrument rating if supplemented by an aircraft powered by an internal combustion engine. Furthermore, while not necessarily required for most instrument training (with the exception of the 250 nautical mile cross-country), if the instructor and/or trainee wish to operate under instrument flight rules (IFR), the aircraft must be IFR-certified.

Training for flight instructor certificates may present the greatest opportunity to practically integrate electric aircraft immediately, without the need for any regulatory relief. No cross-country aeronautical experience requirements are mandated for the certificate in both Part 61 and Part 141. The same is true for the training required for a flight instructor instrument airplane rating. Assuming lesson profiles are designed to accommodate the endurance of an electric aircraft, the entirety of this training can be accomplished with an electric aircraft. Certainly, flight instructors and flight schools would need to consider the implications of the non-exposure of flight instructor applicants to aircraft with internal combustion engines. For example, an internal combustion engine malfunction or failure may be handled much differently, with different instructional considerations, from malfunction or failure of the electric propulsion system in an electric aircraft.

With the aforementioned regulatory limitations and suggestions, training for the private pilot certificate using electric aircraft can be considered to be feasible. All requirements for the certificate could theoretically be met with an electric aircraft today, though regulatory relief would make the integration much more practical without the need to either install additional infrastructure or supplement the training with an aircraft powered by an internal combustion engine for the purposes of meeting the cross-country requirements. Commercial training could be made more possible with the suggested regulatory relief but remains a significant practical challenge without supplement from an aircraft powered by an internal combustion engine.

An additional application of electric aircraft could be as a "time-building" solution towards the aeronautical experience requirements for an airline transport pilot (ATP) certificate required to serve as a required crewmember in a 14 CFR 121 operation (scheduled airlines). 14

CFR 61.159 requires 1500 hours of total pilot time for the ATP, although pilots may qualify for a restricted ATP certificate at 750 hours, 1000 hours, or 1250 hours depending on the type of previous experience and/or whether flight training was conducted in a collegiate setting. Without additional aeronautical experience beyond that acquired during flight training, an instrument, and multi-engine rated commercial pilot is likely to have approximately 200 to 300 hours upon completion of training, leaving a deficit of approximately 800 to 1300 hours of pilot time. Some may choose to gain this experience through traditional "experience-building" jobs such as pipeline patrol, aerial survey, or flight instructor, all of which allow the pilot to receive compensation while time-building. Electric aircraft could, however, provide a modern, alternate, and low cost means of gaining this experience.

The Mesa Airlines Pilot Development Program utilizes a fleet of Pipistrel Alphas, the internal combustion version of the Pipistrel Velis Electro (*Mesa Pilot Development*, n.d.). The program allows cadets to build time, up to 40 hours per week at $25/hour, all financed by Mesa Airlines. The cadet would then repay this loan after employment by the carrier. Flight schools could adopt similar programs, offering an electric aircraft such as the Velis Electro to conduct low-cost time-building.

Required Airport Infrastructure

The change from internal combustion engines (ICE) to electric-powered aircraft requires a paradigm shift in the required airport infrastructure. For example, a *theoretical* airport with a 100% electric fleet would no longer require in-ground or above-ground liquid fuel tanks for local tenants, yet would need some electric power-grid replacement. Additionally, the risk of fuel spillage, environmental damage, or unintended combustion of flammable liquids would be mitigated. Although these longer-term benefits may serve as a vision of sorts towards decarbonizing aviation, it is expected that significant investment (expense) in airport infrastructure will be required to facilitate electric aircraft in the near term as well as the ongoing support needs of legacy ICE aircraft whether based locally or transient.

Limitations

This study was conducted using flight lesson data at a collegiate flight institution in the midwestern United States. The flight hour dataset and its associated analysis are influenced by the current-state curriculum in place at the institution as approved by the Federal Aviation Administration (FAA). In addition to the impact of the current-state curriculum, the analysis may be impacted by the airport, airspace, and environment. For example, a flight school at a smaller airport with fewer flight operations may require less ground taxi time and less flight time to transit to and from a 'practice area' if a practice area has even been designated. Conversely, a flight school or institution based at a larger airport may require more time for ground taxi and transit to and from any practice areas. An additional consideration that may impact some analyses are weather conditions. Significant weather variations such as high cross-winds, low ceilings, thunderstorms, winter weather, and icing may have a nominal impact on any dataset and could influence an individual training provider's experience depending on their local climate. Consumers of this dataset should understand that curriculum, airport, flight operations, and weather may change how you interpret the data included in this study as well as how similarly or differently another collegiate aviation organization or flight school may witness similar analysis.

One final limitation of this study relates to the method by which the researchers generated the operational and training factors listed in Table 9. Although the authors are all FAA-certified pilots and instructors and have a variety of management or instructional backgrounds, this portion of the manuscript did not include input from a broader audience and could be improved through additional research. In fact, the purpose of this table was to assist future researchers in identifying potential research topics, adoption considerations, and/or performing research to further the knowledge in the aviation discipline.

Conclusions and Future Implications

Flight training is expensive, and Universities have a responsibility to explore green initiatives. Today's collegiate aviation students are building high levels of debt to pay for their flight training. Universities and training providers are doing what they can to keep costs as low as possible while remaining competitive. At the time of writing, the average price of 100LL nationally is just under $7 per gallon (*100LL - Aviation Fuel Prices*, n.d.). That means a training aircraft with a 180 HP combustion engine requires over $50 an hour for fuel alone. Utilizing electric aircraft is an option that could lower fleet operating costs, lower the cost burden to the student, and enable Universities and training providers to adapt to greener alternatives. However, the authors of this paper have identified many considerations for adopting electric flight in a collegiate environment.

If a battery-powered aircraft can sustain flight for 60 minutes plus reserve, a simplified analysis suggests that approximately 11.5 percent of training flights at a given Part 141 collegiate flight program could benefit from such aircraft without respect to flight curriculum. If the battery duration plus reserve expands to 90 minutes, nearly half of all candidate flights within the curriculum could benefit from an electric aircraft. Although battery duration is one important factor, many other factors must be considered. Regulatory requirements suggest that charging infrastructure at the base and remote airports must be developed across our nation to facilitate cross-country length requirements, or conversely, the regulations must be changed. Additionally, any potential flight school may need to consider environmental factors (e.g., temperature), maintenance, and charge-discharge cycles with any adoption decision. In addition to the questions we have raised in this research, there are additional human factors considerations such as potential time pressures, changes (improvement) in pilot fatigue, and others yet to consider. More work remains within this developing field to understand the long-term implications of electric flight. Two questions remain. When will electric-powered aircraft become commonplace at collegiate aviation institutions? Will converting a fleet of aircraft from ICE to electric-powered and training its associated support personnel and facility updates result in lower or higher costs over time?

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #6

4-15-2023

Flying Under the Radar: A Survey of Collegiate Pilots’ Mental Health to Identify Aeromedical Nondisclosure and Healthcare-Seeking Behaviors

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The disclosure of a new or existing mental health condition in a pilot complicates their medical certification status. It has been proposed that the threat of losing medical certification often discourages pilots from seeking treatment for mental health issues or disclosing such information to aeromedical professionals, contributing to a barrier to seeking healthcare that affects pilots of all certification levels. The current study focused on the nondisclosure and healthcare-seeking behaviors of the collegiate pilot population (N = 2,452) at a large, accredited, private institution that offers flight training in accordance with Pilot Schools (2022). Data collected from our anonymous online survey over the course of 30 days found that 56.6% of a sub-sample (n = 232) of collegiate pilots met the criteria for some degree of depression, and 13.8% reported the prevalence of self-injurious or suicidal ideation within the past two weeks. Additionally, 67.7% of the sample (N = 256) expressed concern about seeking care for mental health issues because of potential effects on their medical certification, while 29.3% admitted to withholding mental health information from aeromedical professionals out of concern for their medical certification. The current study found that the same barrier to healthcare present in the airline pilot and military populations is also present in the collegiate pilot population. While previous research has focused on healthcare aversion and nondisclosure in airline, commercial, and military pilot populations, these findings focus on collegiate pilots, a population not accounted for in existing studies. Further studies are necessary to explore additional factors contributing to the pilot healthcare barrier and nondisclosure in aeromedical settings.

Recommended Citation:
Pitts, L. & Faulconer, E. (2023). Flying under the radar: A survey of collegiate pilots’ mental health to identify aeromedical nondisclosure and healthcare-seeking behaviors. *Collegiate Aviation Review International,* 41(1), 115-133, Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9422/8472

Introduction

Medical nondisclosure and the pilot healthcare barrier are serious, yet largely unresearched, issues for aviation safety. In the past ten years, few articles have been published on pilots' healthcare-seeking behaviors, including their aversion to seeking care and the anxiety that surrounds their healthcare-seeking decisions. In a survey of 154 female pilots of varying certification levels, Hoffman et al. (2021) found that nearly 67% withheld information from their healthcare providers. In another survey of 3,765 civilian pilots in the United States, nearly 46% admitted to withholding information from healthcare providers out of fear of aeromedical certificate loss (Hoffman et al., 2022a). The same study also found that more than 56% of pilots reported at least one healthcare avoidance behavior, such as flying despite experiencing new symptoms that the pilot felt warranted medical evaluation, failure to disclose prescription medication use, or misrepresenting or withholding information on a written health questionnaire. Hoffman et al. (2022a) linked motivations for these behaviors to the fear of losing the Federal Aviation Administration (FAA) medical certification.

While the Hoffman et al. (2021, 2022a) studies have been valuable for quantifying the existence of a barrier to healthcare in various pilot populations, they do not specifically concentrate on mental health issues. Wu et al. (2016) examined the prevalence of depression and suicidal ideation in 1,848 commercial airline pilots. Findings revealed that over 12% of pilots met the threshold for a clinical depression diagnosis, while 4% of respondents that reported working as an airline pilot within the previous seven days ($n = 1,430$) also reported suicidal thoughts within the past two weeks (Wu et al., 2016). Disclosing depression and suicidal ideation on aeromedical examinations may jeopardize the career and livelihood of an airline pilot. However, untreated mental health conditions can also be detrimental. When left untreated, psychiatric disorders can increase in frequency, severity, and spontaneity; additionally, treatments that may have been effective in earlier stages of illness might not have the same effectiveness in a more progressed condition (Post & Weiss, 1998)

Previous studies have quantified healthcare aversion and nondisclosure patterns in female pilots, civilian pilots of various certification levels, and commercial airline pilots, but no study has explored the prevalence of such issues and their connection to the mental health of the collegiate pilot population. Recent events have brought attention to the mental health needs of collegiate pilots. On October 18, 2021, University of North Dakota sophomore flight student John Hauser committed suicide by intentionally crashing his aircraft into a field on a solo flight (Henson, 2021). While Hauser's family was unaware of his struggles with mental health, he left a letter detailing his depression and desire to seek mental healthcare; Hauser wrote that "life was not worth living if he could not fly," alluding to the potential loss of flight privileges that accompanies disclosure of mental health conditions (Henson, 2021). Based on the findings of previous studies of other pilot populations and the recent death of a collegiate pilot directly related to healthcare aversion, there is a clear need for further research on the aeromedical nondisclosure and healthcare-seeking behaviors of the collegiate pilot population. The current study hypothesizes that collegiate pilots will demonstrate aeromedical nondisclosure behaviors as well as an aversion to seeking healthcare for mental health.

Literature Review

Data on pilots' disclosure of specific health concerns mirror the larger trend of general healthcare disclosure. Hoffman et al. (2019) utilized an anonymous, 20-question online survey to quantify trends in the healthcare-seeking behavior of pilots of various certification levels; nearly 39% of respondents (n = 613) reported that they intentionally withheld information about chest pain from their aeromedical examiner (AME) for fear of losing their medical certification. Hoffman et al. also revealed that a significant number of pilots surveyed (nearly 79%) experienced worry related to the implications of seeking health care on their ability to fly. Medical certification systems rely on pilots to be honest in disclosing medical conditions; even with serious health concerns such as cardiovascular disease symptoms, pilots are reluctant to disclose health information (Hoffman et al., 2019).

Hoffman et al. (2022b) sought to understand the factors that influence aeromedical nondisclosure by applying the Andersen Behavioral Model of Health Services Use to the pilot population. They concluded that several psychosocial factors contribute to a pilot's decision to access healthcare, including the pilot's attitude (such as the perceived likelihood of re-obtaining medical certification if theirs is deferred or denied), social norms (such as changes in identity that may accompany the loss of medical certification), and perceived control (such as lack of autonomy while the pilot completes the processes for re-certification, anxiety, or lack of education on the processes to regain medical certification). Additionally, the study proposed formally defining "pilot healthcare barriers" as "factors that impede healthcare-seeking behavior by individuals who hold a pilot certificate. These barriers include perceptions about potentially negative consequences of new health information on future ability to perform piloting duties" (Hoffman et al., 2022b). A formal definition of "pilot healthcare barriers" prompts further research into the validity of that definition among different pilot populations.

The FAA publishes literature to aid Aviation Medical Examiners (AMEs) in their decision to issue medical certificates. The FAA (2022) *Guide for Aviation Medical Examiners* summarizes the most recent information available to AMEs regarding FAA airmen medical certification, including guidelines for issuance regarding potentially disqualifying conditions. The *Guide for Aviation Medical Examiners* explains that applicants are asked to disclose "mental disorders of any sort" and that a report of "an established history of a personality disorder that is severe enough to have repeatedly manifested itself by overt acts, a psychosis disorder, or a bipolar disorder must be denied or deferred by the AME" (Federal Aviation Administration, 2022). In cases where defer/denial protocols are not explicitly stated, such as with diagnoses of depression or anxiety, AMEs are encouraged to defer the certification decision to the FAA. AMEs must also defer applicants that report a history of suicidal attempts or gestures to the FAA, which will request additional testing and records from the applicant to determine certification eligibility. In addition to the *Guide for Aviation Medical Examiners*, standards for medical certification are also outlined in the federal standards, where Medical Standards and

Certification (2022) details the standards that pilots must adhere to in order to qualify for medical certification.

Because of varied healthcare quality, access, and cost globally, it is challenging to compare healthcare-seeking behavior in different regions. However, the nondisclosure issue is not limited to the United States. Carmon et al. (2016) explore the healthcare-seeking patterns of pilots in the Israeli Air Force, reporting that nearly 63% of pilots surveyed reported clinical symptoms (the nature of which was not explicitly defined), of which nearly 71% admitted to not seeking medical treatment for from a physician; nearly 18% of symptomatic respondents elected instead to visit non-MD practitioners such as chiropractors and dietitians for treatment. The study stopped short of investigating the aviators' motivations for seeking treatment from non-MD practitioners rather than physicians but noted that cost of care was not a factor in an aviator's decision (Carmon et al., 2016).

The safety implications of nondisclosure and delayed treatment cannot be ignored. The 2007 FAA Oversight Report from the Department of Transportation found that 8% of the roughly 40,000 airmen studied were receiving Social Security benefits for conditions that would disqualify them from holding FAA medical certification (The Federal Aviation Administration's Oversight of Falsified Airman Medical Certificate Applications, 2007). This data has been used by experts as a call for further research because, while this statistic is sufficiently concerning, it only represents disabilities for which individuals actually sought treatment and disability compensation (Amster et al., 2012). Experts also point to the FAA Civil Aerospace Medical Institute's (CAMI) review of the postmortem toxicology results of pilots involved in fatal aviation accidents between 1993 and 2003 (Amster et al., 2012). The FAA CAMI study found that nearly 10% of the pilots examined used psychotropic, cardiovascular, or neurological medications, while only 8% had accurately disclosed the detected medications that they were taking (Canfield et al., 2006). The study also fails to address the magnitude of nondisclosure since it did not consider pilots who might have been taking medication that could affect their performance but was not revealed in the toxicology tests (Amster et al., 2012).

While it is clear that there are safety issues with medical disclosure of physical health concerns, there are also risks related to the nondisclosure of mental health issues. For example, nondisclosure of depression was the root cause of the 2015 Germanwings crash (Clark, 2016). The Germanwings Airbus A320 crashed in the Swiss Alps in 2015, with investigators determining that First Officer Andreas Lubitz intentionally crashed the aircraft in a culminating mental health episode. Lubitz had a history of mental health issues and a diagnosis of depression that had not been disclosed to Germanwings and thus maintained an active flying status (Clark, 2016). The FAA initially denied Lubitz's application for a first-class medical certificate and then issued one at a later date (The Bureau d'Enquêtes et d'Analyses, 2015, as cited in Clark, 2016). After this incident, the FAA policies regarding pilot mental health issues have come under scrutiny. The European Union Aviation Safety Agency's (EASA) regulations governing aeromedical certification are more subjective than the FAA's and rely more heavily on an individual's willingness to self-disclose disqualifying conditions (Clark, 2016). This accident revealed how the threat of losing medical certification could negatively impact a pilot.

While the research on mental health disclosure and healthcare-seeking behavior is extremely limited, there is some data to suggest that, as with physical health concerns, mental health issues may not be adequately disclosed or treated among pilots to protect their flight privileges. Over 12% of pilots surveyed (n = 1,848) met the threshold for diagnosis with clinical depression (Wu et al., 2016). Surprisingly, 4% of respondents that reported working as an airline pilot within the previous seven days (n = 1,430) also reported suicidal thoughts within the last two weeks (Wu et al., 2016). The respondents were commercial airline pilots from multiple countries recruited from unions, airline companies, and airports (Wu et al., 2016). From the study, it can be assumed that a significant number of commercial airline pilots are flying with depressive symptoms, and a percentage of those have active suicidal thoughts. Disclosure and treatment for these issues may jeopardize their careers.

A challenge for researchers has been the lack of available data; research concerning healthcare aversion, the relationship between disclosure and confidentiality, and reports analyzing the implications of the Special Issuances processes and FAA policies are plentiful. However, minimal research data exists on the explicit relationship between suicidality and nondisclosure among pilots. The most recent articles from Hoffman et al. (2019), Hoffman et al. (2021), and Hoffman et al. (2022a) are the three main studies of nondisclosure and its relationship with medical certification, while Wu et al. (2016) established clear concerns for certain mental health issues. Presently, no studies exist that explore the link between suicidality and nondisclosure among collegiate pilots in the United States.

Purpose of the Research

Safety culture in aviation begins with a pilot’s first flight lesson and remains paramount throughout their training and professional career. Flight training should not only produce a certificated pilot but also instill safety habits that are foundational for career development and contribute to aviation safety on a larger, professional scale. (Federal Aviation Administration, 2020). The current study aims to investigate the nondisclosure and healthcare-seeking behaviors of flight training students at a large, accredited, private institution that offers flight training in accordance with Pilot Schools (2022) regarding mental health issues such as the symptoms of suicidality.

Research Questions

The current study seeks to answer the questions: What is the current likelihood that collegiate pilots will seek care for mental health issues? What is the role that fear of loss of medical certification plays in a collegiate pilot’s decision to seek care?

Hypothesis

We hypothesize that collegiate pilots will demonstrate aeromedical nondisclosure behaviors as well as an aversion to seeking healthcare for mental health.

Methodology

Research Site & Participants

The research site was a U.S.-based, large-sized, accredited, private university (not for profit). The university includes physical campuses in the U.S. Southeast and U.S. Southwest, offering collegiate flight training programs in accordance with Pilot Schools (2022). A single case study approach was used due to time and accessibility constraints and as a preliminary exploration into the previously unreported nondisclosure and healthcare-seeking behaviors of this population.

From the total population of students enrolled in the flight training program at the institution studied during the study time frame, the sample for survey data was determined through non-probability self-selection. Survey participants were recruited through emailed recruitment messages and bulletin board posters. Participation in the survey was not incentivized. The survey response rate was 10.4% (N = 2,452). Survey responses were collected over a period of 30 consecutive days, from September 1, 2022, to September 30, 2022.

All survey data were collected anonymously, with no individually identifying information. The study was reviewed by the Institutional Review Board and deemed “exempt” (#23-013). Informed consent was presented during recruitment, and the survey required acknowledgment of informed consent prior to starting the research questionnaire. Criteria for participation included a minimum age of 18, the possession of a valid FAA medical certificate, and an active flight training status at the institution being surveyed.

Instrumentation

Surveys were administered through Qualtrics; data collection was ongoing for a period of 30 days, and responses were gathered from September 1, 2022, to September 30, 2022. The survey contained a section for demographic questions and primary survey questions (Appendix A). Demographic questions included age, gender, flight training tenure, and any history of diagnosed depression. The primary survey section included three questions about nondisclosure, ten questions from the Patient-Health Questionnaire Depression Module (PHQ-9), and a final question that asked about participants’ intention to seek care for any symptoms reported on the PHQ-9; the three questions regarding nondisclosure and final question regarding intent compose the four “primary survey” questions. Well-validated in Kroenke et al. (2001) and Gilbody et al. (2007), the PHQ-9 evaluated participants’ depressive symptoms and suicidality. In a clinical setting, the PHQ-9 is often used as a diagnostic tool; in the current study, the PHQ-9 was utilized to measure the prevalence of symptoms in the collegiate pilot population.

Survey questions were closed-ended, with both multiple-choice and Likert scale questions. The primary survey questions were adapted from the Hoffman (2022a) study to focus on behavior specific to mental health and gauge participants’ nondisclosure habits; these questions featured binary responses and one Likert response to evaluate the degree to which pilots correlate their fear of loss of medical certification with their decision to seek medical care.

Data Analysis

The data collected from the survey was both binary and ordinal in nature. For certain survey questions, such as whether a respondent has ever worried about seeking care for mental health due to fear of loss of medical certification, the responses were either “yes” or “no,” with an additional option not to provide an answer. For other questions, such as those from the PHQ-9, the answers followed a scale that assessed the prevalence of mental health symptoms. The responses corresponded to categories that allowed the participant to choose the severity of their symptoms. Each participant’s PHQ-9 responses were scored according to the questionnaire’s instruction manual (Spitzer et al., n.d.). These scores cannot be considered an official clinical diagnosis of depression in any individual.

The data were analyzed with Spearman’s rank-order correlation, which is used for ordinal and binary data and measures the strength and direction of the relationship between two variables; in the current study, the two variables correspond with the PHQ-9 score and participants’ responses to questions 5, 6, 7, 17, and 18. The purpose of Spearman’s correlation is to determine the relationship between the severity of mental health symptoms (as measured by the PHQ-9 score) and healthcare-seeking and nondisclosure behaviors. Separate correlations were determined using Microsoft Excel.

Surveys were excluded from analysis if the respondent abandoned the survey after answering demographic information, if the respondent left any primary survey question unanswered, or if the respondent left any PHQ-9 question unanswered. Surveys were pooled into two categories for analysis: respondents that answered all four primary survey questions and respondents that answered all four primary survey questions plus all nine PHQ-9 questions. It was necessary for respondents to answer all PHQ-9 questions in order to receive a depression severity score, as per the questionnaire manual. Categorical data were summarized using percentages and analyzed using the Spearman Rank Correlation test. Significance for results was established when p-values were less than 0.05, 0.025, and 0.001.

Limitations

Since the current study relies on survey participation, several limitations exist. Participation bias may affect the data since students may be more inclined to complete a voluntary survey about mental health if they have a particular interest in the topic or some other connection to the topic, such as personal mental health concerns. The bias could occur in either an upward or downward fashion: those with more severe mental health symptoms might be more likely to participate in a survey about mental health than those with less severe or no symptoms because they are more familiar with the study’s topic. On the other hand, those with more severe symptoms might be more suspicious of mental health questionnaires and be more reluctant to participate due to fear of repercussions on their medical certification; the current study’s efforts to ensure anonymity and confidentiality may have mitigated this bias. Most survey questions, aside from the PHQ-9 questions, included “choose not to answer” options, which may have lowered the positive answers to especially sensitive questions.

The use of the PHQ-9 to measure depressive symptoms is also subject to limitations. The current study was not designed to rule out “normal bereavement, a history of a Manic Episode (Bipolar Disorder), and a physical disorder, medication, or another drug as the biological cause of the depressive symptoms” (Spitzer et al., n.d.). Therefore, the PHQ-9 responses and categories cannot be considered a formal diagnosis of Major Depressive Disorder or Other Depressive Disorder. There may be other factors not measured by the PHQ-9 that might have influenced the prevalence of depressive symptoms in respondents.

Results

Demographics of Collegiate Pilots

A total of 256 collegiate pilots answered all four primary survey questions but did not answer all nine PHQ-9 questions; these respondents are our total valid sample, N = 256. The demographics for the total valid sample are presented in **Table 1**. The majority of collegiate pilots were between the ages of 19 and 21 (148 respondents or 57.8%). Most respondents identified as male (183 respondents or 71.5%), while 69 (27%) respondents identified as female, and two (0.8%) respondents identified as non-binary or other gender identities. Most collegiate pilots (199 respondents or 77.7%) have been active in flight training for less than four years; 73 (28.5%) reported a flight training tenure of 1-2 years, 66 (25.8%) reported training of fewer than six months, and 60 (23.4%) reported tenure of 3-4 years.

Prevalence of Depression in Collegiate Pilots

Of the collegiate pilots recruited to participate in the current study, 232 completed the entire survey, including all four primary survey questions and nine PHQ-9 questions. The results show that 132 (56.6%) collegiate pilots met the PHQ-9 threshold for some degree of depression, ranging from mild to severe, within the past two weeks (**Figure 1**). Of the 132 respondents that met the threshold for depression, 23 (17.4%) expressed intent to seek, or have already sought, treatment for mental health symptoms. The results also show that 32 (13.8%) respondents reported some degree of self-injurious or suicidal ideation within the past two weeks (**Figure 2**). Of the 32 respondents that reported self-injurious or suicidal ideation, 8 (25%) expressed intent to seek, or have already sought, treatment for mental health symptoms.

Table 1
Demographics (N = 256)

Factor	Total
Age	
< 18	70 (27.3%)
19-21	148 (57.8%)
22-24	23 (9.0%)
25-27	8 (3.1%)
28-30	0 (0%)
31-33	1 (0.4%)
Prefer not to answer	4 (1.6%)
Unanswered	2 (0.8%)
Gender	
Male	183 (71.5%)
Female	69 (27.0%)
Non-binary/other	2 (0.8%)
Prefer not to answer	1 (0.4%)
Unanswered	1 (0.4%)
Flight training tenure	
< 6 months	66 (25.8%)
6 months- 1 year	38 (14.8%)
1-2 years	73 (28.5%)
3-4 years	60 (23.4%)
> 5 years	14 (5.5%)
Prefer not to answer	5 (2.0%)

Note. Percentages may not total to 100 due to rounding.

Figure 1
Depression Severity (according to PHQ-9 score) (n = 232)

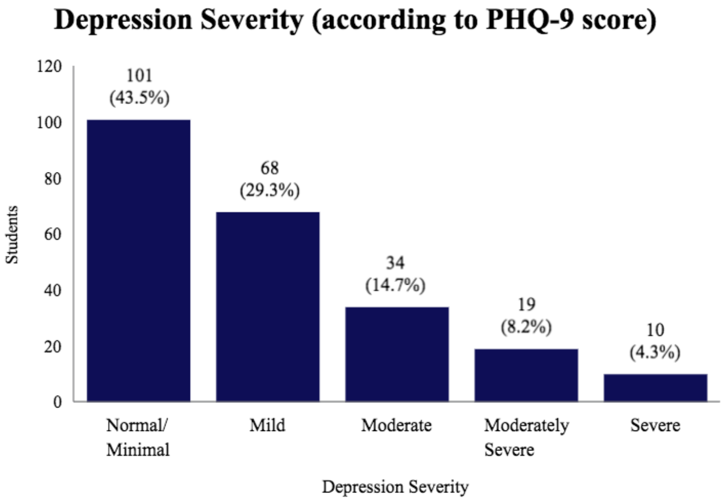
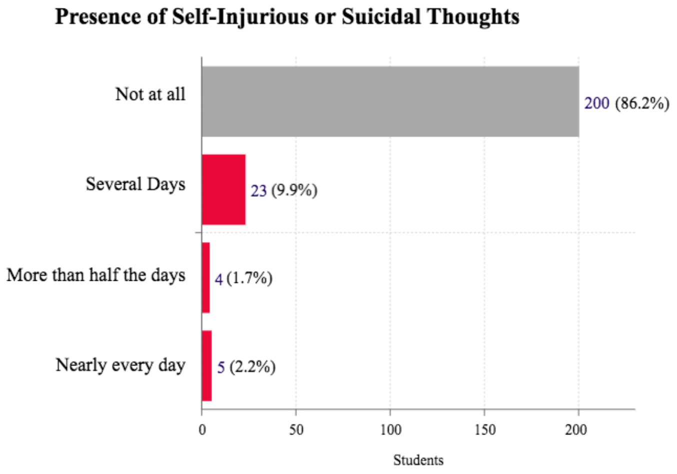


Figure 2

Presence of Self-Injurious or Suicidal Thoughts (n = 232)



Mental Healthcare-Seeking Behaviors of Collegiate Pilots

Of the 256 respondents that answered all four primary survey questions, 16 (6.3%) reported a prior depression diagnosis, 173 (67.6%) reported that they worry about seeking care for mental health concerns because of potential effects on their medical certification, and 75 (29.3%) reported withholding information about mental health from aeromedical examiners and screenings out of concern for their medical certification. The results show that 222 (86.7%) respondents agreed to some degree in the final primary study Likert question that they would choose not to seek medical treatment if their decision to do so might threaten their medical certification. The responses to the three binary primary survey questions are summarized in **Table 2**.

Table 2

Responses to Primary Survey Questions 4-6 (n=256)

Question	No	Yes	Prefer Not to Answer
History of diagnosed depression	231 (90.2%)	16 (6.3%)	9 (3.5%)
Worry about seeking care for mental health concerns	80 (31.3%)	173 (67.6%)	3 (1.2%)
Withheld information about mental health from AME or purposefully omitted mental health information on aeromedical screening	152 (59.4%)	75 (29.3%)	29 (11.3%)

Note. Percentages may not total to 100 due to rounding.

A total of 232 collegiate pilots answered all four primary survey questions and all nine PHQ-9 questions, allowing for a look at the correlation between self-reported depression and healthcare-seeking behaviors. Spearman's rank-order correlation was computed to assess the relationship between depression severity (PHQ-9) and intensity of worry surrounding healthcare-seeking decisions; there was a weak linear correlation between the two variables, r (227) = 0.38, *p* = 0.000. This means that as the severity of depression increases, the intensity of worry also increases, but in a weak manner. Spearman's rank-order correlation was also computed to assess the relationship between depression severity (PHQ-9) and nondisclosure behaviors; there was a weak linear correlation between the two variables, r (206) = 0.45, *p* = 0.000. Therefore, as the severity of depression increases, the likelihood of respondents omitting mental health information from aeromedical screenings also increases, but in a weak manner. This model did not yield any other statistically significant values in the remaining correlations, summarized in **Table 3**.

Discussion

The current study seeks to explore the prevalence of mental health nondisclosure among collegiate pilots, specifically exploring how the fear of the loss of medical certification might influence this nondisclosure. At this time, the authors are unaware of any other studies exploring this issue in a collegiate pilot population. However, it is essential that we should explore the prevalence of self-reported depression and the self-disclosure of medically diagnosed depression in the collegiate pilot population.

Before we can fully understand the implications of depressive symptoms in collegiate pilots, it is necessary to establish a context in terms of national averages and comparable populations. Of the sample, 56.6% of collegiate pilots (n = 232) met the PHQ-9 threshold for some degree of depression (mild or greater) within the past two weeks. While the PHQ-9 cannot be used as the sole basis for a clinical depression diagnosis, participants' responses to the nine questions provide insight into the specific issues that the collegiate pilot population faces. Recent data is scarcely available on the depression and suicide rates of college students specifically. However, the 18-24 age range accounts for 94% (n = 241) of the current study's 256 respondents; data from the Centers for Disease Control and Prevention show that 52.3% of persons aged 18-24 were symptomatic of depressive disorder (Czeisler et al., 2020). The results indicate that the prevalence of depressive symptoms among collegiate pilots is consistent with national data for individuals of the same age. Digging deeper into this, we can consider published data for other high-stress college programs. Medical students and residents have reported depression symptoms in just 17.2% of participants (Goebert et al., 2009). More recently, Mirza et al. (2021) estimated that the mean prevalence of depressive disorders in university medical students in North America was 30.3%. Therefore, more collegiate pilots report depressive symptoms than students in other competitive, high-stress college programs.

Table 3
Spearman Rank Correlations

Variables	N	Correlation Coefficient (rs)	Correlation Interpretation	P value
Depression severity and worry about seeking care	229	0.38	Weak linear	1.98E-09**
Depression severity and "Yes/No" responses to history of nondisclosure	208	0.45	Weak linear	1.02E-11***
Depression severity and "Prefer not to answer" responses to history of nondisclosure	232	0.09	No linear correlation	1.70E-1*
Depression severity and intent to seek treatment	214	0.21	No linear correlation	1.99E-3**
History of diagnosed depression and history of nondisclosure	221	0.16	No linear correlation	1.88E-2**
Self-injurious or suicidal ideation and intent to seek treatment	214	0.15	No linear correlation	2.49E-2**
Intent to seek treatment and impact of symptoms on everyday life	213	0.17	No linear correlation	1.52E-2**

*Significance at the 0.05 level, **Significance at the 0.025 level, ***Significance at the 0.001 level

Self-harm and suicide are associated with, and symptoms of, depressive disorders. In the current study, 13.8% (n = 232) of collegiate pilots reported some degree of self-injurious or suicidal ideation within the past two weeks. The PHQ-9 instrument used in the current study was also used by Wu et al. (2016) to explore suicidal thoughts among airline pilots but reported a much lower prevalence, with just 4.1% of airline pilots reporting suicidal thoughts. Therefore, more collegiate pilots report suicidal ideation than airline pilots. Looking at national data for individuals ages 18-25 in the United States, 11.3% reported suicidal thoughts; therefore, the prevalence of suicidal thoughts in collegiate pilots is consistent with the national average (Centers for Disease Control and Prevention, 2022). The rate of suicidal ideation in collegiate pilots is comparable to students in other high-stress programs. In 2009, only approximately 6% of medical students and residents reported suicidal ideation (Goebert et al., 2009). More recently, a 2016 study found that the overall prevalence of suicidal ideation in medical students was 11.1% (n = 21,002) (Rotenstein et al., 2016). Therefore, compared to other competitive, high-stress college programs such as medicine, collegiate pilots reported similar rates of suicidal ideation.

The discrepancy between airline pilots and collegiate pilots may be attributed to the additional stressors that college students face and environmental factors that have driven increasing rates of depression and suicide in young adults in recent years, such as the Coronavirus pandemic (Czeisler et al., 2020). Age may also be a factor in this discrepancy. According to the 2021 FAA Active Airmen Statistics, the average age of airline transport pilots is 51 (U.S. Department of Transportation, 2022). The data from the Centers for Disease Control and Prevention show that 14.4% of respondents aged 45-54 were symptomatic of depressive disorders (Cziesler et al., 2020). The CDC data for the older and younger age groups affirm the discrepancy in depressive symptoms also reflected in the Wu et al. (2016) study and the current study.

While understanding the prevalence of depressive symptoms in collegiate pilots is important, it is even more essential to understand how this may influence student healthcare-seeking behaviors and medical nondisclosure. In the current study, 29.3% (N = 256) reported withholding mental health information from their aeromedical examiners or choosing not to disclose mental health struggles on aeromedical screenings. This statistic is in line with a prior study in which 27% of pilots of various certification levels admitted to withholding such information (Hoffman et al., 2022a). Therefore, the fear of loss of medical certification as a result of disclosing the information is also present in and affects the healthcare-seeking decisions of collegiate pilots. Additionally, 67.6% of collegiate pilots (N = 256) reported that they worry about seeking care for mental health concerns because of the effects on medical certification, while 86.7% agreed to some degree that they would choose not to seek treatment if it might threaten their medical certification. This data reaffirms the presence of a barrier to healthcare that collegiate pilots face as a result of their chosen career path. The consequences of such a barrier could include increased morbidity and mortality as mental health conditions are left untreated (McLaughlin, 2004). On the professional level, a more severe or progressed condition may render a pilot ineligible to hold medical certification altogether, resulting in permanent certificate denial or subsequent unemployment (Hoffman et al., 2022a).

The findings of the current study highlight the need for additional mental health resources for collegiate pilots. Our findings show that collegiate pilots are reluctant to seek healthcare for mental health concerns; perhaps an informal, peer-led support program tailored to the needs of collegiate pilots would be a valuable resource for those in need. In the fall of 2022, the John D. Odegard School of Aerospace Sciences at the University of North Dakota introduced UpLift, the first collegiate aerospace peer support program (Miller & Dulski, 2022). The program's peer supporters are not mental health experts. Instead, the program recruits aerospace students and trains them to offer support and identify useful resources for fellow aerospace students that reach out with "questions about their personal struggles, uncertainties about their aviation medical, and other mental health concerns" (Miller & Dulski, 2022). The program and its peer supporters are overseen by an aerospace psychologist who ensures that the supporters receive appropriate training (Miller & Dulski, 2022). Collegiate aviation programs should consider adopting similar peer support programs where students are able to receive support for mental health concerns and access resources without the fear of compromising their medical certification.

Conclusion

To the authors' knowledge, the current project is the only study to exist on the nondisclosure and mental healthcare-seeking behaviors of collegiate pilots, thus filling an important knowledge gap in the research of pilot mental health and healthcare-seeking behaviors. The current study found that 56.6% of respondents (n = 232) met the PHQ-9 criteria for some degree of depression. Additionally, 13.8% of respondents (n = 232) reported the prevalence of self-injurious or suicidal ideation. The data shows that 67.7% of collegiate pilots (N = 256) worry about seeking care for mental health concerns because of the effects on medical certification, while 29.3% of collegiate pilots (N = 256) have withheld information about mental health issues from their AME or purposefully omitted mental health information from aeromedical screenings out of concern for preserving their medical certification. The current study also found that 86.7% of collegiate pilots agree to some degree that they choose not to seek medical treatment if their decision to do so might threaten their medical certification. Weak linear correlations were established between depression severity and intensity of worry surrounding healthcare-seeking decisions ($r(227) = 0.38$, $p = 0.000$), as well as between depression severity and nondisclosure behaviors ($r(206) = 0.45$, $p = 0.000$).

The findings of the current study support the conclusion that healthcare-seeking anxiety and nondisclosure issues established in previous studies are not limited to airline and military pilots and are indeed present in the collegiate pilot population as well, with substantial effects. Future studies should investigate the increased level of suicidal ideation among collegiate pilots in comparison to the airline pilot population, which reports a lower rate of suicidal ideation (Wu et al., 2016). Additionally, future research should further examine the barrier to pilot healthcare and explore other possible factors contributing to aeromedical nondisclosure across all levels of pilot certification. Further research is needed to understand how demographic factors (age, gender, flight training tenure) affect a pilot's decision to seek care or disclose medical conditions.

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Appendix A Survey Questions

1. What is your age?
   a. <18
   b. 19-21
   c. 22-24
   d. 25-27
   e. 28-30
   f. 31-33
   g. Prefer not to answer
2. What is your gender?
   a. Male
   b. Female
   c. Non-binary/ other
   d. Prefer not to say
3. How long have you been active in flight training?
   a. <6 months
   b. 6 months- 1 year
   c. 1-2 years
   d. 3-4 years
   e. >5 years
   f. Prefer not to answer
4. Have you ever been diagnosed with depression by a medical professional?
   a. Yes
   b. No
   c. Prefer not to say
5. Have you ever worried about seeking care for mental health concerns because it may affect your medical certification?
   a. Yes
   b. No
   c. Prefer not to say
6. Have you ever withheld information about mental health concerns from an aeromedical examiner or purposefully omitted information about mental health concerns from an aeromedical screening out of concern for your medical certification?
   a. Yes
   b. No
   c. Prefer not to say
7. Rate the degree to which you agree with the following statement: Before I seek medical care, I think about how my decision would affect my medical certificate and if my medical certificate might be threatened by my decision, I do not seek care.
   a. Strongly agree
   b. Somewhat agree
   c. Somewhat disagree
   d. Strongly disagree
8. Over the last 2 weeks, how often have you been bothered by the following problem: little interest or pleasure in doing things?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
9. Over the last 2 weeks, how often have you been bothered by the following problem: Feeling down, depressed, or hopeless?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
10. Over the last 2 weeks, how often have you been bothered by the following problem: Trouble falling or staying asleep or sleeping too much?
    a. Not at all
    b. Several days
    c. More than half the days
    d. Nearly every day
11. Over the last 2 weeks, how often have you been bothered by the following problem: Feeling tired or having little energy?
    a. Not at all
    b. Several days
    c. More than half the days
    d. Nearly every day
12. Over the last 2 weeks, how often have you been bothered by the following problem: Poor appetite or over-eating?

   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
13. Over the last 2 weeks, how often have you been bothered by the following problem: Feeling bad about yourself, or that you are a failure, or have let yourself or your family down?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
14. Over the last 2 weeks, how often have you been bothered by the following problem: Trouble concentrating on things, such as reading the newspaper or watching TV?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
15. Over the last 2 weeks, how often have you been bothered by the following problem: Moving or speaking so slowly that other people could have noticed? Or the opposite- being so fidgety or restless that you have been moving around a lot more than usual?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
16. Over the last 2 weeks, how often have you been bothered by the following problem: Thoughts that you would be better off dead or of hurting yourself in some way?
   a. Not at all
   b. Several days
   c. More than half the days
   d. Nearly every day
17. Have you sought care, or do you have the intention of seeking care for any mental health symptoms in the previous questions?
   a. Yes
   b. No
   c. Prefer not to answer
18. How difficult have these problems made it for you to do your work, take care of things at home, or get along with people?
   a. Not at all
   b. Somewhat
   c. Very
   d. Extremely

UNIVERSITY AVIATION ASSOCIATION

Collegiate Aviation Review International

Volume 41 | Issue 1

Peer Reviewed Article #7

6-14-2023

Evaluating the Impact of Nonconcurrent Flight Laboratory and Ground Course Progress on the Academic Outcomes of Collegiate Aviation Students

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Flight training is often conducted as a two-part model, where a student completes an academic ground course to learn the knowledge and also enrolls in a flight laboratory course to apply the knowledge and skills required to earn a new certificate or rating. Often, these two parts are offered as separate courses to provide flexibility to students in the training environment. The intent is that the ground course and flight laboratory are conducted concurrently so the students apply knowledge from the ground course during their flight training. However, external factors may delay the flight training progress in the laboratory environment, causing the student to disconnect their flight training and ground course into a nonconcurrent status. This study aims to assess the impact of concurrent versus nonconcurrent flight lab enrollment on the academic outcomes of collegiate aviation students in the classroom. The study will determine whether a student conducting flight training in their current course of study (concurrent training) performs significantly better academically than a student conducting training in a previous flight lab in their current course of study (nonconcurrent training). Quantitative data was collected in the form of academic scores on classroom block exams to evaluate the impact of students in concurrent versus nonconcurrent training environments. A series of independent sample t-tests were used to find consistent evidence that students in a concurrent flight laboratory perform better on block exams in their academic ground course than students enrolled in a nonconcurrent flight laboratory. The results of this research will be used to inform educational practices within flight training departments and will assist in providing clarity to external parties interested in evaluating the impact of students completing a lab course that is nonconcurrent to their current ground course of study.

Recommended Citation:
Guthridge, R. (2023). Evaluating the impact of nonconcurrent flight laboratory and ground course progress on the academic outcomes of collegiate aviation students. *Collegiate Aviation Review International*, 41(1), 134-147. Retrieved from http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9479/8475

Decades of research have been published concerning improving student performance, learning, and attitudes toward college-level introductory science courses (Matz et al., 2012). However, little study has been done on the impact of nonconcurrent flight lab training in the aviation industry. Aviation, much like any academic discipline, benefits from the use of technology to assist an instructor in delivering content. Similar to a class in the laboratory sciences, Aviation provides a two-part model of instruction. Students must commonly attend a ground school class to learn the knowledge-based topics while also conducting a laboratory course that teaches them the skill-based maneuvers that are required to earn their certificate or rating. Additionally, after a student completes their initial training, many professional pilots must continuously attend training to maintain their proficiency, which is often referred to as "recurrent training." These training modes employ a variety of training methodologies, including in-person instruction (both in the classroom and in the airplane), video-based instruction, and simulator-based instruction.

This two-part model has been recognized industry-wide as a method to help improve the knowledge and skills of pilots while reducing the risk of accidents and incidents in an increasingly complex airspace system. In an attempt to lead efforts in training quality, the International Air Transport Association (IATA) "led the development of a new training methodology based on evidence collected in operations and training: Evidence-Based Training (EBT)" (IATA, 2013). As defined by IATA, an EBT program focuses on the development and assessment of key pilot competencies to better prepare pilots to manage potentially dangerous situations in flight operations. This program focuses on developing a competency framework to provide a minimum standard of knowledge for pilots, along with the standardization of instructors in the effective training and assessment of pilots. Ultimately, the EBT program methodology was endorsed by the International Civil Aviation Organization (ICAO) in 2013, along with the publication of an "Evidence-Based Training Implementation Guide" to assist operators with the implementation of EBT in their organizations.

The role of the academic ground course as part of an EBT program is to provide the required knowledge for a given course of study. Through FAA and ICAO guidance, collegiate flight schools have prescriptive knowledge requirements for each level of training, as well as a minimum standard of exam performance within the ground courses. For example, Part 61 of the Code of Federal Regulations (14 CFR 61.105) describes the aeronautical knowledge requirements to obtain a Private Pilot Certificate. A ground course curriculum that complies with FAA regulations would include each of these subject areas, and students must pass each block of learning with at least 76% proficiency. These subject areas include:

(1) Applicable Federal Aviation Regulations of this chapter that relate to private pilot privileges, limitations, and flight operations;
(2) Accident reporting requirements of the National Transportation Safety Board;

(3) Use of the applicable portions of the "Aeronautical Information Manual" and FAA advisory circulars;
(4) Use of aeronautical charts for VFR navigation using pilotage, dead reckoning, and navigation systems;
(5) Radio communication procedures;
(6) Recognition of critical weather situations from the ground and in flight, windshear avoidance, and the procurement and use of aeronautical weather reports and forecasts;
(7) Safe and efficient operation of aircraft, including collision avoidance and recognition and avoidance of wake turbulence;
(8) Effects of density altitude on takeoff and climb performance;
(9) Weight and balance computations;
(10) Principles of aerodynamics, powerplants, and aircraft systems;
(11) Stall awareness, spin entry, spins, and spin recovery techniques for the airplane and glider category ratings;
(12) Aeronautical decision-making and judgment; and
(13) Preflight action that includes -
    (i) How to obtain information on runway lengths at airports of intended use, data on takeoff and landing distances, weather reports and forecasts, and fuel requirements; and
    (ii) How to plan for alternatives if the planned flight cannot be completed or delays are encountered. (14 CFR 61.105)

At the collegiate level, flight laboratories and the corresponding classroom ground courses are offered as separate components to provide flexibility in the training environment. In some schools, students are required to enroll concurrently in the flight lab and the corresponding classroom course. However, in other schools, students are allowed to progress more rapidly through the classroom courses and may lag behind in the flight labs. This is due to multiple external factors that can delay the flight training progress in the laboratory environment. These factors can include adverse weather, flight instructor availability, or aircraft availability, to name a few.

There are a number of ways to improve student success in the flight training environment. The Airline Owners and Pilots Association (AOPA) published an article in 2015 that highlights nine habits of successful students. Many of the habits are controlled completely by the student, such as coming ready to fly, setting goals, and communication. However, there are uncontrollable factors that the AOPA study highlights, such as the ability to fly often (Deener, 2015). At the time of this publication, flight instructors are being hired for airline jobs at record rates. This leaves a shortage of qualified instructors at flight schools available to teach an increasing number of student pilots. Because of this dynamic, student progress is often dictated by their flight instructor's availability. If their availability decreases, students must find a way to become more efficient during their lessons just to remain on a reasonable timeline. Otherwise, their flight progress slows down, their flight laboratory becomes delayed, and they find themselves finishing the academic ground course without being finished with the flight laboratory course.

In 2017, advancing research in the field attempted to predict factors that attributed to student pilot success in Part 141 collegiate flight training environment (McFarland, 2017). This research assessed the academic, cognitive, and performance attributes of 242 student pilots in a collegiate flight training program to determine which factors predicted training success. A logistic regression method was employed, which found that it was possible to predict student completion of the multi-engine flight course 73.2% of the time. The study also found a number of significant correlations among performance variables, which indicated that academic performance is a driver of flight training success. One aspect this research assumes is that flight training and academic performance are linked in the same general timeframe. A challenge with this assumption is that many flight training schools will disconnect flight training from the academic ground course in order to continue the student's academic progress. While the organization tracks academic progress as a key indicator of success, the student's flight training progress suffers, as they can only progress at the rate by which the flight instructor and external environment can support.

Research that expands upon existing studies in the field of concurrent enrollment in lectures and laboratories comes at an optimum time with unique dynamics in the aviation industry. Current practices encourage the disconnect between laboratory and classroom instruction, such as the increased hiring of flight instructors, causing a reduced ability of student pilots to maintain consistent flight training progression. In a 2016 study conducted by Lutte and Lovelace on the Regional Airline pilot shortage, the authors note that one prominent airline had a hiring target of 50 pilots for the first quarter of the year, but they only hired 28 pilots due to an acute shortage of qualified, appropriate pilots on the market. Additionally, earlier that year, this same airline was forced to cancel a scheduled training class due to a lack of qualified candidates (Lutte and Lovelace, 2016). This highlights the trend in the aviation industry, where the airlines are hiring qualified flight instructors faster than the civilian and military sectors can produce newly-qualified pilots to take their place. These dynamics influence the rate at which students complete their training. Student pilots must work one-on-one with their flight instructor to complete the flight lab lessons, whereas classroom ground courses can train upwards of 30-50 students at a time. Pressure is placed on students to accelerate the rate of their training progress, which results in students electing to continue to the next classroom ground course while they are still completing a previous flight lab course. As student enrollment increases and flight instructor availability decreases, the chasm between flight lab progress and classroom progress increases.

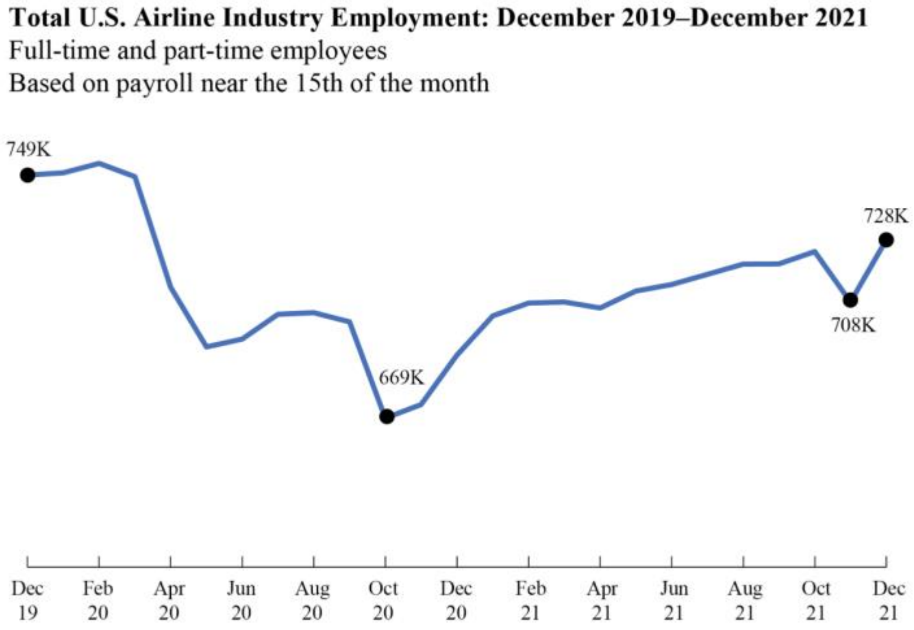
Purpose of Study

The purpose of this study is to assess the impact of flight lab progress on the academic outcomes of collegiate aviation students in the classroom. It provides insight into an integral piece in assessing the impact of students not concurrently enrolled in a flight laboratory and classroom ground course. This research is a valuable addition to current research in the field that evaluates how concurrent enrollment in lectures and laboratory enhances student performance and retention. Additionally, this research helps inform the current educational methodology and training structure to help improve student academic performance in the flight training environment.

When the study was designed in 2019, airline hiring had been at an all-time high (Bureau of Transportation Statistics; BTS, 2022). Due to the COVID-19 pandemic, airline hiring was halted, which resulted in a lack of pilot jobs in the industry. In turn, this resulted in a temporary surplus of flight instructors at flight schools worldwide. While this dynamic helped student pilots progress in flight schools, it is expected that flight instructors will again be rehired at airlines at greater rates than before the COVID-19 pandemic. In fact, the Bureau of Transportation Statistics shows a 2.8% month-over-month increase in airline employee hiring as of June 2022, with total employment approaching pre-pandemic levels of December 2019 (Figure 1) (Bureau of Transportation Statistics, 2022). With this expected increase in airline hiring, student pilot progress will again slow to a point where completion rates suffer in the collegiate flight training environment. Flight schools must be prepared for this effect and rely on research in the field of student success to best prepare for the capacity impact within their organization.

Figure 1.

Total U.S. Airline Industry Employment: December 2019-December 2021 (Bureau of Transportation Statistics, 2022).



At the time of this publication, increased numbers of students enrolled in flight training to fill an industry-wide pilot shortage while facing reduced numbers of certified flight instructors available to perform their training. As student enrollment increases and flight instructor availability decreases, the chasm between flight lab progress and classroom progress is expected to widen. The results of this study will help inform existing research in the field of aviation education and include recommendations for flight training departments that are considering a nonconcurrent training model between flight lab courses and classroom ground courses.

Methods

The primary outcome of this research is to assess the academic impact of nonconcurrent flight lab courses on the academic outcomes of classroom training. A quantitative approach was used to assess the student’s academic outcomes in classroom ground courses based on their progress in the associated flight laboratory course. This scientific approach was chosen due to the standardization of the block exams and the consistency of academic outcome expectations in the ground courses. As described below, a series of t-tests were used to evaluate the mean difference in block exam scores between the concurrent and nonconcurrent groups.

Participants and Group Membership

The participants in this study were selected from students enrolled in an introductory instrument course and a flight instructor course at a midwestern university in the United States. Students were selected from these two courses to collect a dataset that was broadly representative of the total student population, as the courses are spaced at median points across the curriculum. To collect a sample from the population, data were collected from five total classes during the Fall 2020 academic semester. Within the introductory instrument course population, seven total classes were offered, which enrolled a total of 217 students. Three classes were selected from this offering, which equaled a sample size of 78 of the total 217 students enrolled during the semester. Within the flight instructor course population, four total classes were offered, which enrolled a total of 135 students. Two classes were selected from this offering, which equaled a sample size of 66 of the total 135 students enrolled during the semester.

All participants in this study successfully completed their classroom ground courses, with varying levels of progress in their flight laboratory course. Demographics of the participants can be found in Table 1, which represents the combined sample population, along with the sample populations for each of the concurrent and nonconcurrent groups at the beginning of the academic semester.

At the beginning of the semester, students were assigned to groups based on their flight laboratory course enrollment. Students who were in the same flight laboratory as their ground course of training were assigned to the concurrent group, whereas students who were competing in a previous flight laboratory course were assigned to the nonconcurrent group. During the semester, students were expected to continue their training in the flight laboratory course, regardless if they were completing the concurrent laboratory or the nonconcurrent laboratory. Because some students would finish the nonconcurrent laboratory between the academic block exams, their group membership would change from nonconcurrent to concurrent. Because of this factor, each block exam was analyzed independently due to the differences in group numbers at each exam. Additionally, the study accounted for block exams one through four due to the University’s established last day to drop, after which many of the students in nonconcurrent laboratories dropped the academic ground course due to their delayed progress.

Quantitative Study

The purpose of the quantitative study was to determine the degree to which nonconcurrent flight lab training impacts the academic outcomes of students in the classroom ground course. Academic performance data was collected in the form of block exam scores. The structure of the academic ground courses was to provide block exams that are comprehensive to a building block of learning in that course. The block exams were spaced at approximately one-month intervals during the Fall 2020 academic semester. Because of this, each of the two courses was evaluated separately during the data analysis phase due to the difference in evaluation content and criteria for each of the respective block exams. The block exam scores were aggregated into populations based on concurrent and nonconcurrent flight lab enrollment at the time the participant took the Block Exam.

Table 1
Demographic Characteristics

	Combined Dataset	Concurrent	Nonconcurrent
	n = 144	n = 69	n = 75
Gender			
Male, *n (%)*	125 (86.8)	62 (89.9)	63 (84.0)
Female, *n(%)*	19 (13.2)	7 (10.1)	12 (16.0)
Academic Year			
Senior, *n (%)*	51 (35.4)	21 (30.4)	30 (40.0)
Junior, *n (%)*	49 (34.0)	24 (34.8)	25 (33.3)
Sophomore, *n (%)*	41 (28.5)	22 (31.9)	19 (25.3)
Freshman, *n (%)*	3 (2.1)	2 (2.9)	1 (1.4)
Program of Study			
Commercial Aviation, *n (%)*	121 (84.0)	60 (87.0)	61 (81.3)
Commercial Aviation & UAS Operations, *n (%)*	11 (7.6)	4 (5.8)	7 (9.3)
UAS Operations, *n (%)*	9 (6.3)	4 (5.8)	5 (6.7)
Commercial Aviation & Management, *n (%)*	3 (2.1)	1 (1.4)	2 (2.7)

*Note. D*emographics were collected at the beginning of the academic semester.

A series of independent samples *t*-tests were conducted to evaluate the mean difference between students enrolled in a concurrent flight laboratory and a nonconcurrent flight laboratory. Eight *t*-tests were conducted in total, which compared each of the four block exams for two separate academic ground courses during the Fall 2020 semester.

Results

The Introductory Instrument Course

The introductory instrument course is offered immediately after the student finishes their Private Pilot training. In this course, a total of 217 students enrolled during the Fall 2020 semester. This study sampled three classes of the total population of the introductory instrument course, which equaled 78 students (35.9%) of the total population. In this sample, 41 students (52.6%) began the flight laboratory concurrently with the academic ground course. The remaining 37 students (47.4%) were still finishing the Private Pilot flight laboratory and were considered to be in a nonconcurrent laboratory.

Students in this academic course spend Block One reviewing content related to the Private Pilot course, which typically garners higher results during the Block One exam since the students have recently trained on this content to proficiency prior to enrolling in the introductory instrument course. Subsequently, the course proceeds to cover topics of flight instrument systems, methods of basic attitude instrument flying, and navigation systems. Blocks Two through Four offer a more in-depth study of topic areas and may be considered "new content" for the purposes of learning the material. Because of this, the results of Block Exams Two through Four could be related to a traditional academic course that offers new content for all blocks of learning.

In this study, there was no significant effect for Block One exam scores, $t(76) = 1.191$, $p = .237$, despite students in a concurrent lab ($M = 88.41$, $SD = 8.11$) scoring higher than students in a nonconcurrent lab ($M = 86.22$, $SD = 8.17$). For Block Two exam scores, students in a concurrent lab ($M = 88.94$, $SD = 9.15$) scored significantly better than students in a nonconcurrent lab ($M = 80.07$, $SD = 9.59$), $t(76) = 4.065$, $p = .001$. For Block Three, students in a concurrent lab ($M = 89.38$, $SD = 7.56$) scored significantly better than students in a nonconcurrent lab ($M = 78.44$, $SD = 20.01$), $t(76) = 3.517$, $p = .001$. Finally, for Block Four exam scores, students in a concurrent lab ($M = 80.76$, $SD = 10.11$) scored significantly better than students in a nonconcurrent lab ($M = 75.25$, $SD = 11.66$), $t(76) = 2.020$, $p = .047$.

In the results above, the Block One exam presumably did not show significance due to the nature of the content of the Block One exam. Content on this exam is a review of material that was recently completed by the students in the course immediately preceding this course. For the remainder of the Block Exams, significance was found between the concurrent and nonconcurrent groups. Figure 2 and Table 2 show the results of each block exam score for the introductory instrument course.

Figure 2.
Introductory Instrument Course Block Exam Scores

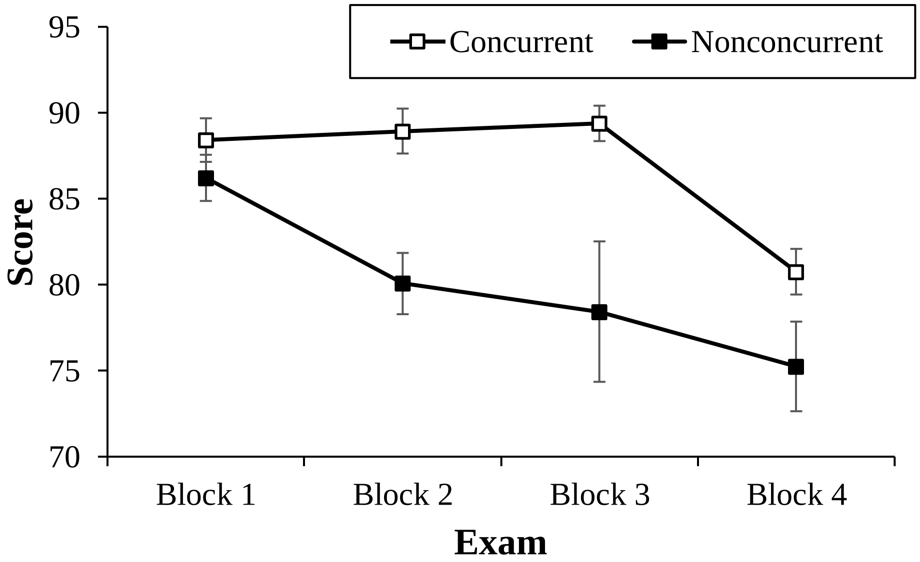


Table 2
Introductory Instrument Course Block Exam Scores

	Concurrent Lab *(n)*	Nonconcurrent Lab *(n)*	*p*
Block One, *score (n)*	88.41 (41)	86.22 (37)	.237
Block Two, *score (n)*	88.94 (49)	80.07 (29)	.001*
Block Three, *score (n)*	89.38 (54)	78.44 (24)	.001*
Block Four, *score (n)*	80.76 (58)	75.25 (20)	.047*

Note. * $p < .05$

The Flight Instructor Course

The flight instructor course is offered immediately after students finish a course in commercial multi-engine flying. Students that enroll in a concurrent flight laboratory learn how to teach fundamentals of aviation instruction in a single-engine aircraft, while students in a nonconcurrent laboratory course learn how to master the pilot-in-command responsibilities of a multi-engine aircraft. These courses are significantly different in structure and content, which likely explains the consistent difference in scores on each block exam.

The initial split of students in nonconcurrent and concurrent flight laboratories was wider in this course, largely due to the complex nature of the preceding multi-engine course. The multi-engine course requires uniquely qualified flight instructors, which slowed down the progress of the population of students planning to enroll in the flight instructor academic ground course. In this course, a total of 135 students enrolled during the Fall 2020 semester. This study sampled two classes of the total population of the flight instructor course, which equaled 66 students (48.9%) of the total population. In this sample, 28 students (42.4%) began the flight laboratory concurrently with the academic ground course. The remaining 38 students (57.6%) were still finishing the multi-engine flight laboratory and were considered to be in a nonconcurrent laboratory.

Students in the academic course will spend time learning the fundamentals of instruction, which includes topics related to lesson planning, content delivery, student evaluation, and assessment. These topics are combined with technical subject areas related to general flight, including aerodynamics, aircraft performance, systems, flight planning, and flight maneuvers. Generally, these topic areas have been previously learned by the students. However, they are now expected to learn and teach these topics at an instructor's level of knowledge. For the purposes of this course, all blocks of learning could be considered "new content" from the fundamentals of instruction perspective, even though there are a number of content areas that are familiar to students in the form of technical subject areas they have previously learned.

In this study, all Block Exam scores showed significance, with similar raw score differences between the concurrent and nonconcurrent groups on each Block Exam. For Block One exam scores, students in a concurrent lab (M = 89.46, SD = 5.75) scored significantly better than students in a nonconcurrent lab (*M* = 85.17, *SD* = 8.06), *t*(64) = 2.402, *p* = .019. For Block Two exam scores, students in a concurrent lab (*M* = 90.65, *SD* = 5.39) scored significantly better than students in a nonconcurrent lab (*M* = 86.86, *SD* = 7.90), *t*(64) = 2.244, *p* = .028. For Block Three exam scores, students in a concurrent lab (*M* = 89.87, *SD* = 4.53) scored significantly better than students in a nonconcurrent lab (*M* = 84.36, *SD* = 6.12), *t*(64) = 4.208, *p* = .001. Finally, for Block Four exam scores, students in a concurrent lab (*M* = 87.37, *SD* = 5.99) scored significantly better than students in a nonconcurrent lab (*M* = 84.36, *SD* = 5.61), *t*(64) = 2.023, *p* = .047. Figure 3 and Table 3 show the results of each block exam score for the flight instructor course.

Figure 3.
Flight Instructor Course Block Exam Scores

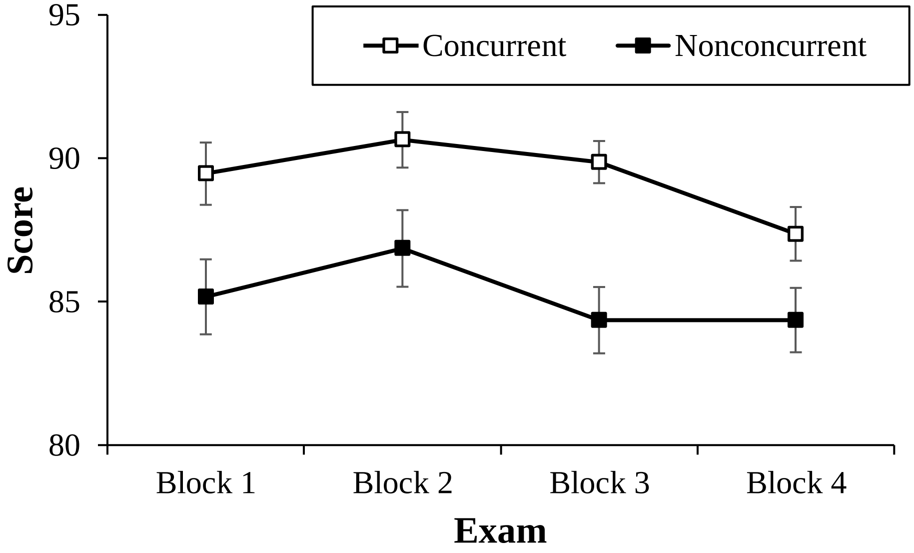


Table 3
Flight Instructor Course Block Exam Scores

	Concurrent Lab *(n)*	Nonconcurrent Lab *(n)*	*p*
Block One, *score (n)*	89.46 (28)	85.17 (38)	.019*
Block Two, *score (n)*	90.65 (31)	86.86 (35)	.028*
Block Three, *score (n)*	89.87 (38)	84.36 (28)	.001*
Block Four, *score (n)*	87.37 (41)	84.36 (25)	.047*

Note. * p < .05

Discussion

The key finding of this study is that concurrent enrollment in aviation ground courses and flight training laboratories positively impacts academic outcomes. As the Aviation industry climbs out of the COVID-19 pandemic and hires airline employees at pre-pandemic rates (Bureau of Transportation Statistics, 2022), these findings provide important guidance to flight training organizations on methods that hinder student pilot academic success. These findings are particularly important when considering methods to alleviate organizational capacity demands when faced with a flight instructor shortage. Additionally, as incoming student enrollments increase, these findings provide guidance to evaluate alternative methods to providing an appropriate training structure that ensures the academic success of students enrolled at the flight school.

One consideration this study addresses is the range of courses and experience offered by a flight training organization. When pursuing a career as a professional pilot, each flight training course provides a different level of intensity due to the wide range of knowledge and skills required across the curriculum. While looking at the programmatic requirements of the flight training curriculum, one might consider the initial private pilot course and the flight instructor course as the most intensive training courses offered. Alternatively, the introductory instrument course might be considered one of the courses with the least training intensity. In any case, the findings of this study highlight the importance of maintaining concurrent enrollment in a flight laboratory that matches the academic ground course.

Nearly all block exams showed statistical significance through the quantitative study, with the one exception being the Block One exam in the introductory instrument course. As stated previously, this exam is a review of material previously learned by students in the course immediately preceding the introductory instrument course. Because of this, it was expected that all students would perform similarly on the Block One exam, regardless of concurrent or nonconcurrent laboratory status.

When considering the raw score differences amongst all block exams in the data set, students in a concurrent flight laboratory consistently scored higher on block exams than students in a nonconcurrent flight laboratory (5.5% higher, on average). Functionally, this is equivalent to a full letter grade change in a student's exam score, which could be the difference between a student successfully passing the academic ground course and a student being required to retake the same course due to a failing grade.

The findings of this study show the importance of maintaining concurrency between a student pilot's flight laboratory and the associated academic ground course. Research has shown that students who engage in well-designed laboratory experiences develop problem-solving and critical-thinking skills, as well as gain exposure to reactions, materials, and equipment in a lab setting (ACS, 2022). However, it is important that students apply the knowledge in a timely manner, which is the primary reason why a student enrolled in a nonconcurrent laboratory suffers academically. These students are applying knowledge from a previous academic course in their laboratory while attempting to learn new content in their current academic ground course. This disconnect may be detrimental to a student's academic success, and therefore every effort should be made to avoid nonconcurrent laboratories during their flight training.

Limitations

Limitations of this study center around the dynamics related to group membership and the reasons for switching from a nonconcurrent to a concurrent laboratory status. There are many reasons that a student becomes delayed in their flight training. Natural causes may include weather, flight instructor availability, or aircraft availability, to name a few. Other variables may be more undetectable, including stress, fatigue, financial hardship, or relationship struggles. It is important to note that these potentially confounding variables were outside of the scope of this research and not accounted for in the dataset.

Finally, when a student finds themselves in a nonconcurrent laboratory status, they may take on an alternative approach to their academic success versus students in a concurrent laboratory. For instance, some students in a nonconcurrent laboratory may put more effort into remaining proficient in the knowledge and skills required by the previous academic course in order to ensure their success in the nonconcurrent laboratory lessons. These students may suffer academically in the concurrent course since they are choosing to focus on different content. Alternatively, students in a nonconcurrent laboratory may choose to focus more intensely on the new content of the concurrent course in order to not fall behind and suffer in the classroom. The academic motivation was not collected during this study and was not accounted for during the analysis.

Implication for Practice

The results of this study show that value should be placed on maintaining a concurrent flight laboratory and classroom ground course with all students in the curriculum. Additionally, this research shows that students may suffer academically if they accelerate their classroom ground courses without first completing any previous flight laboratory courses that are required by the curriculum. Risks to an educational model that provides nonconcurrent flight laboratory and classroom ground training are a significant decrease in classroom academic performance.

What an academic ground course is not able to provide is a way to develop a student pilot’s flying skills in the aircraft, which is a foundational requirement for both initial and recurrent pilot training. When considering the theories of learning that apply to this two-part model of instruction, it is critical to explore the foundations relating to how skills are learned by student pilots. In the process of conducting this exploration, one must consider the perception of the student pilot and what they will be most successful in transferring to learning. “Initially, all learning comes from perceptions, which are directed to the brain by one or more of the five senses: sight, hearing, touch, smell, and taste. Psychologists have also found that learning occurs most rapidly when information is received through more than one sense” (United States, 2008). Research has explored the use of flight simulators as a practical learning technology and has centered around four main themes, which include how the simulator replicates the specific aircraft configuration, how the simulator replicates the real-world environment, the simulator’s visual field of view, and how the simulator replicates the sensations of flight (including motion and tactile feedback). Research consideration should be explored in providing a structured, self-paced pre-training course for student pilots that may help accelerate and increase the proficiency of training in the flight lab courses, thus increasing the probability of maintaining concurrency between the flight lab and classroom ground courses within the flight training curriculum. Finally, future research should be conducted to evaluate the efficacy of low-cost flight simulation technologies that could be used to support a self-paced training curriculum by student pilots, which would not be reliant on flight instructor availability for a successful outcome. Study and research of this topic in the aviation industry are integral to maintaining and bolstering the pilot pipeline while maintaining the proficiency and knowledge standards employed by the industry. Beyond the research presented in this paper, it is suggested to employ these statistical methods on aviation training models outside of the primary flight training environment. These could include recurrent training and initial type rating training. Additionally, researchers may wish to include academic motivation as an additional variable when choosing to replicate this study. For instance, in a recent study by Wilson and Stupnisky (2022), the authors use the Academic Motivation Scale (AMS; Vallerand et al., 1992) to evaluate for differences in motivation between students who enrolled in either a blended course or an online, asynchronous section of a senior-level advanced aircraft systems course. A similar methodology could be employed to evaluate the differences in motivation for students in a nonconcurrent and a concurrent flight laboratory course.

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Collegiate Aviation Review International

Volume 41 | Issue 1 Peer Reviewed Article #8

6-15-2023

Do Different Learning Style Inventories Report Similar Findings Among Pilots?

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This study investigated the gender and generational learning preferences of pilots and non-pilots and the gender and generational differences among the pilots surveyed. The Felder and Soloman Index of Learning Styles questionnaire measured individual learning styles on four continuums: Active-Reflective, Sensing-Intuitive, Visual-Verbal, and Sequential-Global. Survey data indicate a statistically significant difference in learning styles of non-pilots and pilots, males and females, and different generations of pilots. Among all participants, pilots scored higher than non-pilots on the Sensing and Visual scales, and males scored higher on the Visual aspect of that scale. Generation variation occurred between Generation X and Y, where Generation Y favored the Sensing learning style more than Generation X. Among pilots, males scored higher than females on the Visual preference, and Generation Y and Z preferred the Sensing learning style. Generation Z favored the Sequential learning style more than Generation X. Curriculum design, instructional methodologies, and technologies selected to deliver course content should focus on active, sensing, visual, and sequential learning styles while balancing the other styles in the design to produce learners who can thrive in any educational setting.

Recommended Citation:
Reesman, K. & Birdsong, J. (2023). Do different learning style inventories report similar findings among pilots? *Collegiate Aviation Review International*, 41(1), 148-179. Retrieved from https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9494/8476

A publication of the University Aviation Association, © 2023, ISSN: 1523-5955

Introduction

Mandatory age-related pilot retirements and industry growth have resulted in air carriers recruiting younger, less experienced pilots when compared to past industry hiring cycles. Researchers have looked to understand the most effective approaches to educating student pilots. Efforts over the last 25 years have yielded some insight into the learning styles or preferences by using a variety of learning style inventories (Brady et al., 2001; Chui et al., 2020; Fanjoy & Gao, 2011; Fussell et al., 2018; Gao et al., 2013; Kanske & Brewster, 2001). Using existing measurement tools, aviation scholars have sought to determine if student pilots displayed learning preferences unique to the aviation industry. Measurement tools used have been the Visual, Auditory, Read/Write, and Kinesthetic (VARK) or VAK, which is a form of the VARK, the Kolb Learning Style Inventory (KLSI), the Five Factor Model (FFM), and the Myers-Briggs Type Indicator (MBTI). The FFM and MBTI are personality inventories but have been used to see if learning preferences could be associated with personality types. This study used a learning style inventory yet to be identified in the literature for pilots; the Felder and Soloman Index of Learning Styles (ILS). The findings from this research will be compared with previous research for consistency and to note any differences in the emerging pilot workforce, Generations Y (or Millennials) and Z, who have been labeled as digital natives (Prensky, 2001), as well as any gender variations.

Review of Learning Style Inventories in Aviation

VARK/VAK

Chui et al. (2020) used the VARK model, developed by Fleming, to understand how visual and auditory systems contribute to the learning process. A visual learner best acquires information via the visual system (i.e., images, graphs), while the auditory learner prefers a verbal engagement (i.e., lecture, group discussion) (Chui et al., 2020). Their study sampled 18 Generation Z college students (Mean age = 21.89 years).

Significant learning occurs after a flight when a thorough event debrief is conducted. This feedback can have a meaningful impact on the learning process but is often neglected. Chui et al. (2020) cite others who mention four attributes of feedback: 1. the nature of the feedback (i.e., content – “what”); 2. the temporal dimension of the feedback (i.e., frequency and timeliness – “when”); 3. the source of the feedback (i.e., person or apparatus delivering the feedback – “who”); and 4. cognitive engagement which entails coming up with a decision or decisions that are critical to the success of a task. Feedback is an important aspect of aviation training for debriefing a maneuver or flight.

Chui et al. (2020) focused on the relationship between feedback type, visual or auditory, and the pilot's preference for learning, visual or auditory, based on VARK results. The findings from the Chui et al. (2020) study show that:

> During the test flights, when feedback was matched to an individual's preferred learning style, differences in pilot performance were observed (i.e., crossover interaction), and these differences were most notable for auditory learners. Specifically, when auditory learners were presented with visual feedback, their performance was adversely affected. Conversely, when the same auditory learners received auditory feedback, their performance improved. For visual learners, when they were presented with visual feedback, their performance also improved. However, when visual learners received auditory feedback, there was no significant adverse effect. While these results do provide a clear cross-over effect, it is not perfect. For visual learners, auditory feedback did not adversely affect performance. (p. 12)

While visual learners are not significantly affected by the type of feedback they receive, the auditory learner is at a disadvantage if they only receive visual feedback. Chui et al. (2020) note that only focusing on two of the four VARK learning dimensions was a limitation of this study. It remains unknown if the read/write and kinesthetic styles would have been affected similarly.

Karp (2000) noted a difference in the learning style preferences of 117 pilots and the type of classroom instruction they received. He used visual, auditory, and hands-on (kinesthetic) (VAK) to determine the pilot's predominant learning style. His findings revealed that nearly one-half were hands-on learners, and almost two-thirds were either hands-on or hands-on/visual learners. He also noted that the classroom instruction technique for these students included auditory and visual methods with little to no hands-on learning styles suggesting that course designers were unaware of the student learning styles or that matching the teaching style to the learning style provided the best educational experience.

KLSI

Kanske (2001) used the Kolb Learning Style Inventory (KLSI) to identify the preferred learning style(s) of 233 U.S. Air Force pilots. Analysis of the completed KLSI revealed that the predominant learning style of these pilots was the *converger* or *convergent* learning style. Kanske explains that *convergent* learners prefer to know how something works, and they want to do it themselves instead of someone showing them how to do it. Kanske identified *assimilator* as a secondary learning preference in these pilots. The *assimilative* style is facts-driven and will look at the learning experience as a whole. These pilots like abstract ideas and do not focus as much on a practical application of the information. Both the *converger* and the *assimilator* prefer abstract conceptualization over concrete experience. Kanske (2001) concluded that the current demonstration/performance mode of teaching works well for both styles.

Kanske and Brewster (2001) researched the learning style preferences of college aviation students. They found that the predominant college aviation student learning style was *assimilator*, followed by *converger*, then *accommodator*, and lastly, *diverger*. The first two learning styles comprised nearly two-thirds of this study's college students. The first two styles are consistent with Kanske's research with Air Force pilots.

The data from the Fussell et al. (2018) study, which sampled 41 university flight students, revealed that the Concrete-Experiential (CE), where the learner encounters a new or reinterpreted experience, scores of 19 Generation Z aviation students were in the 80th percentile or higher when compared to population norms. Those who begin the learning cycle at the CE stage prefer to learn by being involved in an experience and working with feelings instead of theories. The scores of 16 aviation students were in the 80th percentile or higher of the Reflective-Observation (RO) stage, meaning these learners prefer to observe a situation, reflect on the meaning and implication, and consider the perspective of others as well as their judgment before moving forward (Fussell et al., 2018). The significantly high CE and RO orientation scores within the study align with the *diverging* learning style. These learners typically analyze situations from many perspectives, observe their environment, and assess possible outcomes rather than just merely reacting in any situation (Fussell et al., 2018). This suggests that they rely on a balance of intuition, experience, and rote knowledge (e.g., emergency procedures in a flight) and thrive when the curriculum is less focused on theory in lecture-based instruction and instead is more practical and hands-on with time for observation (Fussell et al., 2018).

FFM

The FFM inventory comprises *extraversion*, *agreeableness*, *conscientiousness*, *neuroticism*/*emotional stability*, and *openness* factors (Ibrahimoglu et al., 2013). A review of the literature related to commercial pilot personality traits indicated that this group scored higher in *extraversion* and *conscientiousness* and lower in *neuroticism* (Chaparro et al., 2020). The two higher traits indicate that these individuals focus on their external environment and thrive on the stimulation they receive. They are also purpose-driven to accomplish a goal. The low *neuroticism* score is a strength because it indicates that they are less affected by negative events that may occur in their environment (Chaparro et al., 2020). Gao and Kong (2016), using the Australian Personality Inventory, a five-factor-type model of personality, found that student pilot personality scales were highest for *agreeableness* and *conscientiousness*. *Openness to experience* and *extraversion* were next, and *neuroticism* was last. The *agreeable* trait generally means one has a more optimistic view of human nature and will get along with others. The *conscientiousness* trait exemplifies the desire to do well and usually indicates a high level of organization and efficiency. Low *neuroticism* shows that these student pilots were less anxious or worried and could cope with high levels of stress (Gao & Kong, 2016).

MBTI

The personality assessment tool appearing most in the literature is the Myers-Briggs Type Indicator (MBTI). The MBTI identifies eight different personality characteristics, which make up four pairings: *Extrovert* (E) - *Introvert* (I), *Sensing* (S) - *Intuition* (N), *Thinking* (T) - *Feeling* (F), and *Judging* (J) - *Perceiving* (P) (Kutz et al., 2004). An individual's test result will indicate the strongest characteristic of each pair. There are 16 different personality types, or combinations, possible. Brownfield (1993) identified learning styles or preferences that relate to each of the four different dimension pairs. *Extroverts* think and learn best when they are talking, prefer group work, and are more trial-and-error, while *introverts* prefer quiet learning environments and would instead work alone. *Introverts* also prefer lecture-based instruction and do not do as well in a discussion format because it limits their time to process information before speaking (Sakamoto & Woodruff, 1992). *Sensing* students are fact and detail-oriented, while *intuitive* students prefer the larger picture and the ability to examine the relationships between concepts (Brownfield, 1993). Lawrence (1993) suggests *thinking* students are often impersonal and use a logical decision-making process when problem-solving while *feeling* students consider the impact on others when arriving at a conclusion. *Thinking* students prefer a more structured classroom while *feeling* students like group work and want to understand how the material will benefit mankind and how they can use the information to improve their world (Brownfield, 1993). The learning environment is an integral part of the educational process, and the *judging-perceiving* scale addresses this aspect. *Judging* students prefer a more structured learning environment and concrete assignments while *perceiving* students prefer a more flexible and spontaneous learning environment with discussion and open-ended assignments (Brownfield, 1993).

Kutz et al. (2004) used the MBTI to determine the predominant personality type of aviation management and professional pilot students who fall into the Generation Y group. They found that most aviation management students were ESTJ, while the professional pilot students were ESTP. Both liked group work, talking, trial and error, as well as dealing with facts in a logical and structured manner. The only real difference between the two was that professional pilot students preferred a less structured, more flexible learning environment. Robertson and Putnam (2008) found that the most common personality types in the population of student pilots surveyed in their study were the ENFP, ISTP, ISTJ, ENTP, and INFP personality types which do not correspond to the Kutz et al. (2004) findings. Fussell et al. (2018) observed that the predominant student pilot MBTI personality type was ISJT. People with this personality type are characterized as practical and systematic; they use logic and trust the known processes and procedures they have used in training to accomplish tasks.

When Fussell et al. (2018) reviewed the characteristics of the prevailing personality type, learning styles, and general preferences associated with the types (i.e., ISTJ, *diverging*, CE, and RO orientation), many similarities emerged. From these findings, a profile of aviation students can be created; the results suggest these students are observant of their surroundings, can adapt as situations change, and trust known procedures they have learned, especially when they have successfully used them or seen them in use (Fussell et al., 2018). Aviation students prefer to use logical and objective methods to reach a solution as opposed to theories and to make decisions. They rely on their observations, experience, and objective analysis to create a whole picture (Fussell et al., 2018). There is a preference for hands-on learning and an appreciation of input from other people; these students are practical and analytical, preferring facts and the concrete over the theoretical (Fussell et al., 2018).

Instruction for aviation students should include the discussion of situations and alternative solutions and should ensure procedures become second nature so students can be reliable in a dynamic environment; scenario-based training is also vital for these learners to have an excess of experience to draw upon (Fussell et al., 2018). Understanding type theory and learning styles can aid educators in creating a better learning environment while giving students the tools to enrich their learning experience (Felder & Brent, 2005). Fussell et al. (2018) suggest that when designing a course or learning experience for aviation students, an instructor should incorporate information on systems and procedures, encourage discussion of past experiences so students may learn from their peers, and engage students in practical exercises to strengthen skills. However, it must be pointed out that in this study, Fussell et al. (2018) found no significant relationship to indicate that personality preference, obtained from the MBTI, predicted learning style, as indicated by the KLSI. In addition, Brownfield (1993) suggested that a perfect correlation between personality type and learning style is not possible because of the many variables involved; however, the MBTI can identify various factors that encourage or hinder learning. Other research with aviation students suggests no significant relationship indicating that personality preferences and learning style are related (Niemczyk, 2020).

Study Introduction

The research efforts previously discussed were either done nearly two decades ago or chose a different learning style inventory. One learning style tool that seems to be absent in the literature for pilots is the Felder and Solomon Index of Learning Styles© (ILS) (Felder & Soloman, n.d.-a). This research effort used the ILS to answer the following research questions (RQs):

1. What is the relationship of pilot status, gender, and generation on learning styles?
2. What is the relationship of gender on learning styles for pilots?
3. What is the relationship of generation on learning styles for pilots?

Assumptions

The following assumptions were made before conducting this study:

1. Pilots have different learning styles than non-pilots.
2. There are generational differences among pilot learning styles.
3. The learning styles between genders are the same.
4. Current curriculum development uses a pedagogical approach rather than an andragogical approach to curriculum development. (Either a switch of approaches or a blending of approaches may be better suited).
5. The use of current technology may not be effective with all pilot generations and may need to be selectively used among the generations.

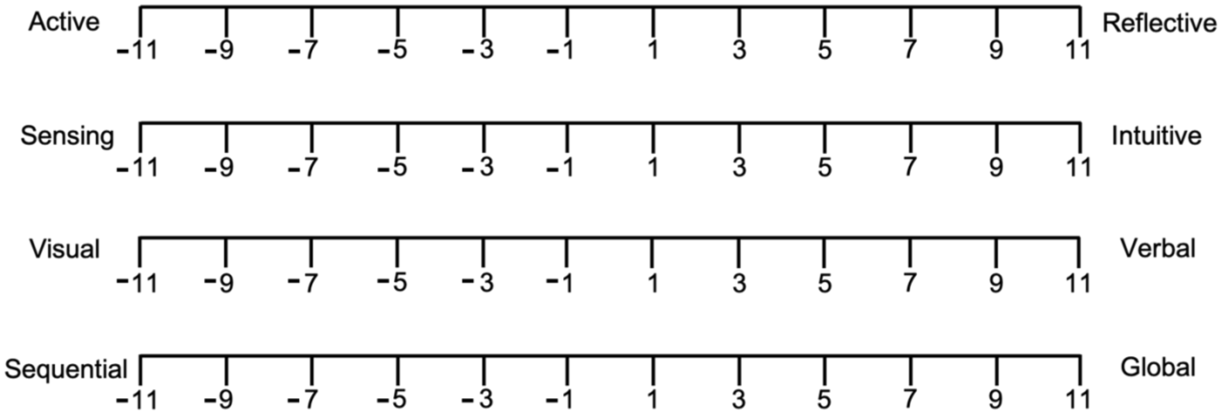
Research Method

The survey design was used for this study. It was administered to a population sample of non-pilots and pilots in various career fields and fields of study. The survey sought to obtain data that might identify unique learning preferences for a non-pilot and a pilot. In addition, in the pilot category, this survey would reveal learning styles or preferences that may vary by gender and generation.

This quantitative correlational research study used a Qualtrics online survey that included demographic questions and the Felder and Soloman Index of Learning Styles (ILS) questionnaire. The demographics collected included gender, ethnicity, race, birth year, educational level, student status, higher education institute attending, major or area of study, FAA certificated status, FAA certificates and ratings held, total flight hours, FAA instructor status, FAA instructor certificates held, total instructor hours, employment status, and place of employment. The birth year was used to determine which generational category the participants were placed in. The generations were categorized as Silent Generation (1928-1945), Baby Boomers (1946-1964), Generation X (1965-1980), Generation Y (1981-1996), and Generation Z (1997-2012) (Dimock, 2019)

The Index of Learning Styles® (ILS) (Felder & Soloman, n.d.-a), developed in 1991 by Richard Felder and Barbara Soloman, is a forty-four-item forced-choice questionnaire used to assess learning style preferences that are measured on the four scales of the Felder-Silverman model (Felder & Brent, 2005). Graf et al. (2007) indicated that each learner has a personal preference for each of the four dimensions. Each scale is expressed similarly, -11 to +11 in increments of $\underline{+}2$ (i.e., -11, -9, -7, -5, -3, -1, +1, +3, +5, +7, +9, +11) as demonstrated in Figure 1. This range configuration is the result of the 11 questions that are posed for each dimension. This range configuration is the result of the 11 questions that are posed for each dimension totaling 44 questions contained on the ILS. There are only two possible answers for each question, “a” or “b.” Each question is scored either with a value of -1 (answer *a*) or +1 (answer *b*). Answer *a* corresponds to the preference for the first pole (left side) of each dimension (active, sensing, visual, or sequential), and answer *b* to the second pole (right side) of each dimension (reflective, intuitive, verbal, or global) (Graf et al., 2007). As an example, reference the *active-reflective* scale in Figure 1. An individual who answered “a” for four of the 11 questions related to that scale would have a minus four on the *active* side of the scale. By default, that person would have answered “b” for the other seven of the 11 questions related to that scale giving a score of positive seven on the *reflective* side of the scale. When you add the two scores together, the resulting score would be a positive seven on the *reflective* side of the scale. The larger number indicates which of the two options for that scale is the learner’s preference. When the two values are added together (-4 plus 7), the strength of preference that would be displayed for that person would be a three on the *reflective* scale and indicate a moderate preference for *reflective* learning. An aggregate score of 1-3 indicates a mild preference for that learning style and can be interpreted as a balanced preference for both styles on that scale. If the score is a 5-7, then an individual would favor that style and learn better in an environment with this teaching style. A person with a 9-11 score shows evidence of a strong preference for that particular learning style, and a classroom environment that does not utilize this style will present real difficulty in learning for that individual.

Figure 1
Felder and Soloman's Index of Learning Styles



Note. Adapted from "Index of Learning Styles – Report of Results," R.M. Felder and B.A. Soloman, 1991 & 1994, (n.p.). Copyright 1991, 1994 by Educational Designs, Inc., Chapel Hill, NC. This document is provided by the authors, along with permission to use the ILS, to those wishing to use this instrument in research. It is not published for individual access.

Felder and Brent (2005) note that the answers to four basic questions may define a student's learning style:

1. What type of information does the student preferentially perceive: sensory or intuitive?
2. What type of sensory information is most effectively perceived: visual or verbal?
3. How does the student prefer to process information: actively or reflectively?
4. How does the student characteristically progress toward understanding: sequentially or globally?

How the student responds to ILS questions related to the first basic question will determine to what degree they are *sensing* or *intuitive*. *Sensing* learners tend to be concrete, practical, methodical, and oriented toward facts and hands-on procedures. In contrast, *intuitive* learners are more comfortable with abstractions and are more likely to be rapid and innovative problem solvers (Felder & Brent, 2005). The answers to the ILS questions, which align with the second basic question, will show if a person is *visual* or *verbal* by nature. *Visual* learners remember best what they see, and *verbal* learners get more out of words (Felder & Brent, 2005). Those ILS questions that are geared to measure a person's standing on the third basic question reveal if the individual is *active* or *reflective*. *Active* learners are more likely to understand and remember information best by doing something active with it – discussing, applying, or explaining it to others. By contrast, *reflective* learners prefer to think about it quietly first (Felder & Brent, 2005). Lastly, responses to specific ILS questions focusing on the final scale will determine whether they are *sequential* or *global*. Sequential learners tend to think in a linear manner and can function with only a partial understanding of the material they have been taught. *Global* learners, on the other hand, learn in large jumps. They may not be able to apply new material until they fully understand it and see how it melds with what they already know. *Global* learners will learn large amounts of information without understanding and then suddenly get it (Felder & Brent, 2005).

This study used the ILS to assess the learning styles of non-pilots and pilots to note any differences. Additionally, it examined generation and gender differences among pilots.

Sampling

The three variables of interest for this study included individuals represented in the FAA pilot status (i.e., yes or no), gender (i.e., male or female), and generations (Silent Generation, Baby Boomer, Generation X, Generation Y or Millennial, and Generation Z) categories. They were all found in the research sample group.

Among those sampled were students from three different Aviation Accreditation Board International (AABI) universities with FAA Part 141 flight programs and participants from aviation-related LinkedIn and Facebook pages.

ILS Internal Consistency and Reliability

Shannon and Davenport (2001) stated that "the more consistent the results from a measurement instrument are, the more reliable they are" (p. 119). Therefore, it was important to establish the Felder and Soloman Index of Learning Styles as reliable. Several studies have used various techniques that measure *reliability* and concluded that if the ILS was used as intended to measure learning styles or preferences, then it is a reliable measurement instrument. There are a few methods to test for an instrument's reliability, but this paper will only focus on two: test-retest and internal consistency. *Test-Retest* examines the consistency of a measure over time, and *Internal Consistency* analyzes the consistency of a measure across items.

Test-Retest looks for an instrument's ability to provide similar results for individuals who are given the instrument at different times. Zywno (2003) warned that the timing of retesting is critical for this approach. If the time between tests is too short, the subjects can remember their responses from one test to the next and invalidate the results (Felder & Spurlin, 2005); however, the longer the time between test and retest, the lower the correlation. Felder and Spurlin (2005) agreed that the 4-week interval used by Seery et al. (2003) is ideal for test-retest. The timing between test and retest for Zywno was eight months which was dictated by classroom realities. Livesay et al. (2002) elected to retest four times, the first at four months, the next at seven months, the third at twelve months, and the final test at sixteen months (Zywno, 2003). The data in Table 1 indicated that both Zywno (at eight months) and Livesay et al. (at seven months) found higher *Active* and *Sensing* scores than they did for the *Visual* and *Sequential* scores. In addition, like Van Zwanenberg et al. (2000), some evidence of overlap was found between the *Sensing-Intuitive* and *Sequential-Global* domains. Zywno (2003) concluded that the strong to moderate reliability of all scales in the test-retest validated the internal reliability of the scales. When Felder and Spurlin (2005) examined the intervals between test and retest for Seery et al. (four weeks) and Zywno (eight months), as well as the findings, they concluded that the test-retest reliability is satisfactory.

Table 1
Test-Retest Correlation Coefficients

Δ*t*	Active-Reflective	Sensing-Intuitive	Visual-Verbal	Sequential-Global	N	Source
No Test-Retest Done						Van Zwanenberg *et al.*
4 wk.	0.804**	0.787**	0.870**	0.725**	46	Seery et al.
7 mo.	0.73*	0.78*	0.68*	0.60*	24	Livesay *et al.*
8 mo.	0.683**	0.678**	0.511**	0.505**	124	Zywno
No Test-Retest Done						Spurlin

*Note. *p < .05, **p < .01.* Adapted from "Applications, Reliability, and Validity of the Index of Learning Styles," by R.M. Felder and J. Spurlin, 2005, *International Journal of Engineering Education*, *21*(1), p. 107. Copyright 2005 by TEMPUS Publications.

For *Internal Consistency* (reference Table 2), the expectation that all items measure a certain variable is necessary. If each part is consistent and points to what is to be measured, then it will be reliable. Cronbach's *alpha* is a test used to estimate a set of test items' reliability, or internal consistency, of a set of test items. Higher *alpha* scores indicate a more reliable measure or one that produces consistent results. Van Zwanenberg et al. (2000) noted that Cronbach's *alpha* (+0.80 or more) is normally the preferred measure of internal consistency for psychometric instruments. It is because their research yielded *alpha* values of less than 0.80. They suggest that because of the low internal reliability of the ILS scales, this assessment tool be used only for informative purposes and nothing beyond that. Litzinger et al. (2007) agreed that Cronbach's *alpha* is a good test for internal consistency reliability. However, they hold +0.50 should be used as the minimum standard for attitude and preference assessments as recommended by Tuckman (Zywno, 2003). Zywno (2003) stated that the minimum acceptable *alpha* for social science is +0.70 because, at this level, the standard error of measurement will be more than half of the standard deviation. However, Zywno mentioned that their *alphas*, which are higher than Van Zwanenberg, exceed Tuckman's acceptable standards and ultimately agrees that the ILS is a suitable psychometric tool to assess learning styles. Zywno (2003) pointed out that Livesay et al., in a study of 255 engineering students at Tulane University, found acceptable *alphas* and high test-retest reliability to conclude that the ILS was an appropriate and statistically acceptable tool for characterizing learning preferences. While the Livesay et al. study was only referred to from Zywno's (2003) study, it is worth noting that they also concluded that the ILS is an appropriate assessment for identifying learning preferences.

Table 2

Cronbach's Alpha Coefficients for the ILS

Active-Reflective	**Sensing-Intuitive**	**Visual-Verbal**	**Sequential-Global**	**N**	**Source**
0.51	0.65	0.56	0.41	284	Van Zwanenberg *et al.*
0.56	0.72	0.60	0.54	242	Livesay *et al.*
0.60	0.70	0.63	0.53	557	Zywno
0.61	0.77	0.76	0.55	448	Litzinger *et al.*
0.62	0.76	0.69	0.55	584	Spurlin

Note. Adapted from "Applications, Reliability, and Validity of the Index of Learning Styles," by R.M. Felder and J. Spurlin, 2005, *International Journal of Engineering Education*, *21*(1), p. 108. Copyright 2005 by TEMPUS Publications and "A Psychometric Study of the Index of Learning Styles©," by T.A. Litzinger, S.H. Lee, J.C. Wise, and R.M. Felder, 2007, *Journal of Engineering Education*, *96*(4), p. 314.

In this study, using IBM SPSS V27, a Reliability Analysis procedure was used to measure the scale reliability of the Felder and Soloman Index of Learning Styles questionnaire. Table 3 indicates that all alpha values fell within the range reported from previous studies and were above the suggested 0.5 cutoff specified by Tuckman, who noted that while an alpha of 0.75 or greater was acceptable for instruments that measured achievement, an alpha of 0.50 or greater is permissible for attitude assessments (Felder & Spurlin, 2005). The highest value was SENINT, and the lowest value was SEQGLO, with ACTREF and VISVER falling in the middle.

Table 3

Cronbach Alpha Coefficients

N	Active-Reflective	Sensing-Intuitive	Visual-Verbal	Sequential-Global
706	0.640	0.754	0.682	0.557

Validity can be described as the extent to which the measurement scale, or variable, represents what it is supposed to and yields the type of information you need (Shannon & Davenport, 2001). Litzinger et al. (2007) found that the factor structure of the ILS provides evidence of construct validity, and the data provided strong evidence of construct validity. Felder and Spurlin (2005) examined the learning style preferences of engineering students at ten academic institutions. They found convergent construct validity on all ILS scales except the sequential-global scale, which had lesser results.

Felder and Spurlin (2005) conclude that as long as teachers use the ILS to arrive at balanced course instruction and to help students understand their learning strengths and weaknesses, and based on the analysis of other studies, the ILS may be considered reliable, valid, and suitable.

Demographics of Participants

Survey invitations were extended to three higher education institutions and published on three LinkedIn pages, one widely circulated aviation newsletter, one well-known aviation blog, and four Facebook pages. The total number of possible participants was unknown, but each outreach option consisted of non-aviation and aviation individuals, male and female participants, and five generations of followers.

Nine hundred forty-seven individuals began the survey; however, only 706 completed the survey, for a total survey completion rate of 74.6%. Almost three-quarters of the sample were males (*N* = 519, 73.5%). Two percent (*N* = 14) of the sample were classified as belonging to the Silent Generation, while the rest of the sample was fairly evenly split across the other four generations: Baby Boomers – 24.4%, Generation X – 21.5%, Generation Y – 26.3%, and Generation Z – 25.8%. Three-quarters of the sample were pilots (*N* = 534, 75.6%). Most participants were not Hispanic (*N* = 660, 93.5%) and described their race as White (*N* = 624, 88.4%). A little over three-quarters of the sample had a bachelor's degree or higher (*N* = 537, 76.1%). Most of the participants were not university students at the time of the survey (*N* = 503, 71.2%).

Males comprised 79.25% of pilots, while only 20.8% of pilots were females. 81.5% of all male participants were pilots, while only 59.4% of all female participants were pilots. Over half of the sample comprised male pilots (59.9%). The mean age for the entire sample was 42 years (*SD* = 17.75). Means, standard deviations, skewness, and kurtosis of the continuous study variables for all participants are presented in Table 4. Descriptives for the study population learning styles broken down by pilot status are presented in Table 5, gender in Table 6, and by generation in Table 7. Tables 8 and 9 present Descriptives of Pilot Certificate and Pilot Generation by Gender, respectively.

Table 4

Descriptives for Continuous Study Variables for Entire Sample

Variable	*N*	Min	Max	*M*	*SD*	Skew		Kurtosis	
						Stat	SE	Stat	SE
Total									
Age	706	18	86	41.996	17.748	0.332	0.092	-1.149	0.184
ACTREF	706	-11	11	0.555	4.791	-0.091	0.092	-0.525	0.184
SENINT	706	-11	11	4.023	5.371	-0.746	0.092	-0.103	0.184
VISVER	706	-9	11	5.734	4.379	-0.866	0.092	0.188	0.184
SEQGLO	706	-11	11	0.544	4.416	-0.189	0.092	-0.406	0.184

Note. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, and SEQGLO = ILS questionnaire Sequential-Global scale.

Table 5

Descriptives of Learning Styles by Pilot Status

Scales	Gender	*N*	Min	Max	*M*	*SD*	Skew		Kurtosis	
							Stat	SE	Stat	SE
ACTREF	P	534	-11	11	0.745	4.813	-0.133	0.106	-0.482	0.211
	NP	172	-9	11	-0.035	4.687	0.031	0.185	-0.590	0.368
	Total	706	-11	11	0.555	4.791	-0.091	0.092	-0.525	0.184
SENINT	P	534	-11	11	4.450	5.273	-0.868	0.106	0.217	0.211
	NP	172	-11	11	2.698	5.472	-0.432	0.185	-0.645	0.368
	Total	706	-11	11	4.023	5.371	-0.746	0.092	-0.103	0.184
VISVER	P	534	-9	11	6.229	4.104	-0.998	0.106	0.606	0.211
	NP	172	-9	11	4.198	4.840	-0.460	0.185	-0.530	0.368
	Total	706	-9	11	5.734	4.379	-0.866	0.092	0.188	0.184
SEQGLO	P	534	-11	11	0.611	4.451	-0.204	0.106	-0.357	0.211
	NP	172	-11	9	0.337	4.310	-0.152	0.185	-0.554	0.368
	Total	706	-11	11	0.544	4.416	-0.189	0.092	-0.406	0.184

Note. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, SEQGLO = ILS questionnaire Sequential-Global scale. P = Pilot and NP = Non-pilot.

Table 6

Descriptives of Learning Styles by Gender

Scales	Gender	*N*	Min	Max	*M*	*SD*	Skew		Kurtosis	
							Stat	SE	Stat	SE
ACTREF	M	519	-11	11	0.680	4.829	-0.093	0.107	-0.487	0.214
	F	187	-9	11	0.209	4.681	-0.099	0.178	-0.640	0.354
	Total	706	-11	11	0.555	4.791	-0.091	0.092	-0.525	0.184
SENINT	M	519	-11	11	4.233	5.314	-0.819	0.107	0.061	0.214
	F	187	-11	11	3.439	5.499	-0.563	0.178	-0.416	0.354
	Total	706	-11	11	4.023	5.371	-0.746	0.092	-0.103	0.184
VISVER	M	519	-9	11	6.214	4.084	-0.917	0.107	0.310	0.214
	F	187	-9	11	4.401	4.880	-0.621	0.178	-0.303	0.354
	Total	706	-9	11	5.734	4.379	-0.866	0.092	0.188	0.184
SEQGLO	M	519	-11	11	0.561	4.442	-0.134	0.107	-0.452	0.214
	F	187	-11	11	0.497	4.353	-0.356	0.178	-0.253	0.354
	Total	706	-11	11	0.544	4.416	-0.189	0.092	-0.406	0.184

Note. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, and SEQGLO = ILS questionnaire Sequential-Global scale. M = Male and F = Female.

Table 7
Descriptives of Learning Styles by Generation

Scales	Gen	*N*	Min	Max	*M*	*SD*	Skew		Kurtosis	
							Stat	SE	Stat	SE
ACTREF	SG	14	-9	7	1.143	5.172	-1.213	0.597	0.382	1.154
	BB	172	-11	11	0.395	4.975	-0.120	0.185	-0.576	0.368
	GX	152	-11	11	0.671	4.923	-0.275	0.197	-0.282	0.391
	GY	186	-11	11	0.667	4.607	-0.049	0.178	-0.538	0.355
	GZ	182	-9	11	0.451	4.702	0.172	0.180	-0.640	0.358
	Total	706	-11	11	0.555	4.791	-0.091	0.092	-0.525	0.184
SENINT	SG	14	-11	9	1.429	6.186	-0.780	0.597	-0.119	1.154
	BB	172	-11	11	4.023	5.592	-0.780	0.185	-0.108	0.368
	GX	152	-11	11	3.158	5.641	-0.634	0.197	-0.423	0.391
	GY	186	-11	11	4.785	5.119	-0.792	0.178	-0.004	0.355
	GZ	182	-11	11	4.165	4.998	-0.725	0.180	0.055	0.358
	Total	706	-9	11	5.734	4.379	-0.866	0.092	0.188	0.184
VISVER	SG	14	-5	7	3.429	3.694	-1.220	0.597	1.059	1.154
	BB	172	-9	11	5.767	4.002	-0.966	0.185	0.618	0.368
	GX	152	-7	11	5.947	4.318	-0.938	0.197	0.322	0.391
	GY	186	-9	11	6.161	4.559	-1.038	0.178	0.691	0.355
	GZ	182	-7	11	5.264	4.574	-0.643	0.180	-0.460	0.358
	Total	706	-9	11	5.734	4.379	-0.866	0.092	0.188	0.184
SEQGLO	SG	14	-3	9	1.857	4.130	0.241	0.597	-1.149	1.154
	BB	172	-9	9	0.233	4.487	-0.334	0.185	-0.538	0.368
	GX	152	-11	11	-0.237	4.947	0.043	0.197	-0.831	0.391
	GY	186	-11	11	0.817	4.209	-0.128	0.178	-0.101	0.355
	GZ	182	-11	11	1.110	4.004	-0.189	0.180	-0.041	0.358
	Total	706	-11	11	0.544	4.416	-0.189	0.092	-0.406	0.184

Note: SG indicates Silent Generation, BB indicates Baby Boomer, GX indicates Generation X, GY indicates Generation Y, and GZ indicates Generation Z. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, and SEQGLO = ILS questionnaire Sequential-Global scale.

Table 8

Descriptives of Pilot Certificate by Gender

		Gender		
		Male	Female	Total
Student	Count	24	15	39
	% w/in Pilot	61.5%	38.5%	100.00%
Private	Count	143	47	190
	% w/in Pilot	75.3%	24.7%	100.00%
Instrument	Count	205	50	255
	% w/in Pilot	80.4%	19.6%	100.00%
Commercial	Count	204	48	252
	% w/in Pilot	81.0%	19.0%	100.00%
ATP	Count	211	43	254
	% w/in Pilot	83.1%	16.9%	100.00%
Other	Count	65	18	83
	% w/in Pilot	78.3%	21.7%	100.00%

Table 9
Descriptives of Pilot Generation by Gender

		Gender		
		Male	Female	Total
Silent Generation	Count	10	0	10
	% w/in Generation	100.00%	0.00%	100.00%
	% w/in Gender	2.40%	0.00%	1.90%
	% of Total	1.90%	0.00%	1.90%
Baby Boomers	Count	125	23	148
	% w/in Generation	84.50%	15.50%	100.00%
	% w/in Gender	29.60%	20.70%	27.70%
	% of Total	23.40%	4.30%	27.70%
Generation X	Count	90	29	119
	% w/in Generation	75.60%	24.40%	100.00%
	% w/in Gender	21.30%	26.10%	22.30%
	% of Total	16.90%	5.40%	22.30%
Generation Y	Count	113	32	145
	% w/in Generation	77.90%	22.10%	100.00%
	% w/in Gender	26.70%	28.80%	27.20%
	% of Total	21.20%	6.00%	27.20%
Generation Z	Count	85	27	112
	% w/in Generation	75.90%	24.10%	100.00%
	% w/in Gender	20.10%	24.30%	21.00%
	% of Total	15.90%	5.10%	21.00%
Total	Count	423	111	534
	% w/in Generation	79.20%	20.80%	100.00%
	% w/in Gender	100.00%	100.00%	100.00%
	% of Total	79.20%	20.80%	100.00%

Limitations

The population and sample selection consisted of participants who may have had more familiarity with the aviation industry, which could have influenced the non-pilot/pilot results. It is unknown if surveying a broader population (i.e., an entire university, non-aviation industry organizations, international populations) might produce different results.

Not enough time was allocated to gain airline and pilot union approval to distribute the invitation to participate in the research survey. Another aspect that should be included in the planning process is to allow enough time needed for any legal disclaimers to be crafted and signed, allowing for the distribution of the survey to the potential participant pool.

Pilot status refers to whether an individual is a FAA certificated pilot or not. The target populations for this study were FAA-certificated pilots and non-pilots. Within these two groups, both gender and generational classification were examined. The survey instrument did not allow military or internationally certificated pilots to be identified in the pilot group if they did not contain an FAA pilot certificate. If they answered the questions as written and intended, their data would have been captured in the non-pilot group. However, if they more broadly interpreted the FAA pilot certificate question and answered yes, then their data would have been captured in the pilot population. There is no way to identify either of these two scenarios because the survey did not allow for those options and was not intended to be in the participant population.

The non-pilot samples were gathered from populations with greater familiarity with the aviation industry, except for the non-aviation students enrolled at a Southeastern university. This assumption was solely based on the major selected and may not be entirely accurate. All social media sites used were connected to the aviation industry in some way. The LinkedIn and Facebook pages targeted for inviting participants were all pilot or pilot-group oriented. The newsletters, websites, and blogs were those of prominent influencers directing their content to the pilot population.

The Index of Learning Styles questionnaire identifies an individual's learning preferences but may not reflect the styles in which the individual best learns. Pilot education takes place in both an academic setting (i.e., classroom) and a non-academic setting (i.e., flight training device or airplane). Each of these learning environments utilizes an individual's senses in different manners. Some individuals may prefer a verbal method for an academic environment but use a visual style in the airplane or training device. One other unaccounted-for aspect of aviation training is the time factor. Many flight situations require timely decisions. Global learners may sometimes need an extended period of time to arrive at a preferred decision. In a time-restricted circumstance, an individual who prefers a global learning style may have to use a sequential style to adapt.

The non-participation of initially identified airlines may limit data collection in underrepresented demographic and generational category participation. The choice of social media platforms and pages was meant to offset this limitation. More than 70% of the participants were identified as non-university students, suggesting that social media solicitation was potentially successful.

The assumption of no multicollinearity is only partially met, which suggests that the MANOVA be abandoned in favor of multiple factorial ANOVAs while using a correction to protect against Type I errors. However, since the outcome variables are subscales from the same instrument, the MANOVA was utilized to learn which subscales matter for different groups recognizing a vulnerability for Type II errors.

Findings

RQ 1: What is the relationship of pilot status, gender, and generation on learning styles?

A MANOVA was conducted on the entire participant population with all four ILS subscales (ACTREF, SENINT, VISVER, and SEQGLO) as the dependent variables (DVs) and Pilot status, Gender, and Generation as the independent variables. All assumptions were met except for the homogeneity of variances. Levene's test of equality of error variances was used to test whether the variance structure was the same for each DV between each level of each independent variable. Although this assumption was met for ACTREF (p = .943) and SEQGLO (p = .189), Levene's test showed significant heterogeneity in the variances for SENINT (p = .033) and VISVER (p = .001). Historically, the ANOVA has demonstrated robustness to the heterogeneity of variance when sample sizes are equal and demonstrate smaller effects when sample sizes are larger (Boneau, 1960; Box, 1954; Glass & Hopkins, 1995; Lindquist, 1956).

There was a statistically significant difference between pilots and non-pilots on learning styles ($F_{4,\ 696}$ = 7.222, p < .001; Wilks' Λ = .960; partial η^2 = .040). There was also a significant difference between males and females ($F_{4,\ 696}$ = 4.582, p = .001; Wilks' Λ = .974; partial η^2 = .026) and between generations ($F_{16,\ 2126.953}$ = 2.029, p = .009; Wilks' Λ = .955; partial η^2 = .012). To decompose each main effect, a separate post hoc analysis was conducted. These post hoc analyses were guided by the results of the between-subjects effects to determine which dependent variables to test for effects (see Table 10).

Table 10

Between-Subjects Effects for RQ 1

Source	DV	Type III SS	*df*	*MS*	*F*	*p*	Partial η^2
Corrected Model	ACTREF	112.344	6	18.724	0.814	0.559	0.007
	SENINT	798.229	6	133.038	4.759	0.000	0.039
	VISVER	958.363	6	159.727	8.888	0.000	0.071
	SEQGLO	234.576	6	39.096	2.023	0.061	0.017
Intercept	ACTREF	30.860	1	30.860	1.342	0.247	0.002
	SENINT	1775.513	1	1775.513	63.517	0.000	0.083
	VISVER	4185.166	1	4185.166	232.887	0.000	0.250
	SEQGLO	79.455	1	79.455	4.111	0.043	0.006
Pilot Status	ACTREF	65.788	1	65.788	2.861	0.091	0.004
	SENINT	352.193	1	352.193	12.599	0.000	0.018
	VISVER	331.361	1	331.361	18.439	0.000	0.026
	SEQGLO	23.849	1	23.849	1.234	0.267	0.002
Gender	ACTREF	14.633	1	14.633	0.636	0.425	0.001
	SENINT	52.536	1	52.536	1.879	0.171	0.003
	VISVER	310.269	1	310.269	17.265	0.000	0.024
	SEQGLO	1.498	1	1.498	0.078	0.781	0
Generation	ACTREF	20.206	4	5.051	0.220	0.927	0.001
	SENINT	375.023	4	93.756	3.354	0.010	0.019
	VISVER	152.453	4	38.113	2.121	0.077	0.012
	SEQGLO	224.859	4	56.215	2.908	0.021	0.016
Error	ACTREF	16072.002	699	22.993			
	SENINT	19539.408	699	27.953			
	VISVER	12561.575	699	17.971			
	SEQGLO	13510.562	699	19.328			

Note. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, and SEQGLO = ILS questionnaire Sequential-Global scale.

Post-Hoc Analysis

The specific type of post hoc test used for each main effect was determined based on the number of levels of the specific independent variable (e.g., Mann-Whitney U tests for binary variables pilot status and gender; and a Games-Howell post hoc test for Generation). All post hoc analyses were selected for their ability to handle the heterogeneity of variances.

Pilot Status

Two Mann-Whitney U tests examined potential differences between pilots and non-pilots in SENINT and VISVER. In both cases, the distributions between pilots and non-pilots were not similar. SENINT scores for pilots were significantly higher for pilots (mean rank = 370.21) compared to non-pilots (mean rank = 301.61; U = 36999.500, z = -3.866, p < .001). Pilots also had significantly higher scores on VISVER (mean rank = 374.800) than non-pilots (mean rank = 287.37; U = 34550.000, z = -4.954, p < .001). In both cases (SENINT and VISVER), the higher scores for pilots over non-pilots indicate that pilots preferred a more sensing and visual learning style than non-pilots.

The primary focus of research question one was on the pilot status and learning style preference of the entire participant sample. Both gender and generation were also examined to determine if differences existed in either sub-group.

Gender

A Mann-Whitney U test examined potential differences between males and females in VISVER. The distributions between males and females were not similar. Males had significantly higher VISVER scores (mean rank = 373.75) compared to females (mean rank = 297.30; U = 38017.500, z = -4.453, p < .001), indicating that males preferred a more visual learning style than females.

Generation

When using a Games-Howell post hoc test, the only difference between generations for either learning type was between Generation X and Y on SENINT (p = .049), where Generation Y was more sensing.

RQ 2: What is the relationship of gender on learning styles for pilots?
RQ 3: What is the relationship of generation on learning styles for pilots?

Research questions two and three were answered using a single MANOVA only on the pilot participants. All four ILS subscales (ACTREF, SENINT, VISVER, and SEQGLO) were the dependent variables and Gender and Generation were the independent variables. All assumptions were met except homogeneity of the covariance-variance matrix and homogeneity of variances. The assumption of homogeneity of the covariance-variance matrix was tested using Box's Test of Equality of Covariance Matrices or Box's M. The test revealed heterogeneity of the variances between pairs of DV's for levels of the two independent variables

(p = .010). Levene's test of equality of variances was used to test whether the variance structure was the same for each DV between each level of each independent variable. Although this assumption was met for ACTREF (p = .695), Levene's test showed marginal heterogeneity in the variances for SENINT (p = .076) and SEQGLO (p = .093) and significant heterogeneity for VISVER (p = .022). The ANOVA has been shown to be robust against heterogeneity of variance when sample sizes are equal and demonstrate smaller effects when sample sizes are larger (Boneau, 1960; Box, 1954; Glass & Hopkins, 1995; Lindquist, 1956).

There was a significant difference between males and females ($F_{4, 525}$ = 4.239, p = .002; Wilks' Λ = .969; partial η^2 = .031), and between generations ($F_{16, 1604.539}$ = 1.911, p = .016; Wilks' Λ = .944; partial η^2 = .014). To decompose each main effect, a separate post hoc analysis was conducted. These post hoc analyses were guided by the results of the between-subjects effects to determine which dependent variables to test for effects (see Table 11).

Table 11

Between-Subjects Effects for RQ 2 & RQ 3

Source	DV	Type III SS	*df*	*MS*	*F*	*p*	Partial η^2
Corrected Model	ACTREF	29.433	5	5.887	0.252	0.939	0.002
	SENINT	412.901	5	82.58	3.027	0.011	0.028
	VISVER	366.588	5	73.318	4.495	0.001	0.041
	SEQGLO	190.189	5	38.038	1.937	0.087	0.018
Intercept	ACTREF	87.137	1	87.137	3.734	0.054	0.007
	SENINT	2232.575	1	2232.575	81.831	0.000	0.134
	VISVER	4049.099	1	4049.099	248.263	0.000	0.32
	SEQGLO	118.905	1	118.905	6.055	0.014	0.011
Gender	ACTREF	2.745	1	2.745	0.118	0.732	0
	SENINT	10.751	1	10.751	0.394	0.530	0.001
	VISVER	267.282	1	267.282	16.388	0.000	0.03
	SEQGLO	0.03	1	0.03	0.002	0.969	0
Generation	ACTREF	27.868	4	6.967	0.299	0.879	0.002
	SENINT	406.944	4	101.736	3.729	0.005	0.027
	VISVER	122.964	4	30.741	1.885	0.112	0.014
	SEQGLO	190.183	4	47.546	2.421	0.047	0.018
Error	ACTREF	12319.931	528	23.333			
	SENINT	14405.234	528	27.283			
	VISVER	8611.539	528	16.31			
	SEQGLO	10368.792	528	19.638			

Note. ACTREF = ILS questionnaire Active-Reflective scale, SENINT = ILS questionnaire Sensing-Intuitive scale, VISVER = ILS questionnaire Visual-Verbal scale, and SEQGLO = ILS questionnaire Sequential-Global scale.

Post-Hoc Analysis

The specific type of post hoc test used for each main effect was determined based on the number of levels of the specific independent variable (e.g., Mann-Whitney U tests for binary variables pilot status and gender; and a Games-Howell post hoc test for Generation). All post hoc analyses were selected for their ability to handle the heterogeneity of variances.

Gender

A Mann-Whitney U test examined potential differences between male and female pilots in VISVER. The distributions between males and females were not similar. Male pilots had significantly higher VISVER scores (mean rank = 279.01) compared to female pilots (mean rank = 223.64; U = 18607.500, z = -3.420, $p < .001$), indicating that males preferred a more visual learning style than females.

Generation

When using a Games-Howell post hoc test, Generation X had significantly lower SENINT scores (less sensing, more intuitive) compared to Generations Y (p = .046) and Z (p = .028). Generation X also had significantly lower SEQGLO scores (less sequential, more global) than Generation Z (p = .065).

Participant Population

Survey data indicated that within the total participant population, there was a statistically significant difference in learning styles between pilots and non-pilots, males and females, and generations. Further examination of the pilot status participants revealed that pilot scores were higher than non-pilots on the SENINT and VISVER scales. Both groups preferred sensing and visual; however, pilots scored significantly higher than non-pilots. When gender was analyzed more closely, the data indicated that males had higher scores than females on the VISVER scale. Again, both groups indicated a preference for visuals; however, males scored significantly higher than females. An inspection of the data for generation indicated a mild difference between Generations X and Y on the SENINT scale, with both generations favoring the sensing preference.

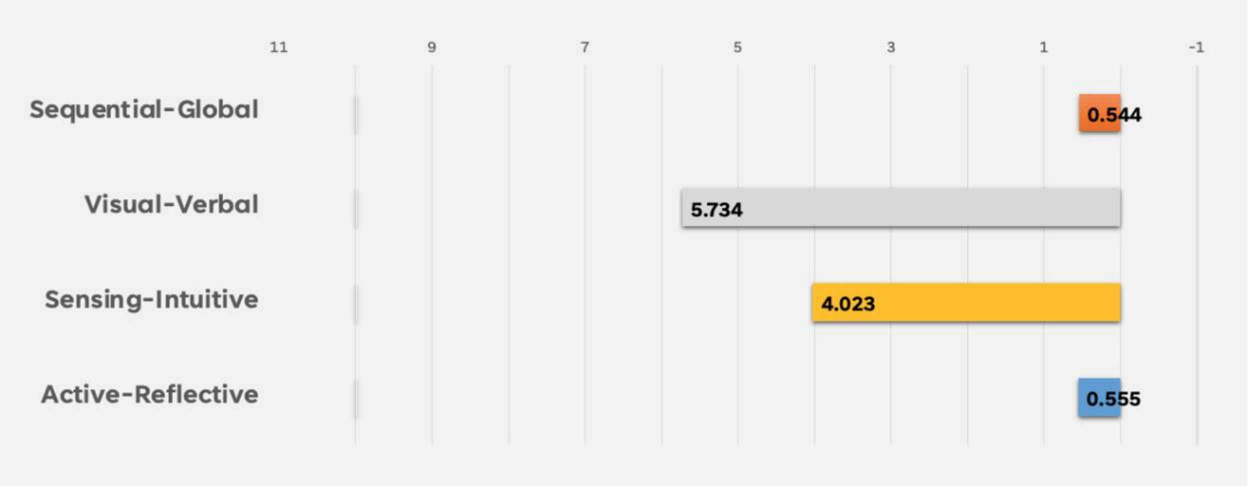
Pilot Population

Consistent with the entire population findings, data for the pilot population indicated that there was a difference between male pilots and female pilots, as well as pilot generations. Gender differences showed that male pilots had higher VISVER scores than female pilots. However, each still preferred the visual side of that scale, consistent with the total sample population. Results for generations were different from the total sample population. The data indicate that Generation X had lower SENINT scores than Generations Y and Z and lower SEQGLO scores than Generation Z. Generations X, Y, and Z on the SENINT scales all preferred the sensing side of the scale, but Generation X did not score as high as the other two generations. On the SEQGLO scale, Generation X indicated a mild preference for the global side, while Generation Z demonstrated a mild to moderate preference for the sequential side of the scale.

Data Visualization

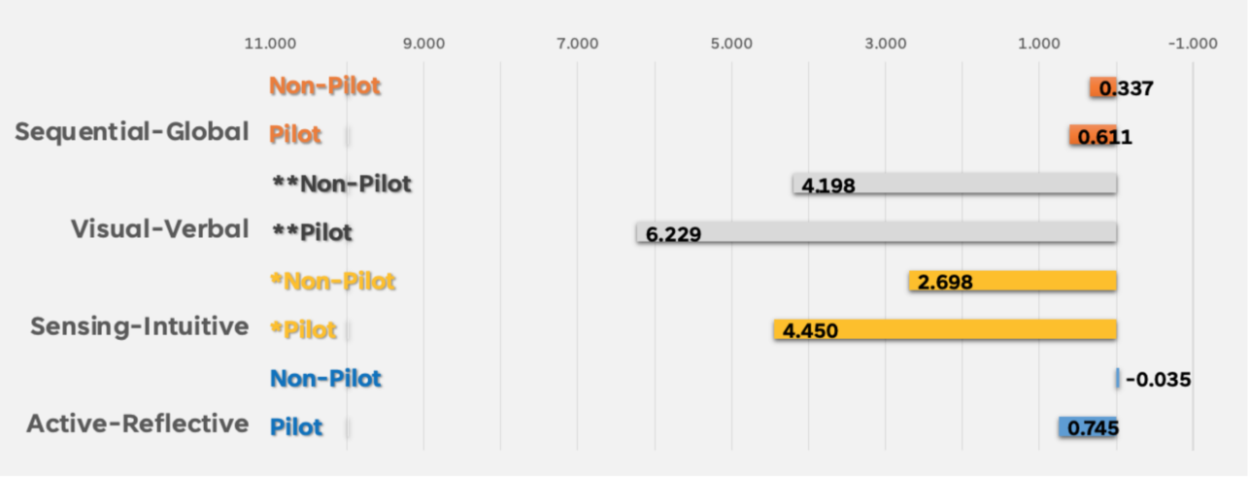
An interesting trend is noted when data for each research question is plotted on the four ILS scales of the ILS. Figure 2 indicates the learning preferences for the total study population. Figures 3, 4, and 5 indicate the learning preferences of the pilot status, gender, and generation, respectively, for the total study population. Figures 6 and 7 indicate the learning preferences for gender and generation, respectively, within the pilot group.

Figure 2
Total Population Learning Preference



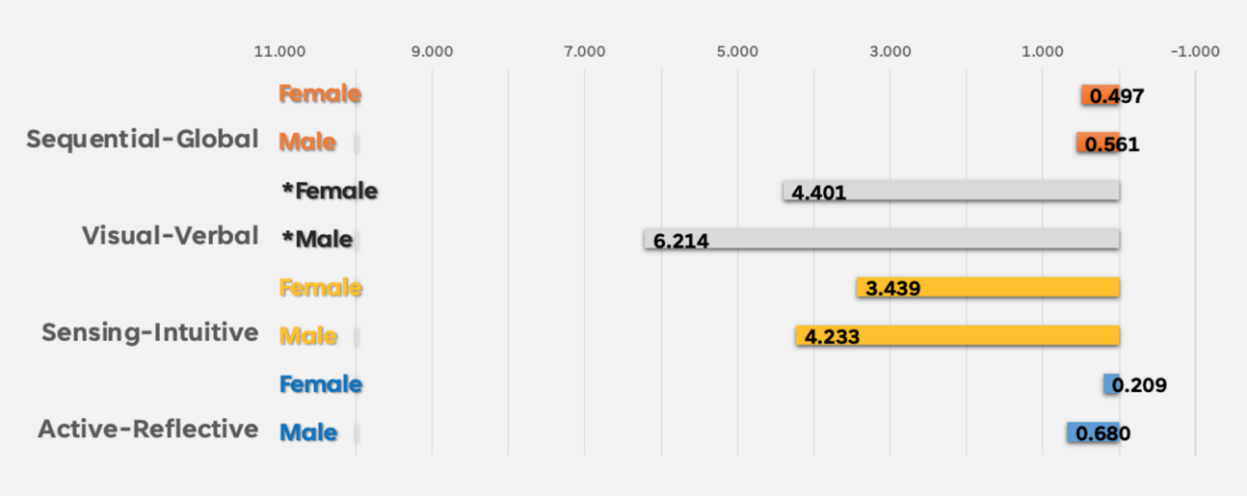
Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

Figure 3
Total Population Learning Preference by Pilot Status



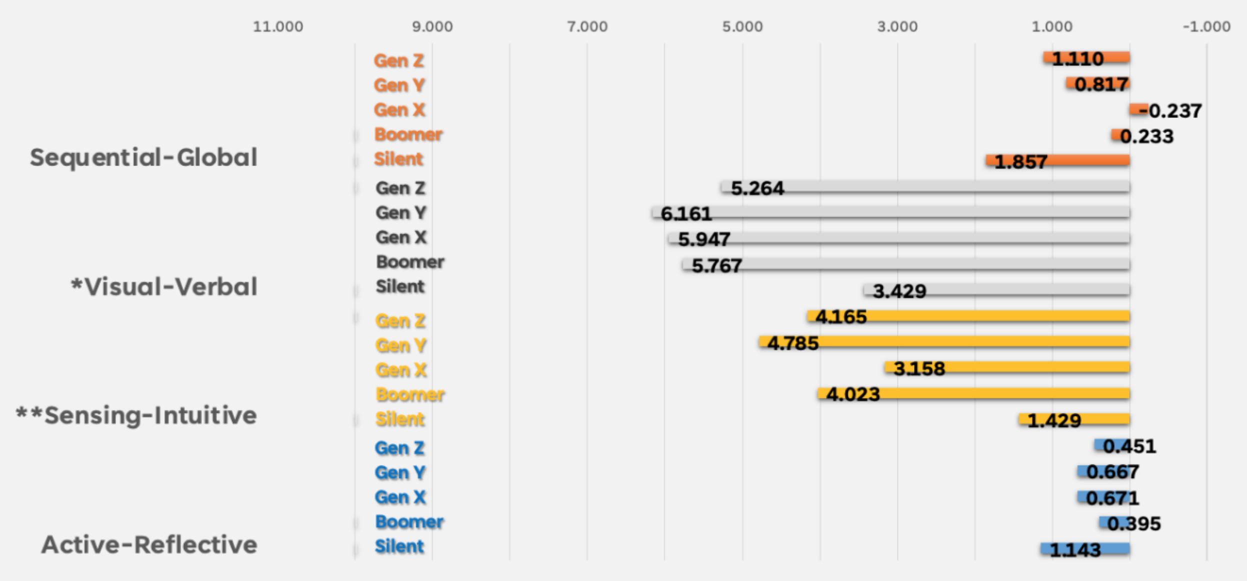
Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

Figure 4
Total Population Learning Preference by Gender



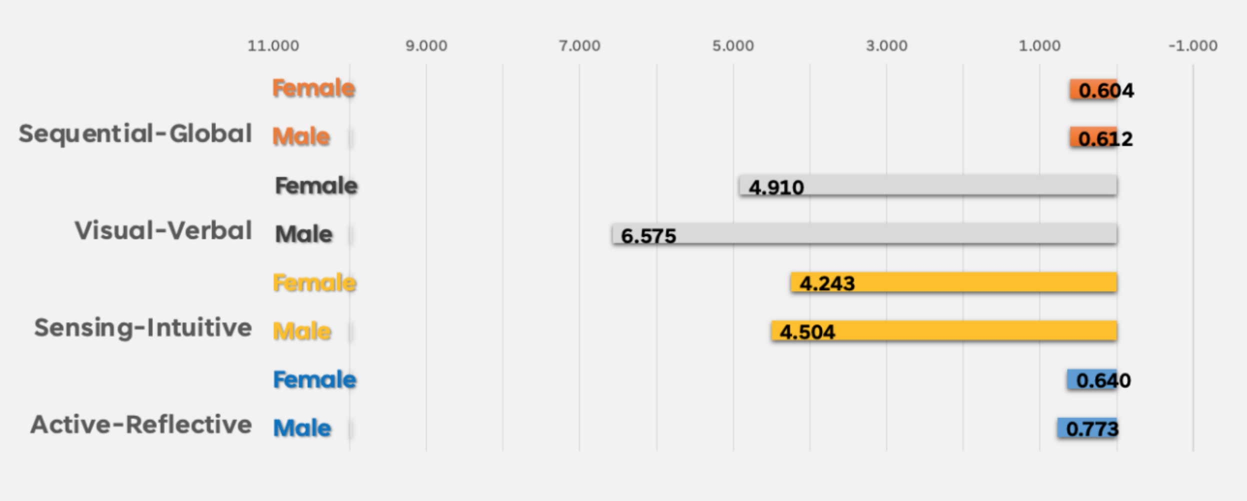
Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

Figure 5
Total Population Learning Preference by Generation



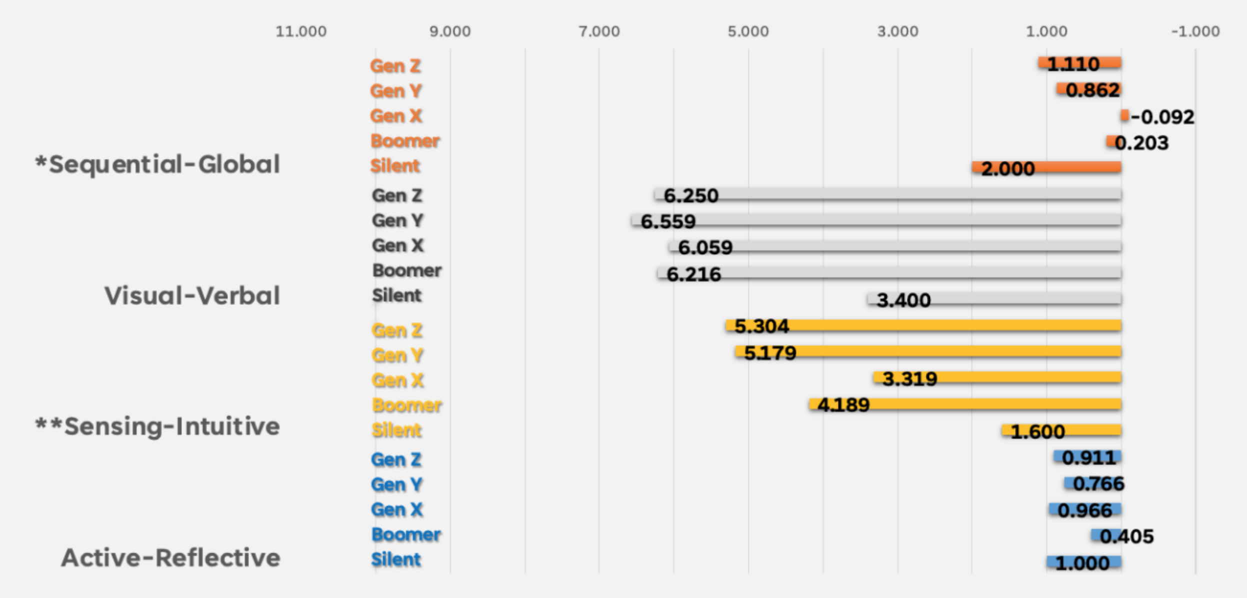
Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

Figure 6
Pilot Population Learning Preference by Gender



Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

Figure 7
Pilot Population Learning Preference by Generation



Note. Since all means favored the left side of each scale (i.e., sequential, visual, sensing, and active), only that side is displayed.

The first observation is that each group in this study indicated that visual information was most effectively perceived. Second, these groups also revealed that the type of information they preferred to perceive was sensory in nature. Felder and Solomon (n.d.-b) explain that visual learners remember best by seeing and that sensing learners tend to be concrete, practical, methodical, and oriented toward facts and hands-on procedures. All groups had a mild preference toward active learning or learning by doing as a means of processing information. The same can be said for each group except for Generation X, where the progress toward understanding is preferred in a sequential manner. Generation X displayed a mild preference for the global, or big picture, approach toward understanding.

Summary

Before looking specifically at the pilot sample, an examination of the total sample of participants is in order. Research question one asked, “What is the relationship of pilot status, gender, and generation on learning styles?” The data indicate that pilots prefer learning environments that are *sensing* and *visual* more than non-pilots. Dissecting the total participant population along gender and generation lines, these data reveal that males would choose a learning environment that used a *visual* teaching modality more readily than females. The only generational differences were between Generations X and Y on the *sensing-intuitive* scale. Both generations preferred a *sensing* learning environment; however, Generation Y had a stronger preference for *sensing*.

A look specifically at the pilot participants was needed to answer research questions two and three. These data were consistent with the total participant population, indicating that male pilots preferred a *visual* learning environment more than females. Pertaining to gender, these data suggest that males and females shared an *active*, *sensing*, and *sequential* learning style environment preference. Both genders had a mild preference, which indicated a balanced learning style preference on that scale for an *active* and *sequential* learning style environment. Even though they prefer *active* and *sequential,* they can learn equally well in a *reflective* or *global* learning situation. When the other two scales were examined, these data suggest that males and females moderately preferred a *sensing* and *visual* learning atmosphere. As was previously noted, males would edge out the females for the *visual* learning scenario.

These data are not so neatly organized when generational preferences are examined. Because the sample size for the Silent Generation was so small and contained only males, it will not be reported in the findings. Baby Boomers, Generation X, Generation Y, and Generation Z generations all have a mild preference for the *active* learning style. This finding indicated that all generations would adapt equally well in a *reflective* learning setting. When examining the *sequential-global* scale, data revealed that the Baby Boomer, Generation Y, and Generation Z generations had a mild preference for the *sequential* learning style. In contrast, Generation X slightly preferred the *global* learning style. The results for the *sensing-intuitive* scale showed that the Baby Boomer, Generation Y, and Generation Z generations had a moderate preference for the *sensing* learning style. In contrast, Generation X had a mild to moderate preference for *sensing* learning preference. Finally, these data show that the Baby Boomer, Generation X, Generation Y, and Generation Z generations moderately preferred the *visual* learning style.

It is important to note how these research data relate to previous research on the pilot population. Studies that used the VARK/VAK, MBTI, and Kolb LSI were examined and compared. Chui et al. (2020) used the VARK learning style tool and identified the importance of feedback type for *visual* and *auditory* learners. They noted that auditory learners who received *visual* feedback were adversely affected in performance. Chui et al. (2020) noted that *visual* learning preference would not be adversely affected by either type of feedback. In 2000, Karp found that of 117 pilots, the predominant preference for learning was that almost one-half were hands-on or *active* learners, and nearly two-thirds were a combination of hands-on (*active*) and *visual* learners. These findings are consistent with the present study. Some researchers have attempted to identify the "best" learning environment based on an individual's personality style using the aspects of one's personality to define the ideal educational situation (e.g., an extrovert is outgoing and would prefer an active environment). These assumptions are drawn based on matching the definition of the terms used in each tool or theory. A review of the literature, however, did not reveal any studies that matched personality style to a particular learning environment. The MBTI is used primarily as a personality inventory but is sometimes used to predict an individual's learning style. Kutz et al. (2004) found that professional pilot students identified at ESTP (Extrovert, Sensing, Thinking, and Perceiving). These students learned best in an environment that was *active*, *sensing*, and *sequential*. Fussell et al. (2018) identified the ISTJ (Introvert, Sensing, Thinking, and Judging) personality type as the most prevalent in their population. These students learned best in an environment that was *reflective*, *sensing*, and *sequential*. Robertson and Putnam (2008) found a greater variety of student personality types in their study; ENFP, ISTP, ISTJ, ENTP, and INFP.

Fussell et al. (2018) used the MBTI to assess an aviation student's personality type and the Kolb LSI to assess the student's learning preference to see if a relationship existed between the two tools. Fussell et al. (2018) and others (Brownfield, 1993; Niemczyk, 2020) found no significant relationship to indicate that an individual's personality preference predicted a specific learning style which may explain the varied findings of previous research on this topic.

Kanske (2001) used the Kolb LSI to identify the learning styles of 233 U.S. Air Force pilots. He found that the *convergent* or *active* learning style was the most prominent, and the *assimilative* or *intuitive* learning style was next, and many preferred using both styles.

Conclusions

The findings of each of the previously mentioned aviation studies broadly align with the findings from this study; however, differences do exist. A parallel can be drawn with observations about generations. While generations may be identified with a certain characteristic, not everyone in that generation necessarily fits that stereotype. The same may be said about pilots and learning styles. These data indicate that pilots are primarily *visual, sensing, active,* and *sequential*; however, not every pilot shares these same learning preferences.

The ILS questionnaire revealed not only an individual's learning style preference but also their non-preference. It may benefit both teachers and students to understand their preferences and non-preferences. Teachers armed with this information can strengthen the learning experience by favoring the predominant learning style while also helping students understand how to learn in a non-preferred way. Teachers must understand that their primary teaching modality is aligned with their individual learning preferences, as well as teaching styles they found successful in previous educational experiences (Fanjoy, 2002; Marshall, 1991; Stitt-Gohdes, Summer 2001) Brown (2003) claimed that instructors who lack an understanding of adult learning theory, or andragogy, will continue to teach with a teacher-centered rather than student-centered approach (Stitt-Gohdes et al., Spring 1999). An andragogical teaching approach (Brady et al., 2001) with an understanding of individual learning styles will help teachers broaden their ability to reinforce learning in multiple educational settings. An awareness of what was preferred and not preferred allowed individuals to work on the weaker or underdeveloped learning preferences to strengthen learning in more learning environments. Felder and Spurlin (2005) insist that:

> To function effectively as professionals, students will need skills associated with both categories of each learning style dimension; if they are never given practice in their less preferred categories, they will not develop the skills that correspond to those categories. The optimal teaching style is a balanced one in which all students are sometimes taught in a manner that matches their learning style preferences, so they are not too uncomfortable to learn effectively, and sometimes in the opposite manner, so they are forced to stretch and grow in directions they might be inclined to avoid if given the option. (p. 105)

Implications

Aviation training curriculum and program implementation should focus on *visual* and *sensing* learning styles because data from this study indicate a moderate preference for these learning styles, but not at the expense of the other styles. *Active* and *sequential* learning styles were favored on their respective scale, but participant responses indicated a mild preference (balanced or normal), meaning the learner could learn equally well using *active* or *reflective* and *sequential* or *global* learning styles. While these unique styles were identified for both gender and generations for pilots, the strength was moderate at most but more typically mild. The more important focus should be on balance, which will not only reach each student but will also teach by example how to strengthen the non-preferred learning styles and make them better learners overall.

It should be noted that the pilot training process takes place in a variety of environments using varying techniques. Ground training can be done in a classroom setting or a one-on-one scenario. Each of these orientations will differ in what training method works best. Classroom settings are limited to lecture and PowerPoint (visual, auditory, and sensing) with some hands-on (active) activities but have limited flexibility for changing teaching methods, while one-on-one scenarios allow an instructor to switch between techniques to enhance the learning experience. Flight training, on the other hand, is solely done one-on-one for pre-flight, in-flight, and post-flight instruction. Flight instructors may possibly have additional resources at his or her disposal (e.g., flight training devices, apps that replay training flights, etc.) to ensure the training process achieves its maximum potential and is only limited by the available resources where instruction is given. These assets can engage more of an individual’s senses which will enhance the learning experience.

Recommendations for Further Studies

This study focused on students attending three higher education institutions and the followers of three LinkedIn pages, four Facebook pages, one popular Aviation Blog and book author, and one popular aviation newsletter publisher. Further research should:

1. Focus on students who are attending non-AABI institutions or not attending an institution of higher education to see if there is a difference in learning styles between non-pilots and pilots.
2. Be conducted at CFR Part 61 and Part 141 (non-AABI higher education institutions) to see if students receiving flight training display learning styles that are different from the AABI-affiliated higher education institutions.
3. Be conducted using regional airlines, major airlines, corporate flight departments, commercial aviation training organizations (i.e., Flight Safety, CAE, etc.), and international airlines to see if the findings from this study can be generalized across the pilot population or if they discover other differences that must be considered in curriculum design and teaching strategies.
4. Focus on other demographics such as cultural background, ethnicity, race, geographic region, socio-economic status, level of education, college major, etc.
5. Conduct a similar study but ask participants to complete both the Kolb Learning Style Inventory 4.0 and the Felder and Soloman Index of Learning Styles to discover how they compare to one another.

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Peer Reviewed Article #9

7-8-2023

Pilot's Guide to Maximum Glide Performance: Optimum Bank Angles in Gliding Turns

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A pilot's awareness of an airplane's power-off glide performance is critical for successfully responding to an engine failure in flight. Pilot's operating handbooks (POH) and airplane flight manuals (AFM) provide the minimum required glide information; however, there is more information that can better equip pilots to extract the maximum glide performance from an airplane. Information about the effect of weight changes on the glide is available but does not seem to be common knowledge among pilots. Information concerning optimum bank angles to use in gliding turns is much less available and seems completely unknown to pilots. This paper provides guidance to pilots for applying weight correction to the best glide speed. It also presents a methodology for determining the optimum bank angle in power-off glides that require a gliding turn to a safe landing location. The results of the study include the optimum gliding bank angles for airplanes with varying glide ratios (GR) along with rules of thumb for determining the optimum bank angle in flight. The findings of this research can be utilized to supplement 1) the glide performance information used and presented by digital avionics, 2) the glide information contained in POHs and AFMs, and 3) flight training for power-off glides with or without turns to safe landing locations, all with the goal of providing pilots with more tools to land safely at a suitable location in the event of an engine failure.

Recommended Citation:
Callender, N. (2023). Pilot's guide to maximum glide performance: Optimum bank angles in gliding turns. *Collegiate Aviation Review International*, 41(1), 180-208. Retrieved from https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9516/8477

Introduction

Power-off glide performance is a consideration that all pilots should have prior to and during every flight, especially when in a single-engine airplane. As with other airplane performance information, an airplane's glide performance is presented in the pilot's operating handbook (POH) and/or the airplane flight manual (AFM). That is, of course, if the airplane was certified after 1996. In February of that year, the Federal Aviation Administration (FAA) mandated that POHs and/or AFMs include a minimum of 1) the airplane's maximum horizontal distance covered over the ground per $1{,}000\ ft$ of altitude lost in a power-off glide and 2) the airspeed required when doing so (Glide: Single-Engine Airplanes, 1996).

While these pieces of performance information are valuable in planning and performing a power-off glide, there is more information that pilots can know about optimizing an airplane's power-off glide performance. Commonly used publications and handbooks such as the FAA's Airplane Flying Handbook (2021) and the well-known text Aerodynamics for Naval Aviators (Hurt, 1965) include aerodynamic information and practical instructions regarding glide performance. These and other pilot-focused texts clearly present the two required glide performance values (or their equivalent) required by the FAA. They go further by indicating that the airspeed necessary for maximum glide performance is a function of weight. Chapter 3 of the Airplane Flying Handbook (2021) states that a weight adjustment is required; however, it does not present a method for making the adjustment. Hurt (1965) refers to the weight correction, and he presents an equation that can be used to make it.

Another important component of power-off glide performance is the planning for and execution of a required turn to a landing destination during the glide. When the engine failure occurs on or shortly after takeoff, the possibility of returning to the departure runway is referred to as the "impossible turn". Chapter 18 of the Airplane Flying Handbook (2021) presents general considerations for attempting such a turn, and articles, such as those by Rogers (1995) and Collazo Garcia et al. (2021), present more specific guidance to include an optimal bank angle to use in the turn.

For power-off glides being conducted from a more substantial altitude, selection of and route planning to a suitable landing location is very important. Much research has been conducted into determining optimum glide trajectories using Dubins paths to landing locations based upon terrain, winds, runway headings, airport locations, and an airplane's aerodynamic characteristics. Examples of such work are the articles by Atkins, Portillo, & Strube (2006); Chitsaz & LaValle (2007); Meuleau, Plaunt, Smith, & Smith (2009); Adler, Bar-Gill, & Shimkin (2012); Di Donato & Atkins (2016); Stephan & Fichter (2016); and Segal, Bar-Gill, & Shimkin (2019). Previous research has been focused on very specific cases, the results of which were only applicable to those cases. The research was also conducted using numerical algorithms, well suited to computational analysis, but much less suited to practical use by pilots either in preparation for the possibility of an engine failure or during an actual power-off glide.

It is the purpose of this research to develop practical guidance for pilots to use in preparation for and in the conduct of power-off glides to safe landing locations that optimize the glide performance of the airplane. This paper intends to serve as an updated source of information and as a practical guide for glide performance. Guidance for applying the known weight correction to glide airspeed will be presented, and new research into optimal bank angles for gliding turns will be shared to include pilot rules-of-thumb for its application.

Glide Performance

Wings Level Glide

Gliding, as discussed in this paper, is considered with no power (engine-out) and in calm wind conditions. Wings-level gliding is presented first. A gliding airplane is shown in Figure 1, along with velocity and forces. Having no engine power to produce thrust, a component of the airplane's weight(W_T), is needed to overcome the airplane's drag (D), which is always directed opposite the direction of the airplane's motion or in the same direction as the relative wind (RW). The only way for this to occur is in descent. The airplane's velocity (v) is shown to be along an axis (the flight direction) at an angle (γ) below the horizon (the horizontal axis). γ is also known as the glide angle. The airplane's flight direction must be set such that its W_T is equal (and opposite) to its D in order to maintain its velocity in the flight direction. Lift (L), by definition, is perpendicular to the RW. When L is equal (and opposite) to the normal component (normal to the flight direction) of the airplane's weight (W_N), the airplane will descend at a constant γ. In short, the sum of forces in any direction is zero for a steady, unaccelerated glide.

A closer inspection can be made of the airplane's W and its components. The angle of separation between W and W_N is equivalent to the glide angle, γ, and W_N and W_T are perpendicular to one another. For right triangles such as this one, a basic trigonometric relationship relates these two components, as shown in Equation 1.

$$\tan\gamma = \frac{W_T}{W_N} \tag{1}$$

In a steady glide, D and L can then be substituted for W_T and W_N, respectively. Following these substitutions and solving for γ results in Equation 2.

$$\gamma = \tan^{-1}\left(\frac{1}{L/D}\right) \tag{2}$$

Equation 2 reveals the aerodynamic nature of glide performance.

All lifting devices, whether 2D airfoils, 3D wings, or entire aircraft, can be described by their aerodynamic characteristics. The typical presentation of these characteristics is in graphical form, with which the reader of this paper is most likely already familiar. An example of such a presentation is shown in Figure 2.

Figure 1

Free Body Diagram of an Airplane in a Power-off Glide

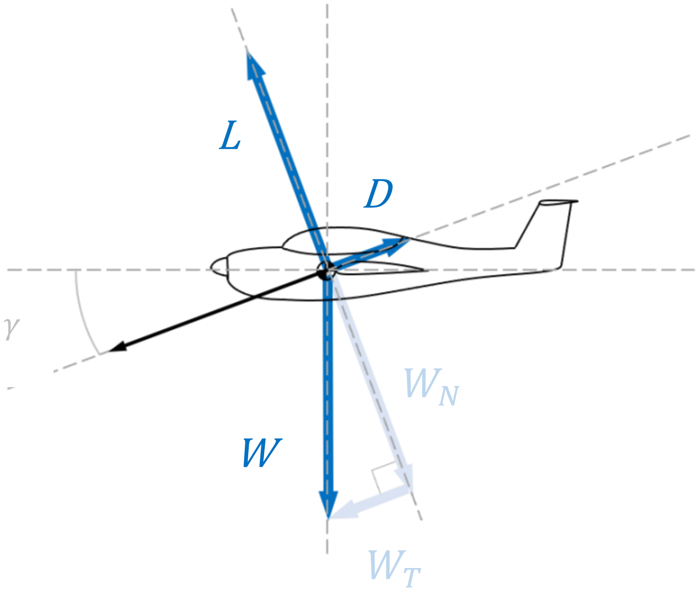
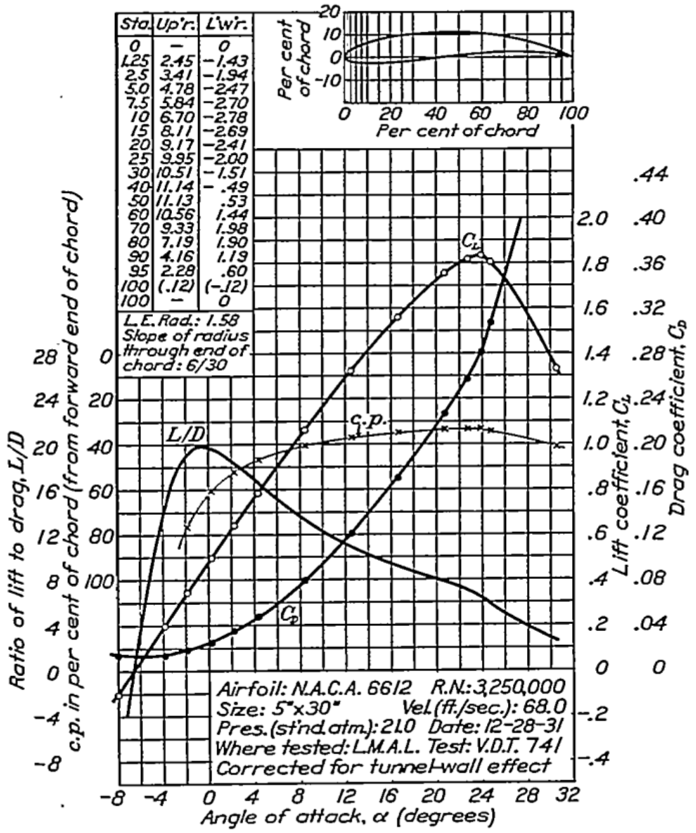


Figure 2

NACA 6612 Aerodynamic Characteristic Curves



Sta.	Up'r.	L'w'r.
0	—	0
1.25	2.45	−1.43
2.5	3.41	−1.94
5.0	4.78	−2.47
7.5	5.84	−2.70
10	6.70	−2.78
15	8.11	−2.69
20	9.17	−2.41
25	9.95	−2.00
30	10.51	−1.51
40	11.14	− .49
50	11.13	.53
60	10.56	1.44
70	9.33	1.98
80	7.19	1.90
90	4.16	1.19
95	2.28	.60
100	(.12)	(−.12)
100	—	0

L.E. Rad.: 1.58
Slope of radius through end of chord: 6/30

Airfoil: N.A.C.A. 6612 R.N.: 3,250,000
Size: 5"x30" Vel. (ft./sec.): 68.0
Pres. (st'nd. atm.): 21.0 Date: 12-28-31
Where tested: L.M.A.L. Test: V.D.T. 741
Corrected for tunnel-wall effect

Note. Adapted from The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel, NACA-TR-460 (1933) by Jacobs, E., Ward, K.E., & Pinkerton, R.M., retrieved from ntrs.nasa.gov.

Four basic aerodynamic characteristics are presented in Figure 2 for the NACA 6612 airfoil: the lift coefficient (C_L), the drag coefficient (C_D), the lift-to-drag ratio (L/D), and the center of pressure (CP). Each of these is a nondimensional value that represents different aspects of the airfoil's aerodynamic behavior as a function of the airfoil's angle of attack (α). C_L and C_D represent the lift and drag forces that can be created by the airfoil. The CP represents the chordwise location of those forces. The airfoil's lift will be maximized when operated at its highest lift coefficient $\left(C_{L_{max}}\right)$. The angle of attack at which this occurs is known as the critical angle of attack (α_{crit}). Maximizing the airfoil's lift is desirable for slow flight and maneuvering; however, it is accompanied by high drag, which requires high power, and is therefore not ideal for all flight conditions, especially power-off, gliding flight. Rather than taking the airfoil's C_L in isolation, comparing the C_L to the C_D at any angle of attack will provide a more complete aerodynamic picture of the airfoil's performance. This comparison was captured by L/D. The higher the L/D, the more lift an airfoil can create for a given amount of drag; or put another way, for a given amount of lift, the airfoil will produce less drag. Therefore, L/D is an indication of the airfoil's aerodynamic effectiveness (effectiveness being defined as the ability of the airfoil to produce what is desired (L) while minimizing what is not (D)). As can be seen in Figure 2, the NACA 6612's L/D curve achieves a maximum value $((L/D)_{max})$ at a specific angle of attack, known as the optimum angle of attack $\left(\alpha_{opt}\right)$.

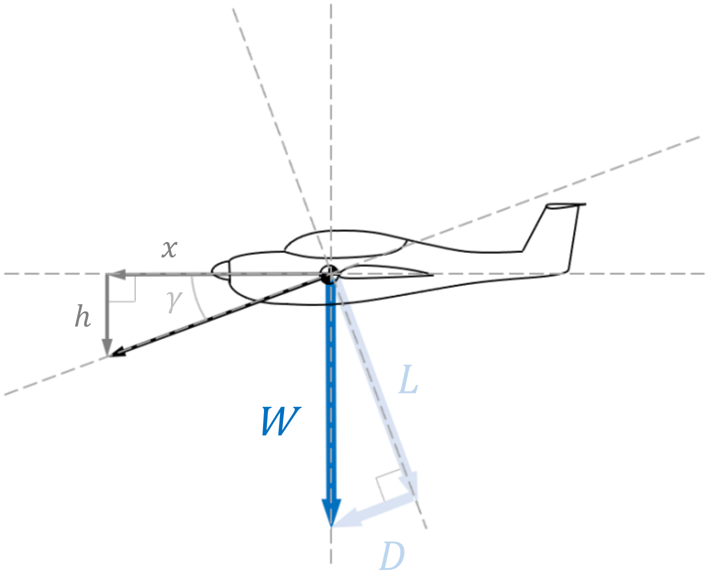
Figure 2 presents an example of one airfoil's aerodynamic characteristics. As previously mentioned, all lifting devices, including entire airplanes, can be described by characteristics such as these; therefore, all airplanes will have an α_{opt} and an associated $(L/D)_{max}$. According to Equation 2, L/D is the only input needed to determine an airplane's glide angle. The lower the glide angle (γ), the higher an airplane's maximum glide range will be. Substituting $(L/D)_{max}$ into Equation 2 yeilds the minimum possible glide angle as shown in Equation 3.

$$\gamma_{min} = \tan^{-1}\left(\frac{1}{\left({}^{L}/_{D}\right)_{max}}\right) \tag{3}$$

The intent of this article, as is articulated in the title, is to provide glide performance guidance to pilots. Although glide performance depends upon a specific aerodynamic characteristic, $\left({}^{L}/_{D}\right)_{max}$, obtained when operating at a specific angle of attack, α_{opt}, that results in the lowest glide angle, γ_{min}; pilot's operating handbooks (POH) and airplane flight manuals (AFM), the primary sources of performance guidance for pilots, do not use this terminology. Recall the right triangle in Figure 2 that includes the airplane's weight, the weight's components, and the glide angle. Figure 3 presents this triangle again, with the substitutions of D and L for W_T and W_N. It also presents another triangle that represents the distance traveled in the flight direction and that distance's components in the horizontal and vertical axes. The distance traveled along the flight direction can be separated into the ground distance covered while gliding (x) and the associated altitude lost (h). These two components are at right angles to one another and can be related to one another via Equation 4.

$$\tan\gamma = \frac{h}{x} \tag{4}$$

Figure 3
Distance Travelled while Gliding



Lift and drag can also be related to one another in the same way via Equation 5.

$$\tan\gamma = \frac{D}{L} \tag{5}$$

Equations 4 and 5 can be equated and solved for x as shown in Equation 6.

$$x = h\left(\frac{L}{D}\right) \tag{6}$$

Equation 6 provides the ability to calculate the ground distance covered from a known altitude for a given L/D. Maximum glide range, R_G, is obtained from Equation 6 by substituting $(L/D)_{max}$ as shown in Equation 7.

$$R_G = h\left(\frac{L}{D}\right)_{max} \tag{7}$$

Again, $(L/D)_{max}$ does not appear in POHs or AFMs, at least not by that name. The ratio of the maximum ground distance covered for a given amount of altitude lost in a glide is defined to be glide ratio (GR). GR is therefore associated with gliding at γ_{min}. Reciprocating and equating Equations 4 and 5 while at γ_{min} reveals that an airplane's $(L/D)_{max}$ and its GR are equal. GR is typically included in POHs and AFMs as one of the primary metrics for an airplane's glide performance capability. Not all handbooks will include GR since glide performance information was not required by federal regulation until 1996. Aircraft certified prior to 1996 might include a GR, a graph of altitude vs. glide range (from which GR can be extracted), the distance traveled for $1{,}000\ ft$ of altitude lost or no glide performance at all.

Substituting GR into Equation 7 yields Equation 8, a more pilot-oriented equation for glide range.

$$R_G = h(GR) \tag{8}$$

Equation 8 can be used, with an appropriate conversion to either statute or nautical miles (assuming h is in ft), to determine possible landing locations within the airplane's glide range. In order to enable the airplane to achieve this range, a pilot needs more information. Specifically, the pilot would need to know the airplane's α_{opt}. Flying at this angle would enable the airplane to achieve its $(L/D)_{max}$ thereby minimizing its glide angle and maximizing its glide range. Flying based on angle of attack is the most effective way to maximize power-off glide range; however, civilian airplanes are not typically equipped with angle of attack indicators. Even if they were, federal regulations do not require POHs nor AFMs to contain an airplane's α_{opt}. What they are required to provide is the airspeed that enables maximum glide range, v_G. Advisory Circular AC 23-8C (2011) provides recommended techniques for flight testing Part 23 certified aircraft, including the flight test used to determine maximum glide performance. The test includes a series of power-off glides to be conducted through a range of airspeeds. An airplane's v_G can be identified from a plot of the data collected during the glides. The value is then published in the POH or AFM in several locations, most notably in the Emergency Procedures chapter. Unless a pilot has v_G memorized (which the author would recommend), the handbook's Emergency Procedure for power-off, maximum range gliding would need to be referenced (which the author also recommends) following an in-flight engine failure where the engine cannot be restarted and a power-off glide to a suitable landing site must take place.

Effect of Weight

One of the necessary conditions for presenting glide information in POHs or AFMs is that the performance information must be for the airplane at its maximum takeoff weight (MTOW). The published v_G is, therefore, accurate if and only if the airplane is at MTOW. The reality for many/most flights is that they begin with the airplane below MTOW, and even if they did begin at MTOW, the airplane's weight is always decreasing in line with its fuel flow. This means that establishing the published v_G in order to maximize the glide range will not actually maximize the glide. It will come close to doing so, but more performance is available. In order to truly obtain maximum glide performance, v_G must be adjusted for the airplane's weight at the time that power is lost. Here is that process. It begins with a conceptual scenario in which an airplane is flying straight and level at *MSL* at its *MTOW*. Let the aircraft be doing this at the published v_G with the angle of attack necessary to develop enough lift (L_i) to balance its weight. This balance is captured in the lift equation, as shown in Equation 9.

$$L_i = \frac{1}{2} C_L \rho_0 v_G^2 S = MTOW \tag{9}$$

The next step is to decrease the weight of the airplane to a new value, W_N, while maintaining altitude and angle of attack. Maintaining altitude keeps density (ρ_0) constant, and maintaining the angle of attack keeps the lift coefficient constant. In order to decrease the lift to L_N, to accommodate the new weight, the only option remaining, assuming the wing area (S) is also constant, is to decrease airspeed. Equation 10 shows this new condition.

$$L_N = \frac{1}{2} C_L \rho_0 v_{G_N}^2 S = W_N \quad (10)$$

Finally, Equation 10 is divided by Equation 9 and solved for the new airspeed, v_{G_N}, as shown in Equation 11.

$$v_{G_N} = v_G \sqrt{\frac{W_N}{MTOW}} \quad (11)$$

With two handbook values, $MTOW$ and v_G, and Equation 11, the airspeed that will actually maximize the airplane's glide range can be calculated.

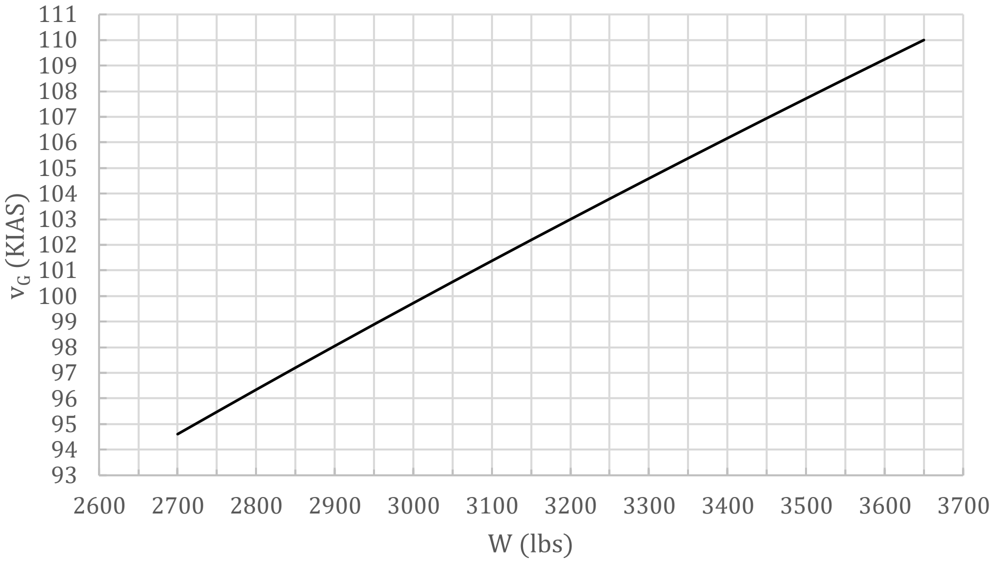
The simplicity of Equation 11 makes it accessible to pilots in an engine-out scenario, especially if the aircraft is equipped with a fuel flow meter or fuel counter that keeps up with the amount of fuel used. The weight of the fuel used subtracted from the airplane's loaded weight results in the new weight, W_N. At a minimum, the author recommends calculating and knowing the lower limit of v_{G_N} for any airplane. For example, an A36 Beechcraft Bonanza has a $MTOW$ of $3{,}650\ lbs$ and a v_G of $110\ KIAS$ (2006). With no usable fuel, no passengers, and no cargo, the A36 and pilot might weigh on the order of $2{,}700\ lbs$. Using Equation 11 with these inputs results in a minimum expected value of v_{G_N} as shown in Equation 12.

$$v_{G_N} = 110 \sqrt{\frac{2{,}700}{3{,}650}} = 94.6\ KIAS \quad (12)$$

With this value for v_{G_N} and the published v_G, the lower and upper boundaries for the speed for maximum glide range for the airplane can be used for interpolation for any airplane weight. Interpolating is relatively easy; however, basic interpolations are linear, whereas the change in speed, according to Equation 11, is not. Another method would be to prepare and use a plot, as shown in example A36 in Figure 4. A pilot equipped with a plot similar to Figure 4 for any airplane could quickly and easily identify the best airspeed to fly in an engine-out situation. This type of plot could easily be created in commonly available spreadsheet software (i.e., Microsoft Excel) using Equation 11. Whether using a plot, interpolating between maximum and minimum speeds, or calculating the value directly, in order to ensure the best glide range possible, a pilot should (and is able to) adjust an airplane's maximum range glide speed for weight.

Figure 4

Speed for Maximum Glide Range vs. Weight for Example A36

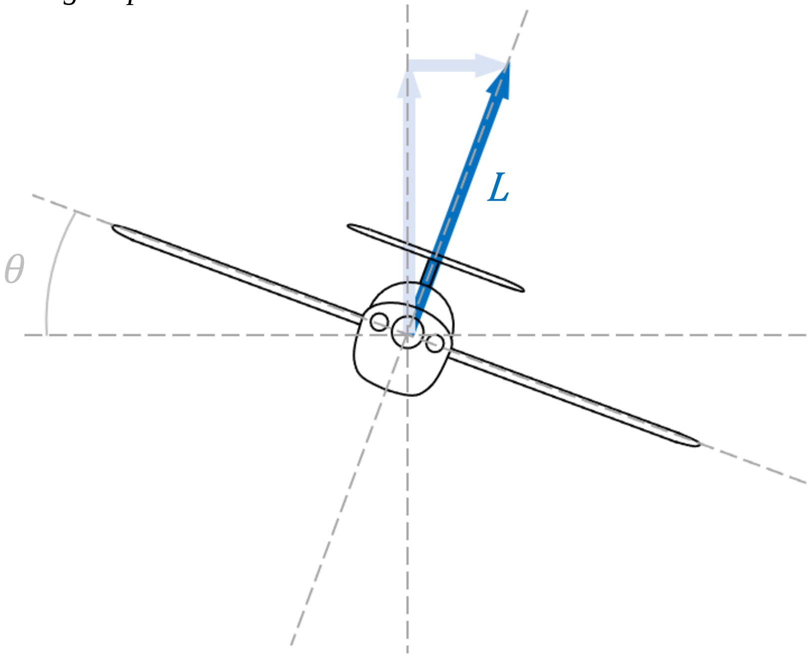


Effect of Turning

Just as glide information in airplanes' POHs and AFMs only applies to MTOW, the glide information that they present is also only for wings-level (non-turning) flights. Figure 5 presents a front view of an airplane in a banked turn.

Figure 5

Front View of Turning Airplane



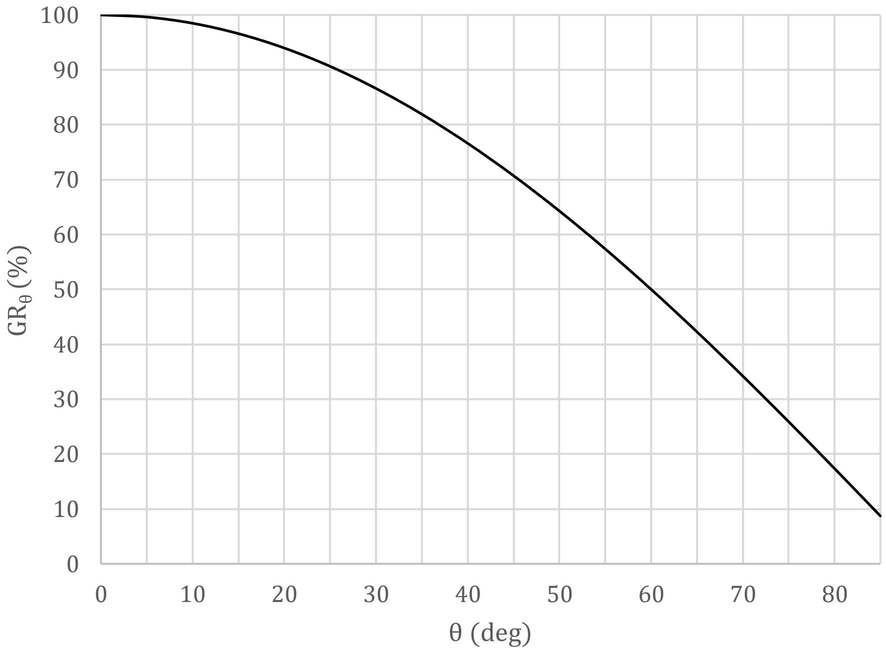
As seen in the figure, the lift is always perpendicular to the lateral axis; therefore, it will change direction in keeping with the bank angle. When the engine is operating, the bank angle would be accompanied by increased back pressure and/or increased power in order to maintain altitude in a coordinated turn. In an engine-out banked turn, maintaining altitude isn't possible, so neither increased back pressure nor increased power is useful (or even possible). Assuming that a turn is initiated at v_G, the same lift-to-drag ratio will be maintained; however, the lift will be directed as shown in Figure 5. With lift at this angle, its component in the vertical direction is reduced. The vertical component of lift is what contributes to glide performance. This is demonstrated by a reduction in GR according to Equation 13 where GR_θ represents the reduced GR in a gliding turn compared to the GR in a wings-level glide.

$$GR_\theta = GR \cos\theta \tag{13}$$

Figure 6 shows the consequence of turning at various bank angles on GR according to Equation 13. The significant effect of bank angle on GR is clear as bank angles increase. For example, an airplane in a gliding turn with $30°$ of bank will still have approximately 87% of its wings-level GR. The same airplane in a gliding turn with $60°$ of bank will only be able to produce 50% of its wings-level GR. The clear takeaway is that wings-level glides offer maximum glide range. If only the best destinations were always straight ahead in engine-out scenarios. How to deal with necessary (and suboptimal) turns to a safe landing location will be dealt with in the next section.

Figure 6

GR_θ vs. θ as a % of Wings-Level GR



Gliding Turns to Destination

Glide Path with Required Turn

Unless an engine failure occurs within the glide range of the destination airport, which would typically be located straight ahead, a turn to an appropriate landing location will be necessary. It is clear from Equation 13 and Figure 6 that turning in a power-off glide isn't great for extending the glide range. If and when a turn is necessary, the question is how best to do it. From Equation 13, the lowest bank angle possible would be best. That is true; however, a turn's footprint as represented by the turn radius (r) must also be considered. In a constant altitude, coordinated turn, turn radius is calculated via Equation 14.

$$r = \frac{v^2}{g \tan \theta} \tag{14}$$

In a power-off glide, Equation 14 must be modified, resulting in Equation 15 (Asselin, 1997).

$$r = \frac{v^2}{g \tan \theta \cos \gamma} \tag{15}$$

The equation for glide angle (γ) is derived by rearranging Equation 5 with a substitution from Equation 13, as shown in Equation 16.

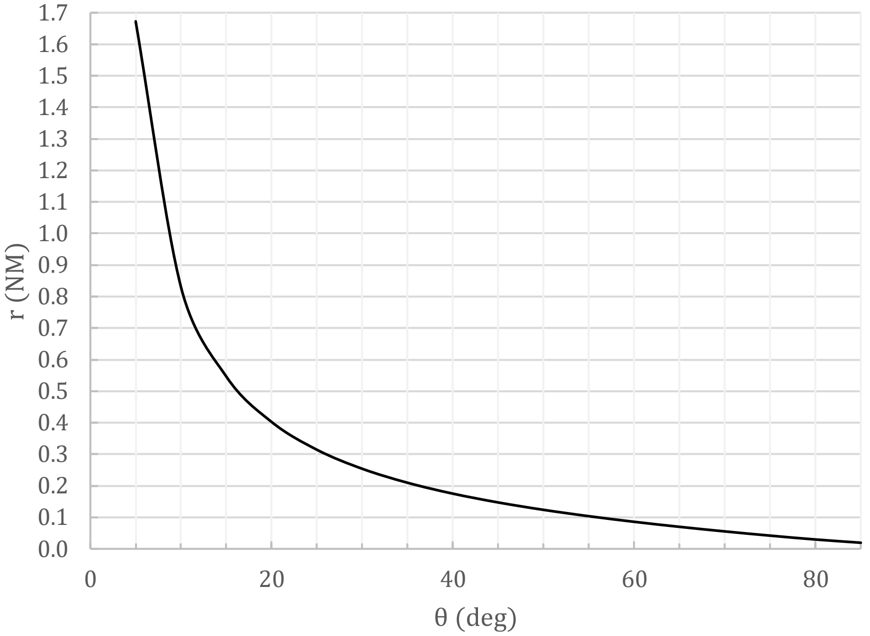
$$\gamma = \tan^{-1}\left(\frac{1}{GR \cos \theta}\right) \tag{16}$$

The results of Equations 15 and 16 can be visualized with an example. Take, for instance, an airplane gliding at $100\ KTAS$. If the airplane has a GR of 10:1, Figure 7 shows its turn radius as a function of bank angle. While a low bank angle will preserve the airplane's GR, it will result in a large turn radius. Turn radius contributes to the distance $\left(d_{\Delta\phi}\right)$ that must be covered, as viewed from above, while making a heading change $(\Delta\phi)$, as shown in Equation 17.

$$d_{\Delta\phi} = r \cdot \Delta\phi \tag{17}$$

Figure 7

Glide Ratio vs. Bank Angle for an Example Gliding Airplane



It is important to note that the heading change must be in radians in Equation 17. Continuing the example from above, let the airplane's distance covered over the ground while gliding at two bank angles $(5° \; and \; 60°)$ be calculated for a $180°$ heading change. The airplane gliding with a $5°$ bank angle will cover $5.25 \; NM$ over the ground, while the airplane gliding with a $60°$ bank angle will cover only $0.27 \; NM\ldots$ almost twenty times less! The distances covered in the turn are depicted in Figure 8. Lower bank angles result in higher lift to drag ratios, GR_θ, but they also result in greater ground distances. Greater ground distances mean more altitude will be lost during the direction change. Large bank angles greatly reduce lift to drag, but they allow for direction changes with much smaller ground distances required. The bank angle that a pilot should choose in a power-off glide when a heading change is necessary is not immediately evident. It is a balancing act between preserving lift to drag ratio and minimizing the ground distance covered in the turn.

Calculating Altitude on Arrival at Destination

Calculations were conducted for an airplane with several different lift-to-drag ratios representative of a range of general aviation airplanes. The airplane's glide range was calculated from an initial altitude from which an engine failure occurred. Safe landing sites were located at bearings from $10°$ to $175°$ from the initial heading of the airplane. Glides were initiated with turns to intercept a path to the landing site. Bank angles in the turn to the intercept path were varied from $10°$ to $80°$. Figure 9 presents an example of a calculated path that would be necessary to reach a safe landing destination.

Figure 8
Distance Covered in a $180°$ *Turn at Two Bank Angles*

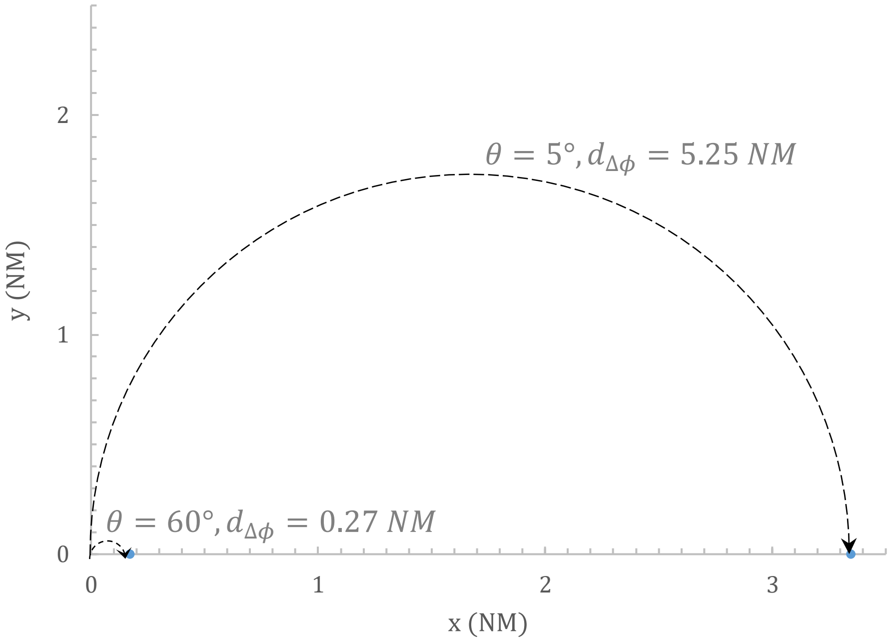
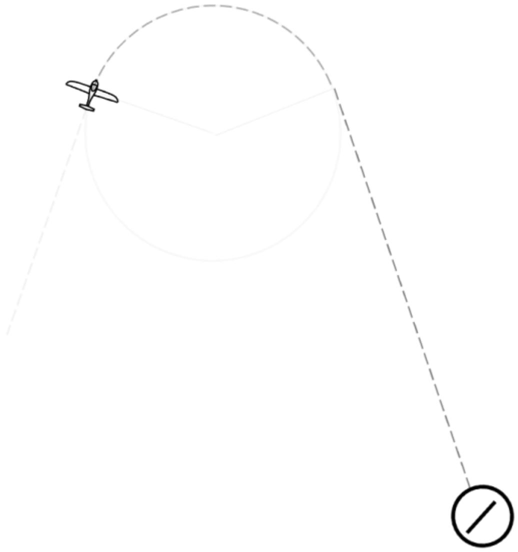


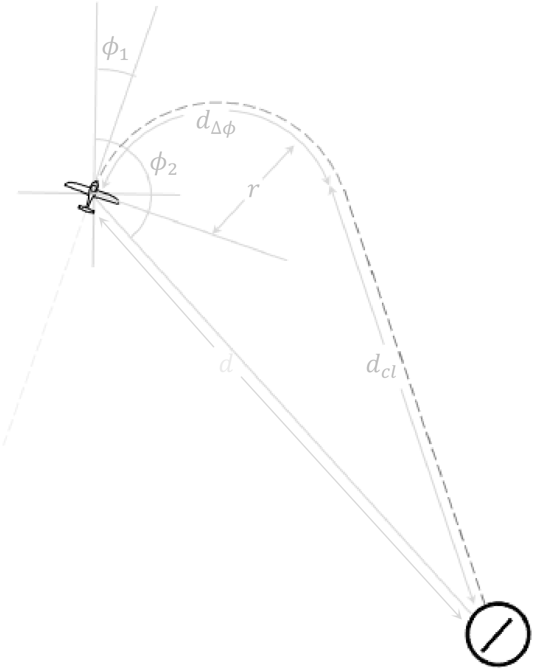
Figure 9
Glide Path to a Safe Landing Destination



Each glide distance calculation began by setting the airplane's GR and v_G. The GR was used, along with a preselected AGL height (h), to calculate and set the distance (d) to a landing location that would allow the airplane to safely glide to the location with altitude to spare, if the landing location was on the airplane's original heading (ϕ_1). In other words, a power-off glide requiring no turn would be possible to the landing location. With the height and distance to the landing location settled, the landing location was set at the first bearing (ϕ_2), which required a gliding turn. The scenario is shown in Figure 10, including all distances and angles used to calculate the glide range.

Figure 10

Glide Path with Distances and Angles used to Calculate Glide Range



The process began with the lowest bank angle (θ). Equation 15 was then used to calculate the airplane's turn radius (r). Equations 18-23 were used to calculate the final heading (ϕ_{int}) that marked the point in the turn at which an intercept path the airport was achieved.

$$d_{cl} = \sqrt{[d\sin\phi_2 - r\sin(\phi_1 + 90)]^2 + [d\sin\phi_2 - r\cos(\phi_1 + 90)]^2} \tag{18}$$

$$\beta_1 = \sin^{-1}\left(\frac{r}{d_{cl}}\right) \tag{19}$$

$$\beta_2 = 90 - \beta_1 \tag{20}$$

$$\beta_3 = \tan^{-1}\left[\frac{d\cos\phi_2 - r\cos(\phi_1 + 90)}{d\sin\phi_2 - r\sin(\phi_1 + 90)}\right] \tag{21}$$

$$\Delta\phi = 180 - \phi_1 - \beta_2 - \beta_3 \tag{22}$$

$$\phi_{int} = \phi_1 + \Delta\phi \tag{23}$$

In these equations, d is the distance from the aircraft location to the airport; ϕ_1 is the aircraft's flight path direction; ϕ_2 is the airport direction from the aircraft position; d_{cl} is the distance to the airport after turning; β_1, β_2, and β_3 are geometric calculations used to determine the aircraft's necessary direction change $(\Delta\phi)$ and its final direction (ϕ_{int}) to the airport.

Equations 17 and 22 were then used to calculate the ground distance covered $\left(d_{\Delta\phi}\right)$ in the turn to the intercept path. The altitude lost in the turn $\left(\Delta h_{\Delta\phi}\right)$ was calculated using Equation 24, which uses GR_θ from Equation 13.

$$\Delta h_{\Delta\phi} = \frac{d_{\Delta\phi}}{GR_{\theta}} \tag{24}$$

The remaining distance to the landing site (d_{int}) on the intercept heading was then calculated using Equation 25.

$$d_{int} = \sqrt{{d_{cl}}^2 - r^2} \tag{25}$$

The altitude lost during the final glide on the intercept heading was calculated using Equation 26.

$$\Delta h_{int} = \frac{d_{int}}{GR} \tag{26}$$

The last step was to calculate the final altitude (h_f) upon arrival at the landing site using Equation 27.

$$h_f = h - \Delta h_{\Delta\phi} - \Delta h_{int} \tag{27}$$

The airplane characteristic that remained constant for all calculations was the airplane's best range glide speed: $v_G = 100\ KIAS$. This was adjusted to TAS as appropriate to the altitude for each calculation.

The first example calculations are based upon an airplane with an GR of 10. The example altitude was $6{,}000\ ft$ with a landing site $9\ NM$ away. In a straight-line glide, this airplane would be capable of gliding to a distance of $9.87\ NM$ over flat terrain. The airplane's heading (ϕ_1) for the example calculation, was $360°$, the bearing to the first landing location (ϕ_2) was set to $010°$, and the first bank angle (θ) used during the turn was $10°$. For this glide, the distance travelled while turning $(d_{\Delta\phi})$ was $0.18\ NM$. The distance traveled after the turn on the intercept course (d_{int}) was $8.83\ NM$ for a total distance (d_T) of $9.01\ NM$, and the final altitude upon arrival at the landing location (h_f) was $529\ ft$.

The scenarios evaluated were for three GRs (8, 10, and 12); four altitude and distance to the landing location combinations per GR (e.g., for $GR = 8$, $1{,}000\ ft\ AGL/1.2\ NM$; $2{,}500\ ft\ AGL/3\ NM$; $5{,}000\ ft\ AGL/6\ NM$; and $10{,}000\ ft\ AGL/12\ NM$); bearings to the landing site ranging from 10° to 175°; and bank angles ranging from 10° to 80°. Results for the example scenario ($GR = 10$; $6{,}000\ ft\ AGL/9\ NM$; $\phi_2 = 10°$) throughout the range of bank angles are presented in Table 1. The data shows that any bank angle from 10° to 80° would result in a similar altitude upon arrival at the destination located on a $10°$ bearing from the beginning of the glide; however, lower bank angles provided a slight advantage with the least altitude lost from a $10°$ bank angle turn.

Table 1

Glide Calculations with: $GR = 10$; $6{,}000\ ft\ AGL/9\ NM$; and $\phi_2 = 10°$

θ (°)	$d_{\Delta\phi}$ (NM)	$\Delta h_{\Delta\phi}$ (ft)	d_{int} (NM)	h_f (ft)
10	**0.18**	**108.0**	**8.83**	**529.4**
20	0.08	54.6	8.92	528.0
30	0.05	37.3	8.95	526.4
40	0.04	29.0	8.96	524.7
50	0.03	24.4	8.97	522.8
60	0.02	21.8	8.98	520.7
70	0.01	20.5	8.99	518.1
80	0.01	21.7	8.99	513.7

For this scenario, the lower bank angle's preservation of GR outweighed the additional travel distance required in such a shallow turn. For comparison, the data for a glide to a landing location on a bearing of $90°$ from the airplane's original heading are presented in Table 2. The glide to this landing location was also possible with a turn using any of the tested bank angles; however, the lowest bank angle was no longer ideal. The additional air distance that accompanied the lower bank angle turns resulted in more altitude lost upon arrival at the destination. The optimal bank angle appears to be very close to $50°$ in this case. Further comparison is presented using the data for a glide to a landing location on a bearing of $150°$ from the airplane's original heading, as presented in Table 3.

Table 2

Glide Calculations with: $GR = 10$; $6{,}000\ ft\ AGL/9\ NM$; and $\phi_2 = 90°$

θ (°)	$d_{\Delta\phi}$ (NM)	$\Delta h_{\Delta\phi}$ (ft)	d_{int} (NM)	h_f (ft)
10	1.68	1038.7	7.95	133.9
20	0.78	506.5	8.51	325.8
30	0.49	342.2	8.69	377.2
40	0.33	264.8	8.79	395.5
50	**0.23**	**222.0**	**8.85**	**400.2**
60	0.16	197.2	8.90	397.0
70	0.10	185.2	8.93	386.7
80	0.06	195.3	8.96	357.8

Table 3

Glide Calculations with: $GR = 10$; $6{,}000\ ft\ AGL/9\ NM$; and $\phi_2 = 150°$

θ (°)	$d_{\Delta\phi}$ (NM)	$\Delta h_{\Delta\phi}$ (ft)	d_{int} (NM)	h_f (ft)
10	2.82	1737.3	8.49	-895.2
20	1.31	846.8	8.76	-166.9
30	0.81	571.6	8.85	53.1
40	0.56	442.1	8.89	153.5
50	0.39	370.5	8.93	206.3
60	0.27	329.0	8.95	233.8
70	**0.17**	**308.9**	**8.97**	**242.8**
80	0.09	325.7	8.98	216.7

Glides to this landing location were not possible using turns at all bank angles. Although $10°$ and $20°$ banked turns preserve a higher GR, the additional flight distance required with such shallow turns resulted in excessive altitude loss and the inability to reach the landing location, as revealed by the negative final altitudes. Of the bank angles that enabled the airplane to reach its destination, the optimum bank angle for this scenario was approximately $70°$. Figure 11 presents curves of final altitude versus bank angle for each landing destination located at a different bearing from the airplane's original heading.

Optimum Bank Angles

In order to identify the optimum bank angle from each curve, second-order polynomials were fitted to the data for the three bank angles that resulted in the highest final altitudes for each glide to a specific destination, examples of which are shown in Figure 12 for final destinations located $10°$ to $90°$ from the airplane's original heading. Using the destination at $\phi_2 = 90°$ from Figure 12 as an example, its second-order polynomial curve fit resulted in Equation 28.

$$h_f = -0.0395908 \cdot \theta^2 + 4.0360093 \cdot \theta + 297.4067019 \tag{28}$$

The derivative of Equation 28 was set equal to zero and solved for θ, which revealed that the optimum bank angle for this scenario was $51°$. The process of differentiating a curve's polynomial, setting it equal to zero, and solving for the optimum bank angle was conducted for each curve. The results were then visualized, as seen in Figure 13 for the $GR = 10$; $6{,}000\ ft\ AGL/9\ NM$ scenario.

Figure 11

Final Altitude vs. Bank Angle for $GR = 10;\ 6{,}000\ ft\ AGL/9\ NM$

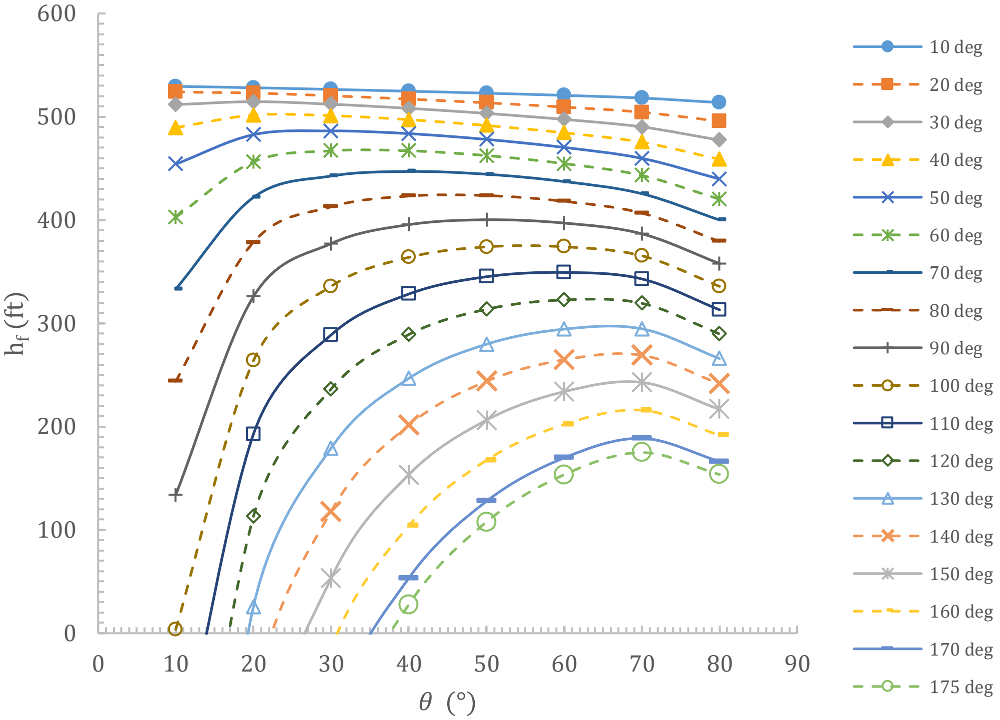


Figure 12

Final Altitude vs. Bank Angle Peaks for $GR = 10;\ 6{,}000\ ft\ AGL/9\ NM;$ *and* $\phi_2: 10° - 90°$

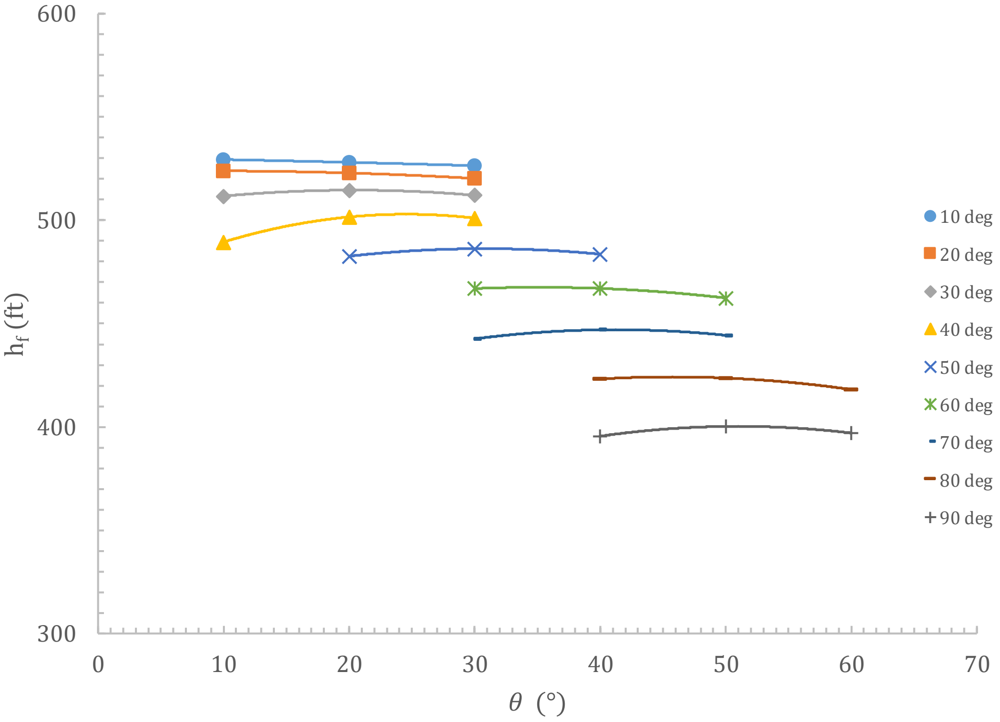
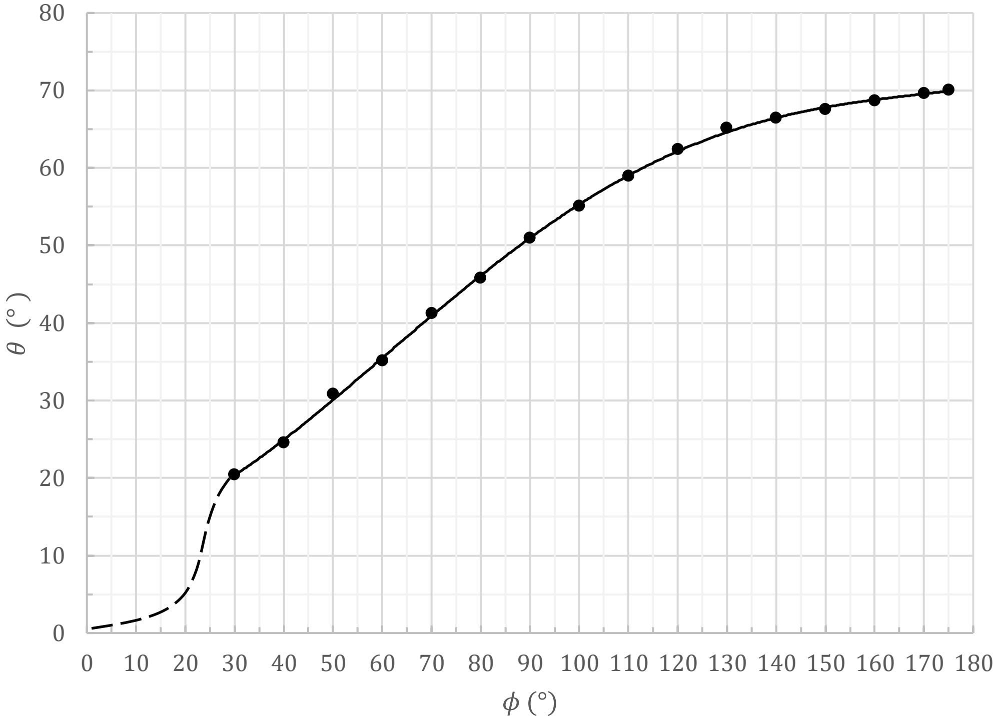


Figure 13
Optimum Bank Angle vs. Bearing to Destination for $GR = 10$; $6{,}000\ ft\ AGL/9\ NM$



Results

Upon completion of the process of calculating the final altitude upon arrival at the landing location (if possible) and identification of the optimum bank angle for each scenario, the data was compiled and in three plots corresponding to each of the three GR values as presented in Figures 14, 15, and 16.

Figure 14

Optimum Glide Angles for $GR = 8$

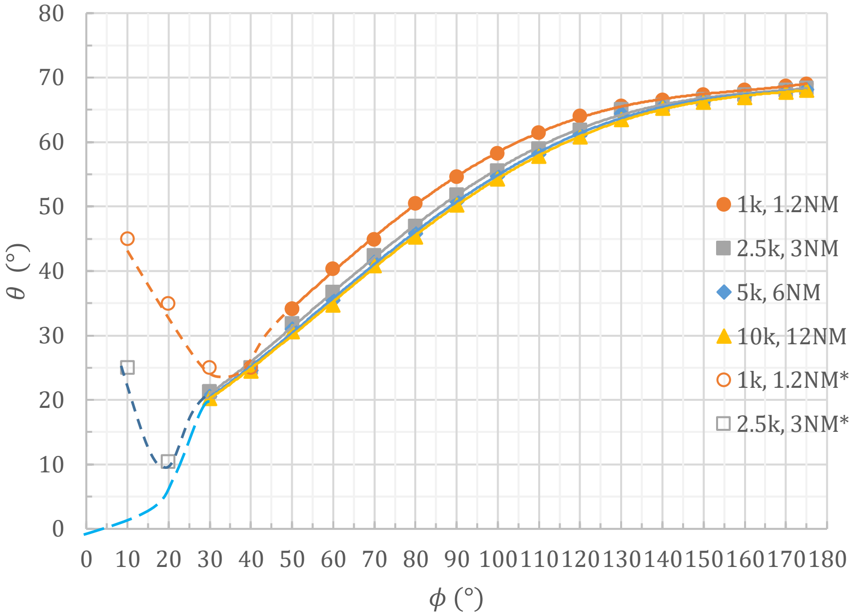


Figure 15

Optimum Glide Angles for $GR = 10$

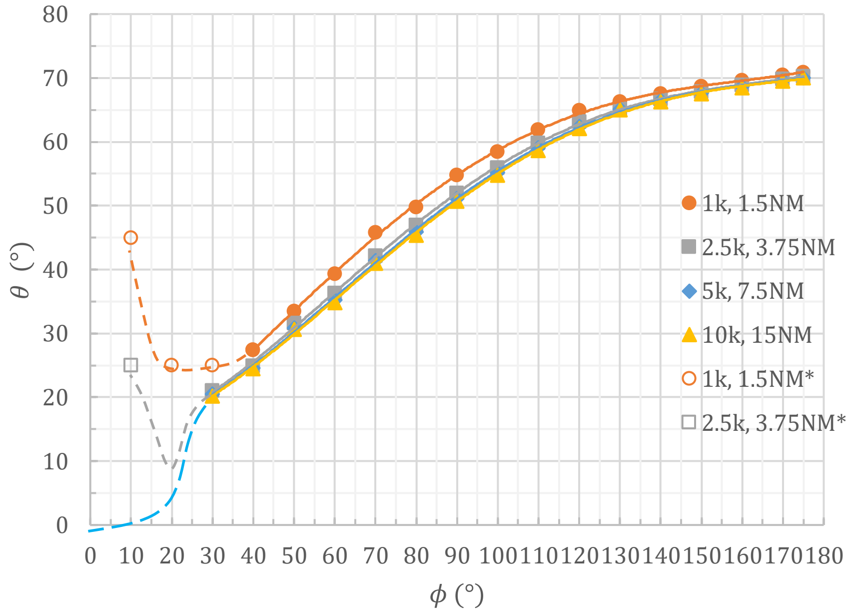
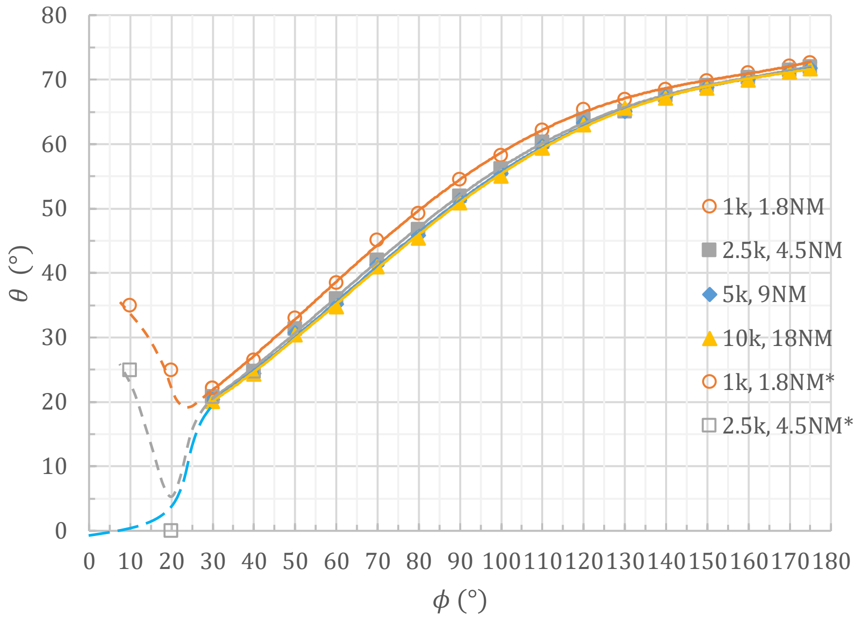


Figure 16

Optimum Glide Angles for $GR = 12$



The data clearly shows that the optimum bank angle (θ) resulting in the least altitude lost in a power-off glide is a strong function of the bearing to the landing location (ϕ) and a weaker function of the airplane's GR and its altitude at the beginning of the glide (h).

For all three GRs, the optimum θ increases as ϕ increases for $\phi \geq 35°$. Although the curves are highly nonlinear, in this range of ϕ, two distinguishable regions appear that can be linearly approximated. Upon visual inspection, the domain of $35° \leq \phi < 120°$ exhibits a nearly linear relationship. Above $120°$ the curves exhibit another nearly linear relationship, albeit with a lower slope. In the domain $35° \leq \phi < 120°$, the weaker functions of altitude and GR can be seen. For all GRs tested, glides from the lowest calculated altitude have up to a $5°$ higher optimum θ when compared to the glides from higher altitudes, and for glides from the same altitude, as the airplane's GR increased, so to did the optimum θ. This relationship was mostly limited to $\phi \geq 120°$ where the difference between optimum θ from the smallest to the largest GR was approximately $5°$. Using the aggregated data for glides from $1{,}000\ ft$, (arguably the most critical altitude tested) the linear relationship for $35° \leq \phi < 120°$ was identified and is presented in Equation 29.

$$\theta \cong 0.5\phi + 10° \tag{29}$$

Glides from higher altitudes require a slight modification of Equation 29 to account for the effect of altitude. Equation 30 approximates the effects of altitude (at least for the altitudes used in these calculations) on the optimum θ, where h_k is the airplane's altitude at the beginning of the glide in thousands of feet.

$$\theta \cong 0.5\phi + \frac{5°}{h_k} + 5° \tag{30}$$

The linear relationship for $\phi \geq 120°$ was also identified using the aggregated data for glides from $1{,}000\ ft$ and is presented in Equation 31.

$$\theta \cong 0.1\phi + 52° \tag{31}$$

The altitude functionality in this domain is much weaker than that in the previous domain and is approximated in Equation 32.

$$\theta \cong 0.1\phi + \frac{1°}{h_k} + 51° \tag{32}$$

The GR functionality in this domain is slightly more prominent than was demonstrated at lower values of ϕ. This addition is approximated using Equation 33.

$$\theta \cong 0.1\phi + \frac{1°}{h_k} + \left(\frac{GR-8}{2}\right)° + 51° \tag{33}$$

An example glide calculation using Equations 30 and 33 is as follows. Suppose the airplane being flown has a published GR of 10. Equation 30 remains unchanged, but Equation 33 is updated as shown in Equation 34.

$$\theta \cong 0.1\phi + \frac{1°}{h_k} + \left(\frac{10-8}{2}\right)° + 51° = 0.1\phi + \frac{1°}{h_k} + 52° \tag{34}$$

Adjustment of Equation 33 to Equation 34 could take place well before the flight begins since the GR is a published value for the airplane. At the time of an engine failure, the closest/best landing location is found to be on a bearing of 90° (either to the left or to the right) from the airplane's heading. This means that Equation 30 should be used. If the airplane is at $2{,}500\ ft\ AGL$, the calculation of the optimum bank angle is shown in Equation 35.

$$\theta \cong 0.5(90°) + \frac{5°}{2.5} + 5° = 52° \tag{35}$$

The regions of data in the domain for $\phi < 35°$, the optimum bank angle exhibits an inverse functionality with ϕ and is much more sensitive to altitude and GR. For altitudes up to $2{,}500\ ft\ AGL$ for all GRs, there is a value of ϕ below which optimum θ increases as ϕ decreases. As an example, the $2{,}500\ ft\ AGL$ curve on the $GR = 8$ graph (Figure 14) shows a minimum θ of 25° for $\phi = 35°$, below which the optimum θ increases to 45° for the lowest calculate bearing, $\phi = 10°$. All of the curves for glides at or below $2{,}500\ ft\ AGL$ exhibit the same tendency, with the bearing associated with the minimum bank able decreasing as both altitude and GR increase. At $\phi = 10°$ the $GR = 8$ and $GR = 10$ data shows an optimum θ of 45°, while the $GR = 12$ data shows an optimum θ of only 35°. At the next altitude for $\phi = 10°$, all GRs have an optimum θ of 25°. The highest two altitudes, for which calculations were made, have optimum θs that is less than 10° at $\phi = 10°$. Given the nature of the method of identifying the optimum θ presented in a previous section, no optimum value could be identified. The blue dashed curves in Figures 14-16 extending from the higher altitudes curves is the author's estimated curve fit taking into consideration 1) the shape of the lower altitudes' curves and 2) the fact that no bank angle is necessary for a landing location on a bearing of 0° (the origin). No simple functional relationship is obvious from the data in the domain of $\phi < 35^\circ$, so a different view of the data is necessary.

Figures 14-16 represent the optimum values of θ that will minimize the altitude lost for a glide on any bearing to a landing location (ϕ); however, the curves do not make clear whether or not glides using the optimum values of θ will result in a positive altitude at the landing location. The glides might not be possible. Tables 4, 5, and 6 present the optimum values of θ along with whether or not the glide would be possible $\left(h_f \geq 0\ ft\right)$ for all glides with GRs of 8, 10, and 12 respectively.

Table 4

Optimum θ with $GR = 8$

$\phi\ (^\circ)$	$\theta\ (^\circ, 1k, 1.2NM)$	$\theta\ (^\circ, 2.5k, 3NM)$	$\theta\ (^\circ, 5k, 6NM)$	$\theta\ (^\circ, 10k, 12NM)$
10	45.0	25.0	<10	<10
20	35.0	10.4	<10	<10
30	25.0	21.3	20.6	20.3
40	25.0	25.0	24.7	24.5
50	34.1	31.9	31.0	30.6
60	40.3	36.7	35.5	34.8
70	44.9	42.4	41.4	40.9
80	50.5	47.0	45.8	45.3
90	54.6	51.8	50.8	50.3
100	58.3	55.6	54.7	54.3
110	61.4	59.0	58.2	57.8
120	64.1	61.9	61.2	60.8
130	65.6	65.1	64.5	63.5
140	66.5	65.7	65.5	65.3
150	67.3	66.6	66.3	66.2
160	68.1	67.4	67.1	67.0
170	68.7	68.1	67.9	67.8
175	69.0	68.4	68.2	68.1

Note. Shaded values of θ indicate that the glide resulted in only negative altitudes; therefore, it was not possible. Blue values of θ indicate that the glide was possible; however, at least the lowest, if not several of the lowest, values of θ resulted in failed glides. Green values of θ indicate that the glide was possible; however, at least the lowest θ, if not several of the lowest, and at least the highest values of θ, if not several of the highest, resulted in failed glides. Black values of θ indicate that the glide was possible for all θ (10° − 80°).

Table 5

Optimum θ with $GR = 10$

$\phi\ (^\circ)$	$\theta\ (^\circ, 1k, 1.5NM)$	$\theta\ (^\circ, 2.5k, 3.75NM)$	$\theta\ (^\circ, 5k, 7.5NM)$	$\theta\ (^\circ, 10k, 15NM)$
10	45.0	25.0	<10	<10
20	25.0	<10	<10	<10
30	25.0	21.0	20.5	20.2
40	27.4	24.9	24.6	24.5
50	33.5	31.6	30.9	30.6
60	39.3	36.3	35.3	34.8
70	45.8	42.1	41.4	41.0
80	49.8	46.9	45.9	45.4

90	54.8	51.9	51.1	50.7
100	58.4	56.0	55.2	54.8
110	61.9	59.8	59.1	58.7
120	64.9	63.1	62.5	62.1
130	66.3	65.1	65.1	65.0
140	67.5	66.7	66.4	66.3
150	68.7	67.9	67.6	67.5
160	69.6	68.9	68.7	68.5
170	70.5	69.8	69.6	69.5
175	70.9	70.3	70.1	70.0

Note. Shaded values of θ indicate that the glide resulted in only negative altitudes; therefore, it was not possible. Blue values of θ indicate that the glide was possible; however, at least the lowest, if not several of the lowest, values of θ resulted in failed glides. Green values of θ indicate that the glide was possible; however, at least the lowest θ, if not several of the lowest, and at least the highest values of θ, if not several of the highest, resulted in failed glides. Black values of θ indicate that the glide was possible for all θ $(10° - 80°)$.

Table 6

Optimum θ *with* $GR = 12$

ϕ (°)	θ (°, $1k$, $1.8NM$)	θ (°, $2.5k$, $4.5NM$)	θ (°, $5k$, $9NM$)	θ (°, $10k$, $18NM$)
10	35.0	25.00	<10	<10
20	25.0	<10	<10	<10
30	22.2	20.8	20.4	20.1
40	26.5	24.8	24.5	24.4
50	33.0	31.4	30.8	30.5
60	38.5	36	35.2	34.8
70	45.2	42	41.3	41.0
80	49.2	46.8	45.9	45.5
90	54.5	52	51.3	50.9
100	58.3	56.2	55.5	55.1
110	62.2	60.3	59.7	59.4
120	65.4	63.9	63.3	63.0
130	66.9	65.1	65.1	65.6
140	68.5	67.6	67.4	67.2
150	69.9	69.1	68.8	68.7
160	71.1	70.4	70.1	70.0
170	72.2	71.5	71.3	71.2
175	72.7	72	71.8	71.7

Note. Shaded values of θ indicate that the glide resulted in only negative altitudes; therefore, it was not possible. Blue values of θ indicate that the glide was possible; however, at least the lowest, if not several of the lowest, values of θ resulted in failed glides. Green values of θ indicate that the glide was possible; however, at least the lowest θ, if not several of the lowest, and at least the highest values of θ, if not several of the highest, resulted in failed glides. Black values of θ indicate that the glide was possible for all θ $(10° - 80°)$.

Values in the table are coded using shading and text color. Shaded cells indicate that glides from those altitudes and to those bearings are not possible. Blue text indicates that the glides are possible; however, they are only possible when using higher bank angles. Turning with at least the lowest bank angle won't allow the airplane to reach its destination. Green text indicates that the glides are possible but not at the lowest or the highest bank angles. It indicates that several of the low and high bank angles will result in unsuccessful glides. Black text indicates that glides are possible from those altitudes and to those bearings and that they are possible throughout the range of tested bank angles $(10° - 80°)$.

From inspection of the tables, an obvious and expected result is that increased GRs provide more gliding options. Another obvious result is that within one $GR's$ data (i.e., Table 4), higher altitudes provide more gliding options. The data for glides from altitudes up to $2{,}500\ ft$ for all GRs shows that the lowest bank angles should be avoided for glides to destinations at low bearings, and glides to the locations at higher bearings (if possible) are only possible when avoiding the lowest and the highest bank angles.

Recall that Equation 30 applies to $35° \leq \phi < 120°$, and Equation 33 applies to $\phi \geq 120°$. The first three rows of Tables 4-6 are for $\phi < 35°$. The majority of glides described by these rows are optimized at extremely low bank angles but will still be possible at high bank angles (black text). An approximate functional relationship in this domain of low bearings is presented in Equation 36.

$$\theta \cong \phi - 10° \tag{36}$$

This equation only applies to glides from altitudes at or above $2{,}500\ ft$ and for bearings of no less than $20°$. The critical glides are from the lower altitudes and bearings, located in the upper left corner of the tables. These glides aren't possible when using the lowest bank angles and are optimized at bank angles of up to $45°$. The reason for this is that the lowest bank angles have high turn radii and will not allow an airplane to reach an intercept path to the landing location. A turn must be tighter to achieve an intercept path when the landing location is so close. These findings are in agreement with those of Rogers (1995) for low-altitude gliding turns. Equation 37 presents the criteria that enable a turn to an intercept course to be possible, where r is the turn's radius from Equation 15 and d is the airplane's distance from the landing location.

$$r \leq \frac{d}{2} \tag{37}$$

The most critical of the scenarios tested was a glide from $1{,}000\ ft$ to a landing destination on a bearing of $10°$ with an GR of 10 or less. These glides have an optimum bank angle of $45°$ and are not even possible at bank angles of less than $40°$ due to the inability of lower banked turns to achieve an intercept course. No simple functional relationship for optimum bank angle was developed for gliding turns to locations within the critical domains shown in the tables due to the highly nonlinear relationship between θ and r in Equation 15; however, a $45°$ banked turn will not only enable a successful glide in the critical domains, it will also work for glides from higher altitudes in this domain for any of the tested GRs.

Conclusions

It is common (and required) knowledge among pilots that in order to maximize power-off glide distance an airplane must be flown at its v_G. It seems to be less common (and not required) knowledge among pilots that an airplane's v_G is a function of its weight and that the published v_G only applies to the airplane at its $MTOW$. Adjusting a published v_G using Equation 11 is necessary to ensure that the highest $GR\ (a.k.a.\ \ L/D)$, and hence the maximum range, is achieved.

Even less known among pilots is that when a turn is required to make it to a safe landing location in a power-off glide, the bank angle used in the gliding turn can be optimized for maximum glide performance. It was shown that for glides requiring a turn to a landing location with a bearing greater than or equal to $120°$ from the airplane's heading, Equation 33 (reproduced here) provides a simplified approximation to the turn's optimum bank angle.

$$\theta \cong 0.1\phi + \frac{1°}{h_k} + \left(\frac{GR-8}{2}\right)° + 51° \tag{33}$$

The equation is simplified using an airplane's GR, after which the only inputs are the bearing to the landing location and the airplane's AGL altitude in thousands of feet. Due to the simple nature of Equation 33, it is perfectly suitable for mental math. As an example, an airplane with a GR or 10, which can be incorporated into the equation beforehand, loses its engine at $3{,}000\ ft$ with the best landing location on a $150°$ bearing. The simple nature of Equation 33 (e.g., multiplying by 0.1 only requires that the bearing's decimal point be moved once to the left) quickly reveals a $67°$ optimal bank angle for the turn. This example exposes the issue of bank angles exceeding $60°$. CFR 14, Part 23.3 (2011) prohibits normal category airplanes from being flown at bank angles that exceed $60°$; however, CFR 14 Part 91.3 (1989) allows a pilot in command to deviate from other regulations in order to deal with an emergency. In-flight engine failures are definitely emergencies. If turning to a safe landing destination during an engine-out glide is best performed with a bank angle higher than $60°$, regulations won't prevent it. Concerns associated with high bank angle turns are related to pilot skill while operating at unusual attitudes and high load factors. Pilot skills will be left to training and experience. The normal category load factor limit is an issue at bank angles above $74°$ for constant altitude turns. This is not an issue for gliding turns, since 1) load factors are lower when not maintaining altitude and 2) all of the optimum bank angles were less than $72°$.

For gliding turns to landing locations with bearings between $35°$ and $120°$, Equation 30 (reproduced here) provides an even simpler (independent of GR) approximation to the turn's optimum bank angle.

$$\theta \cong 0.5\phi + \frac{5°}{h_k} + 5° \tag{30}$$

As an example, an airplane loses its engine at $3{,}000\ ft$ with the best landing location on a $60°$ bearing. The simple nature of Equation 30 quickly reveals a $37°$ optimal bank angle for the turn.

For gliding turns to landing locations with bearings of less than $35°$, the optimum bank angle is approximated by Equation 36; however, the equation is limited to certain bearings and altitudes. Due to the critical low-bearing, low-altitude domain that has high optimum bank angles, all gliding turns to landing locations with bearings of less than $35°$ would be successful, albeit not optimized, when conducted with a bank angle of $45°$.

Recommendations

Using the information presented in this paper, the majority of which is the result of original research into optimum bank angles to be used during power-off glides, the author makes the following recommendations.

1. Digital avionics and flight management systems should incorporate real-time glide performance information to include:
    a. Displays of weight-corrected v_G using 1) an initial weight entered at the beginning of a flight by the pilot and 2) fuel flow measurements,
    b. Real-time glide range corrected for range losses due to turns in all directions using optimal bank angles, and
    c. The optimum bank angle to use during a power-off glide to an intercept course for a suitable landing location 1) that has been identified and selected by the pilot or 2) that has been selected by the system and presented to the pilot.

2. Pilot education/instruction and reference materials (i.e., course content, handbooks, and manuals) should present more detailed power-off glide performance information including:
    a. Use of Equation 11 for weight-correcting v_G along with recommending the options of 1) calculating the minimum possible v_G corresponding to the airplane's lowest possible weight for interpolation in-flight or 2) creating a graph similar to Figure 4 for quick reference in flight and
    b. Use of rule-of-thumb equations/guides for calculating optimum bank angle to include 1) Equation 33 for glides to bearings above $120°$, 2) Equation 30 for glides to bearings between $35°$ and $120°$, and 3) $45°$ for glides to bearings less than $35°$.

3. Flight training should include the practice of in-flight power-off glide scenarios that include 1) the identification of safe landing locations within glide range, 2) the calculation of optimum bank angles for glides to different bearings, and 3) turns to intercept courses.

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Collegiate Aviation Review
International

Volume 41 | Issue 1 Literature Review #1

7-8-2023

What Causes Aviation Sanctions? A Systematic Review

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Aviation sanctions have emerged as a pivotal concern for the sustainability of the aviation industry. Although extensive research has been done on the economic impact of aviation sanctions, there is a noticeable gap in the literature regarding the factors that precipitate such sanctions. Consequently, this study represents a significant contribution to aviation sector research by elucidating the key factors leading to sanctions. The research adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) review method, ensuring a rigorous and systematic approach. In this study, a meticulous selection process was employed, utilizing prominent databases such as Scopus and Web of Science, alongside supplementary databases including Science Direct and SAGE. Through a systematic analysis of these databases, a total of 21 relevant studies were identified. The review's findings revealed five overarching themes: safety, environment, terrorist attacks, political conflicts, and disease outbreaks. Furthermore, this research concludes by offering recommendations for future scholars. These recommendations serve as a valuable resource for further exploration and study in the field.

Recommended Citation:
Khairuddin, N. A., Sarmidi, T., Palil, M. R. & Khalid, N. (2023). What causes aviation sanctions? A systematic review. *Collegiate Aviation Review International,* 41(1), 209-227. Retrieved from https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/9475/8478

Introduction

The global aviation sector plays a crucial role in the global economy by connecting people, cultures, and businesses across continents. Over the years, the industry has experienced significant growth, as indicated by the continuous increase in the number of air passengers worldwide. According to a report released by the International Air Transport Association (IATA), the number of air passengers surpassed 4.3 billion trips in 2018 (IATA, 2019). The World Bank also highlights the substantial growth of the industry, with airline passenger numbers rising from 0.432 billion in 1975 to 4.233 billion in 2018. This trend has persisted since the 1970s, with a notable increase in passenger numbers since 2010 (World Bank, 2019). This growth can be attributed to several factors, such as rising disposable incomes, affordable airfares, expanding tourism, and globalization. All of these factors contribute to the interconnectedness of economies and the promotion of international trade and investment.

The aviation industry, like other sectors, faces challenges and pressures, including the imposition of restrictions and impediments on its activities. Aviation sanctions are specific economic measures frequently imposed by countries or entities on the aviation sector, encompassing air travel, aircraft manufacturers, and airlines (Gordon, 2011). These targeted measures aim to restrict various aspects of aviation activities, such as air travel routes, trade-in aircraft, and related components, as well as financial transactions. They serve specific objectives and exert pressure on targeted entities within the industry, driven by factors like political conflicts, aviation safety, terrorist attacks, environmental concerns, and disease outbreaks (Dube, Nhamo & Chikodzi 2021; Edelman 2015; Henderson 2009; Huliaras 2001; Latipulhayat & Ariananto 2012; Manuela & De Vera 2015; O'Connell 2015; Wu, Jiang & Yang 2018).

The consequences of aviation sanctions are directly felt in the air passenger market, leading to a decline in tourist arrivals, receipts, and international mobility (Manuela & De Vera, 2015; Seyfi & Hall, 2019; Yang, Tjiptono & Poon, 2018). Studies conducted by Manuela and De Vera (2015) and Yang, Tjiptono, and Poon (2018) highlighted the significant impact of these sanctions on the air passenger market, resulting in reduced tourist arrivals and subsequent economic losses in affected regions. Moreover, businesses reliant on international air transportation, such as the export and import industries, may encounter challenges in accessing global markets, hindering trade and impeding economic growth. The crucial role of aviation in facilitating economic growth and international connectivity further underscores the potential negative effects of restrictions within the aviation sector. Consequently, understanding the factors contributing to the imposition of aviation sanctions and their consequences is essential for policymakers, industry stakeholders, and researchers to formulate effective strategies that mitigate the negative impacts and foster sustainable growth in the aviation industry.

The Need for a Systematic Review

The aviation sanctions issues have received considerable critical attention. Over the last century, there has been tremendous growth in aviation sanctions, as well as numerous conceptual and empirical studies examining various aspects of aviation, including factors that contribute to the imposition of aviation sanctions. However, there is a lack of systematic review papers that comprehensively collect and analyze previous studies specifically related to aviation sanctions (Lohmann & Scott, 2018; Sanchez-Rebull & Campa-Planas, 2012; Spasojevic et al., 2018; Yadav & Dhingra, 2018). While existing reviews often focus on the relationship between aviation and other areas, such as tourism, developments in low-cost carriers, and air transportation, a comprehensive systematic review specifically addresses the factors leading to aviation sanctions worldwide has yet to be conducted. This study aims to fill this gap and provide an in-depth examination of sanctions in the aviation context. By conducting a systematic review, this study not only contributes to improving existing knowledge but also offers valuable guidance to industry stakeholders in making decisions to enhance and transform the aviation sector in their respective countries.

In general, systematic reviews, which are academic research papers that utilize a method called "proof synthesis" to investigate predefined questions (The Campbell Collaboration, 2017), play a crucial role in knowledge synthesis. These reviews involve gathering, analyzing, and synthesizing empirical data that meet specific criteria, with the ultimate aim of addressing research issues (Yannascoli et al., 2013). By systematically identifying and critically assessing relevant articles, systematic reviews offer a clear and rigorous approach to exploring well-defined research or review questions. Systematic reviews are recognized for their effectiveness, comprehensiveness, repeatability, and reduced bias compared to traditional literature reviews (Koutsos et al., 2019; Menexes & Dordas, 2019). Furthermore, systematic reviews provide several advantages over other approaches. They promote evidence-based conclusions by including all pertinent empirical data and adhering to pre-specified inclusion criteria (Snyder, 2019). Additionally, they enhance research integrity by employing transparent article retrieval procedures, focusing on broader research areas, and setting significant objectives that help mitigate research bias (Shaffril et al., 2019). The systematic review process is extensively described, facilitating replication, expansion, or updating of the review to align with current research needs (Koutsos et al., 2019).

To ensure the construction of a comprehensive and relevant systematic review, the selection of existing articles is guided by the main research question: what are the factors that contribute to the imposition of aviation sanctions? The primary objective of this analysis is to investigate and examine the variables that lead to the imposition of aviation sanctions. By conducting a systematic literature review of existing articles, this study aims to gather and analyze the available evidence. Through a comprehensive search strategy and rigorous inclusion criteria, this review will identify relevant journal articles that meet the research question's criteria. This rigorous approach enables a thorough examination of the selected articles and contributes to a more comprehensive understanding of the subject matter, at the same time providing valuable insights into the factors influencing the imposition of aviation sanctions.

The analysis is categorized into sections. Section 2 discusses the material and methods used to obtain the answer to the current research question. Section 3 dives into the general and main findings from factors that lead to aviation sanctions according to their respective themes. Section 4 is about the discussion of findings, and Section 5 contains suggested recommendations that may be helpful in future research. Finally, Section 6 concludes the overall systematic review.

Material and Methods

This section explains the four main sub-sections used in the current research reviews, namely guided review, resources, the systematic review process for selecting the articles, and data abstraction and analysis.

Guided Review

The current review is guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which is a widely recognized approach for conducting systematic reviews and meta-analyses (Moher et al., 2009). PRISMA provides a structured and transparent method for defining, selecting, and critically analyzing relevant issues in a systematic review. It ensures that the review incorporates essential components, such as a clearly formulated research question, systematic search strategy, study selection criteria, data extraction, quality assessment, data synthesis, and transparent reporting.

Systematic reviews, which involve the use of PRISMA, play a crucial role in the field of economics. They have become integral to policy-making and technology evaluation processes and are commonly published in health economics journals (Anderson, 2010). As such, it is relevant to study the PRISMA statement from an economic perspective. Recent studies in economics, such as those conducted by Saddiq and Bakar (2019) and Wang et al. (2018), have utilized PRISMA as a guideline. This methodology can be effectively employed to investigate the factors that lead to sanctions on the aviation sector worldwide. By employing the PRISMA framework, researchers can ensure a comprehensive and rigorous approach to conducting systematic reviews and meta-analyses in various fields, including economics. It facilitates transparency, replicability, and a thorough analysis of the relevant literature, thus enhancing the validity and impact of the review findings.

Resources

The review methods of this paper utilized two primary databases, namely Web of Science (WoS) and Scopus, which are widely recognized and extensively used in various scientific fields (Burnham, 2006; Guz & Rushchitsky, 2009). WoS is a publisher-independent global citation database that encompasses over 21,000 peer-reviewed academic journals, conference proceedings, and books from worldwide sources, including Open Access publications (Burnham, 2006). Scopus, which is the largest abstract and citation database, covers a broad range of sources, including book series, journals, and trade journals, with over 34,000 peer-reviewed journals across top-level subject areas (Burnham, 2006). There are several previous studies that have utilized Web of Science (WoS) and Scopus as databases for conducting systematic literature reviews in the field of aviation (Edward et al., 2021; Karthik et al., 2021; Pang et al., 2020). To enhance the probability of finding relevant papers, manual searching efforts were also conducted on additional established sources such as Science Direct and SAGE. Science Direct provides access to over 2,500 scholarly journals, including fully open-access publications and more than 39,000 reference books (Younger, 2010). Similarly, SAGE offers access to over 1,000 journal titles in health, materials, and social sciences, along with numerous professional society affiliations (Younger, 2010). By employing these databases and sources, the review process aimed to comprehensively cover a wide range of relevant literature in the field.

The Systematic Review Process for Selecting the Articles

Identification

The systematic review process consists of three main stages in choosing several relevant papers for the present study. The first stage was to identify keywords, which was followed by a search for related and comparable phrases using thesaurus, dictionaries, and previous research. After the appropriate keywords were established, search strings on the Scopus and Web of Science databases were created in April 2022 (refer to Table 1). A total of 977 articles from both databases were successfully reclaimed. Meanwhile, an additional 24 articles from other databases, namely Science Direct and SAGE, were identified through a manual search conducted using similar keywords. In the first stage of the systematic review process, 1,001 articles were retrieved in total.

Table 1
The Search String

Database	Search String
WoS	TS=(sanction* OR ban OR bans OR embargo* OR boycott* OR banned OR "airline* ban" OR "airline* bans" OR "flight* ban" OR "flight bans" OR "travel* ban*") AND TS=(airline* OR aviation* OR "air transport*" OR "passenger carrier*" OR "air cargo carrier*" OR "air cargo" OR "air freight*" OR "air travel*" OR "air passenger*" OR "air traffic" OR flight* OR airspace*)
Scopus	TITLE-ABS KEY ((sanction* OR ban OR bans OR embargo* OR boycott* OR banned OR "airline* ban" OR "airline* bans" OR "flight* ban" OR "flight bans" OR "travel* ban*") AND (airline* OR aviation* OR "air transport*" OR "passenger carrier*" OR "air cargo carrier*" OR "air cargo" OR "air freight*" OR "air travel*" OR "air passenger*" OR "air traffic" OR flight* OR airspace*)

Screening

There are several stages of screening. First, duplicate articles were identified and removed. This stage resulted in the omission of 458 articles. The researchers then screened 543 articles based on the inclusion and exclusion criteria specified in the second stage. The type of literature selected for review was specified to only journals. This implies that publications in the context of a systematic review, review, meta-analysis, meta-synthesis, book series, essay, journal chapter, or conference proceedings were omitted from these reviews. It should be noted that the review also focused only on articles published in English. Articles published in the fields of Social Sciences, Business, Management, Accounting, Economics, Econometrics, and Finance were chosen to increase the probability of receiving similar articles. Subsequently, the timeline of the review was also taken into account. It is crucial to note that this review also considered literature chosen within a specific timeline, which was the beginning of the year (1984-2022) in Web of Science, and the year (1927-2022) for Scopus. The timeline for these two databases is different because this study does not consider the criteria of the year of publication but the history of sanctions in the aviation sector. In total, 391 articles were excluded based on these criteria (Refer to Table 2), leaving 152 articles for the next step.

Table 2

The inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Literature type	Journal (research articles)	Conference paper, review, book chapter, short survey, note, book, business article, editorial, and letter
Language	English	Non-English
Subject area	Social Sciences, Business, Management and Accounting, and Economics, Econometrics and Finance	Other than Social Sciences, Business, Management and Accounting, and Economics, Econometrics and Finance

Eligibility

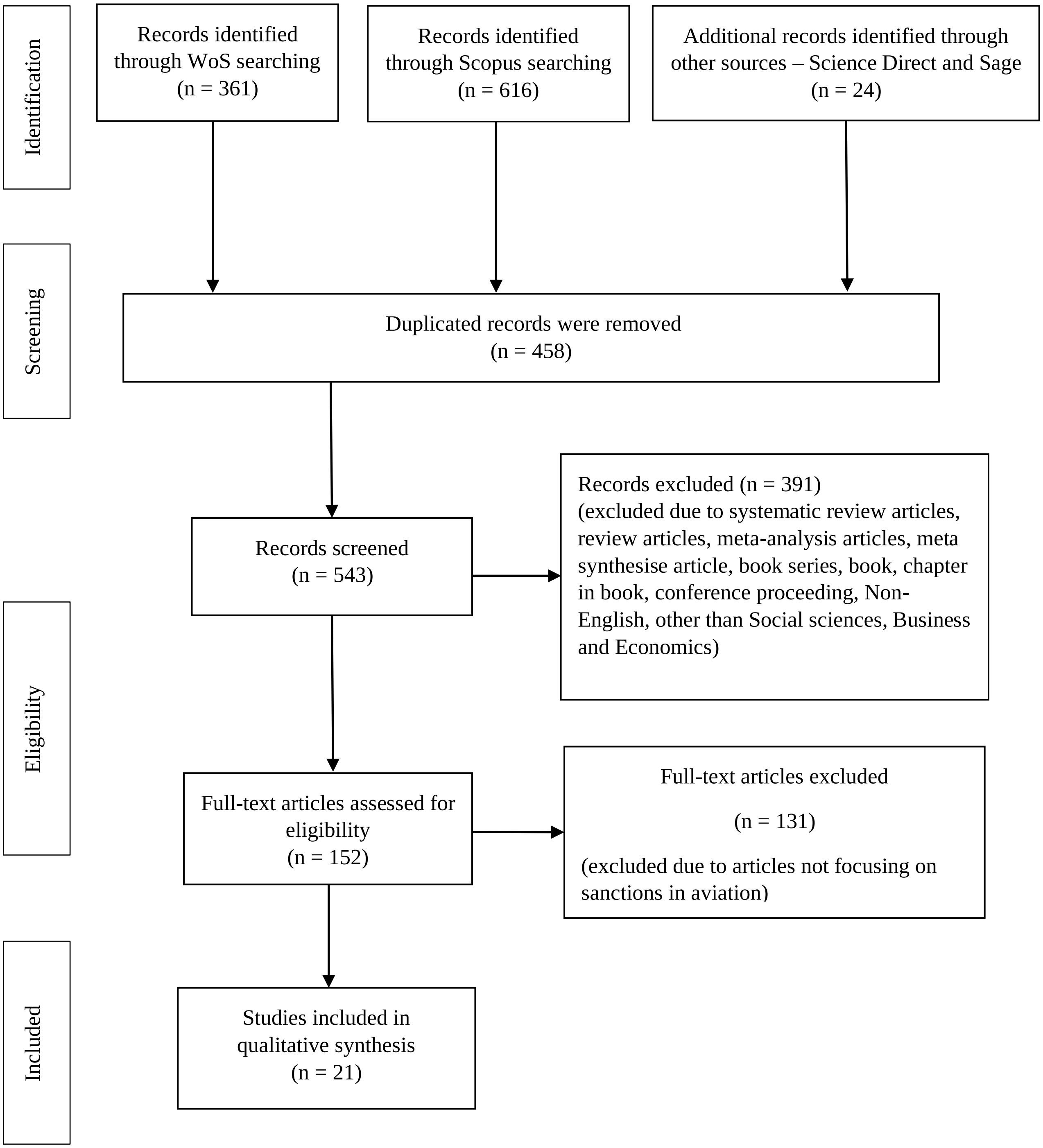
In the third stage, known as eligibility, a total of 152 items were compiled. This critical process entailed the authors conducting a meticulous manual review, specifically by reading the titles and abstracts of the articles, to ensure that the remaining articles after the initial screening process conformed to the predefined criteria. This was performed to verify that they met the inclusion criteria and were eligible for use in this study to achieve the current research objectives. This process excluded 131 articles due to their lack of reliance on empirical data, inadequate definition of the methodology section, emphasis on hard sciences rather than social sciences, and insufficient focus on sanctions within the aviation industry. Finally, a total of 21 remaining articles were ready to be analyzed.

Data Abstraction and Analysis

The final process is data abstraction and analysis. The remaining articles were assessed and analyzed using a systematic approach. The data were extracted by initially reading through the abstracts and then thoroughly reviewing the full articles to identify relevant themes. In the first phase of this process, the authors carefully analyzed a selected group of 21 articles to extract statements or data related to the research questions. To develop a meaningful classification system, the researcher employed a coding process in the second phase, wherein raw data was transformed into usable data by identifying concepts, values, or ideas for more practical and interconnected knowledge (Patton, 2002; Sandelowski, 1995). The end result of this analysis has led to the identification of five main themes: safety, environment, terrorist attack, political conflict, and outbreak of disease.

Figure 1

Flow diagram of this study (adapted from Moher et al. 2009)



Throughout this research, the team of researchers actively collaborated together by reading and thoroughly analyzing each article. Together, they identified and extracted the relevant themes that emerged from the data. Once these themes were identified, the researchers took an additional step to ensure their validity and applicability within the aviation domain. They presented the results to domain experts, seeking their professional opinions on the relevance of these themes within the aviation field. By engaging with experts, the researchers were able to obtain valuable insights and validate the alignment of the identified themes with the specific context of aviation.

Results

There are two types of results outlined below. Firstly, the general findings and background of the study included in the review are presented, encompassing the year of publication and the types of aviation sanctions examined. Secondly, the main findings are presented, focusing on the factors that contribute to aviation sanctions.

General Findings

In the context of this study, the articles included in the review span across different years of publication. In 2022, Kumari et al. (2022) published an article, followed by Munawar et al. (2021) in 2021. Four articles were published in 2020, namely Iacus et al. (2020), Arellana et al. (2020), Marquez & Cantillo (2020), and Gossling et al. (2020). Additional articles from 2020 including Scott & Hall (2020), Maheshwari & Goyal (2020), Wu et al. (2020), and Jiang & Yang (2020) were published. In 2018, Wu et al. (2018) published an article, while Mhlanga et al. (2017) and Steyn & Spencer (2017) published articles in 2017. Several articles were published in 2015, including Manuela & de Vera (2015), Petzel et al. (2015), Edelman (2015), and O'Connell & Vanoverbeke (2015). Other articles include Daramola (2014) in 2014, Latipulhayat & Ariananto (2012) in 2012, O’Connell (2011) in 2011, and Henderson (2009) in 2009. Reitzfeld & Mpande (2008) and Henderson (2008) published articles in 2008, Huliaras (2001) in 2001, Pirie (1990) in 1990, and Griffiths (1989) in 1989 (see Figure 2). Furthermore, the review identifies two types of aviation sanctions, specifically flight bans and liquid bans. The findings indicate that 19 articles discussed flight bans, while two articles focused on liquid bans (see Table 3).

Main Findings

This section will discuss the factors that lead to the imposition of sanctions on aviation. A total of 21 past research identified as themes for the current review focused on factors that led to aviation sanctions in this case. Among them are safety issues (9 studies), political conflicts (4 studies), environment (1 study), terrorist attacks (1 study), and outbreak disease (6 studies) (Refer to Table 4).

Safety

Flight bans are frequently implemented in response to safety concerns involving countries or airlines. Various security issues can lead to restrictions on a nation's flight systems and operations, including non-compliance with international aviation safety standards set by the International Civil Aviation Organization (ICAO). When a country's civil aviation safety standard is categorized as Category 2 (unsafe), the European Union takes action by prohibiting the national carrier from entering its airspace. For instance, both the Philippines and Indonesia have been banned from operating in the European Union airspace (Henderson, 2009; Latipulhayat & Ariananto, 2012; Manuela & de Vera, 2015; O'Connell, 2015). Similarly, the European Union imposes a ban on airlines from third-world countries if they fail to meet the established safety criteria (Reitzfeld & Mpande, 2008). African and Zimbabwean airlines, for example, are prohibited from operating in the European Union due to safety concerns (Mhlanga et al., 2017; O'Connell, 2011). Furthermore, safety issues such as a high frequency of accidents have also led to the imposition of flight bans. A study conducted by Daramola (2014) highlighted the Nigerian government's ban on the use of BAC 1-11 aircraft due to its frequent crashes.

Table 3

Types of Aviation Sanctions

Authors	Flight Ban	Liquid Ban
Griffiths (1989)	/	
Pirie (1990)	/	
Huliaras (2001)	/	
Reitzfeld & Mpande (2008)	/	
Henderson (2008)		/
Henderson (2009)	/	
O’Connell (2011)	/	
Latipulhayat & Ariananto (2012)	/	
Daramola (2014)	/	
O'Connell (2015)	/	
Manuela & de Vera (2015)	/	
Petzel et al. (2015)		/
Edelman (2015)	/	
Mhlanga et al. (2017)	/	
Wu et al. (2018)	/	
Arellana, Marquez, & Cantillo (2020)	/	
Gossling, Scott, & Hall (2020)	/	
Iacus et al. (2020)	/	
Maheshwari & Goyal (2020)	/	
Munawar et al. (2021)	/	
Kumari et al. (2022)	/	

Environment

Aviation sanctions resulting from environmental issues have been studied by previous researchers.

This is shown by the study conducted by Latipulhayat and Ariananto (2012), in which the EU bans all flights that do not comply with the EU emission Trading Scheme. This is due to the EU-ETS covering some 4,000 aircraft operators that arrive and depart in the EU starting in 2012. Similar to industrial facilities, airlines will acquire tradable permits covering certain limits of CO2 emissions from their flights each year. Failure to comply with the EU emission Trading Scheme will result in the restriction of the said country’s airlines by the European Union (Latipulhayat & Ariananto, 2012).

Terrorist Attacks

Factors such as terrorist attacks have been known to trigger significant aviation sanctions. These attacks can lead to the imposition of restrictions and penalties on airlines involved, affecting their operations and access to certain airspace. The occurrence of terrorist attacks during flights has raised concerns globally. For instance, the PanAm airstrike carried out by terrorists from Libya resulted in the imposition of United Nations (UN) sanctions, including flight prohibitions, against Libya (Huliaras, 2001). These incidents highlight the necessity for robust aviation security measures. To mitigate the risk of liquid-based terrorist threats, regulations limiting the quantity of liquid allowed on board have been enforced, typically restricting passengers to containers of 100 ml or less (Petzel et al., 2015). Furthermore, a terrorist incident in 2006 that disrupted UK aviation services prompted authorities to implement restrictions on the amount of liquid passengers can carry, beyond which is strictly prohibited (Henderson, 2008).

Political Conflict

Issues such as political conflicts can prompt a country to implement sanctions in response to governmental tensions. This also applies to the aviation sector, where sanctions are employed as a measure in times of international conflict. An illustrative example of such conflicts is the political strain between countries beyond the southern African peninsula stemming from the Apartheid conflict in South Africa (Griffiths, 1989; Pirie, 1990). As a result, Algeria, Egypt, Ethiopia, Libya, Sudan, and Angola imposed a comprehensive ban on South African aircraft, affecting all airlines serving South Africa (Pirie, 1990). Simultaneously, the United States restricted South African Airways (SAA), and Iberia terminated scheduled flights to South Africa due to the ongoing conflict (Griffiths, 1989). Moreover, the political conflicts between the United States and Russia have led to a ban on all Russian-owned Aeroflot flights to the United States (Edelman, 2015). Additionally, the political issues arising from the 1949 civil war between Mainland China and Taiwan resulted in a prohibition on direct flights between these two countries which were imposed by their respective governments (Wu et al., 2018). Thus, these aforementioned cases exemplify how aviation can be utilized as a tool in response to international political conflicts.

Outbreak Disease

The outbreak of Coronavirus Disease 2019 (COVID-19) on a global scale has resulted in the implementation of aviation sanctions. The prevention of disease transmission has been recognized as a key factor behind flight bans, necessitating the suspension of air travel to contain the spread of the virus across borders. Countries have undertaken significant measures, such as the closure of national borders as well as the reduction of air travel and related activities in the aviation industry, including tourism and hospitality (Arellana et al., 2020; Gossling et al., 2020; Iacus et al., 2020; Kumari et al., 2022; Maheshwari & Goyal, 2020; Marquez & Cantillo, 2020; Munawar et al., 2021). These restrictions have had a profound and adverse impact on the transportation sector, particularly in aviation.

Table 4
The main themes

Authors	Safety	Environment	Terrorist attack	Political conflict	Outbreak Disease
Griffiths (1989)				/	
Pirie (1990)				/	
Huliaras (2001)			/		
Reitzfeld & Mpande (2008)	/				
Henderson (2008)			/		
Henderson (2009)	/				
O’Connell (2011)	/				
Latipulhayat & Ariananto (2012)	/	/			
Daramola (2014)	/				
O'Connell (2015)	/				
Manuela & de Vera (2015)	/				
Petzel et al. (2015)			/		
Edelman (2015)				/	
Mhlanga et al. (2017)	/				
Wu et al. (2018)				/	
Arellana et al. (2020)					/
Gossling et al. (2020)					/
Iacus et al. (2020)					/
Maheshwari & Goyal (2020)					/
Munawar et al. (2021)					/
Kumari et al. (2022)					/

Discussion

Aviation sanctions pose a significant global challenge, underscoring the need to identify the factors that contribute to their imposition. The objective of this systematic review is to analyze previous research and identify the key issues that lead to aviation sanctions. Based on an extensive search of two main databases, a total of 21 articles were found to be relevant to the factors influencing aviation sanctions. The review identified five major themes that emerged from the analysis: safety, environment, terrorist attacks, political conflicts, and outbreak of diseases.

One of the primary factors leading to aviation sanctions is safety-related concerns. Flight bans, which are commonly implemented as sanctions, often target countries or airlines with safety problems. Various security-related cases can result in the banning of airlines from operating in a specific country. One such case is air safety downgrade, which occurs when the Federal Aviation Administration (FAA) determines that a flight fails to comply with the international aviation safety standards established by the International Civil Aviation Organization (ICAO), thereby classifying the flight as unsafe. Non-compliance with these safety standards can lead to a downgrade of a country from Category 1 (safe) to Category 2 (unsafe). Instances of such downgrades have been observed in several countries, including Thailand, the Philippines, and Indonesia. Furthermore, as a result of the air safety downgrades, the European Union has taken measures to ban national airlines from entering its airspace. European Union member countries possess the authority to prohibit airports that are believed to be unsafe from operating within their airspace (Henderson, 2009). Similar scenarios have been witnessed in the case of the Philippines and Indonesia, where both countries were banned from operating in the airspace of the European Union (Henderson, 2009; Latipulhayat & Ariananto, 2012; Manuela & de Vera, 2015; O'Connell, 2015). Additionally, the European Union has imposed bans on airlines from third-world countries flying within its airspace (Reitzfeld & Mpande, 2008). For example, African and Zimbabwe Airlines have been prohibited from operating in EU airspace due to safety concerns (O'Connell, 2011; Mhlanga et al., 2017). Moreover, security issues such as the frequency of accidents can also contribute to sanctions within the aviation sector. A study conducted by Daramola (2014) highlighted the Nigerian government's ban on the use of BAC 1-11 aircraft due to their proneness to accidents. Despite the fact that flying is generally considered one of the safest modes of transportation, aviation mishaps can have catastrophic consequences in terms of human mortality, damage to aircraft and ground infrastructure, and the erosion of customer trust.

Political conflicts constitute another significant factor that leads to the imposition of aviation sanctions. In certain cases, sanctions on aircraft are driven by political events rather than economic considerations, such as poor product quality (Heilmann, 2016). For example, the political tension between Africa and several countries in the 1970s, arising from the issue of Apartheid in South Africa, led to the closure of airspace to South African aircraft by Algeria, Egypt, Ethiopia, Libya, Sudan, and Angola. These countries imposed a blanket ban on all airlines serving South Africa due to political conflicts (Pirie, 1990; Griffiths, 1989). Additionally, the United States imposed sanctions on South African Airways (SAA) airlines, and Iberia terminated its scheduled flights to South Africa as a result of the conflict (Griffiths, 1989). Similarly, political conflicts between the United States and Russia have resulted in the United States banning all Russian Aeroflot flights to its country (Edelman, 2015). Likewise, the political conflict between Mainland China and Taiwan, which has been strained since the 1949 civil war, led to sanctions where direct flights between the two countries were banned by their respective governments (Wu et al., 2018). These factors indirectly affect the tourism industry as tourism and air transport are interrelated sectors (Duval, 2013). This bilateral relationship between tourism and air transport is evident in the connection between air transport passengers and tourist travel services (Khan et al., 2017).

Terrorist attacks also contribute to the imposition of aviation sanctions. Given the interconnectedness of the growing aviation sector across countries in the global economy, terrorist attacks have a significant impact on the industry worldwide. The terrorist attacks on September 11, 2001, in the United States aimed to harm global security and the US economy, relied heavily on aviation (Price & Forrest, 2016). As a response, two aviation sanctions were implemented to address the issue of terrorist attacks based on the study's findings. First, the United Nations imposed a flight ban on Libya (Huliaras, 2001). Second, liquid bans were enacted, restricting passengers to 100 mL liquid containers on board to safeguard aviation security from terrorist attacks using liquid explosives (Petzel et al., 2015). Similar sanctions were also introduced in the UK, where passengers were prohibited from carrying liquids exceeding specified limits, following a terrorist incident that disrupted UK aviation services in 2006 (Henderson, 2008). The results of previous studies underscore the clear and severe challenge that terrorist attacks pose to aviation security.

In addition to the aforementioned factors, another significant issue that has been extensively debated in previous studies is the environment. Latipulhayat and Ariananto (2012) highlighted that the European Union (EU) has imposed a ban on flights that do not comply with the EU Emission Trading Scheme (ETS). The EU's Emission Trading System is a long-standing initiative whereby energy-intensive businesses, including electric utilities, are allocated carbon emission quotas by the EU Commission and national governments (Niels et al., 2011). According to Latipulhayat and Ariananto (2012), the EU enforces the ban on flights that do not adhere to the EU Emission Trading Scheme (ETS). This is primarily driven by the fact that the EU-ETS encompasses approximately 4,000 aircraft operators engaged in landing and departing within the EU.

The COVID-19 pandemic has had a profound impact on nearly every industry worldwide, bringing many of them to a halt. It has resulted in widespread travel bans and movement restrictions, significantly affecting the transportation sector, particularly aviation. Although travel bans are temporary and have initially reduced mobility, they are expected to have lasting effects, potentially leading to permanent job losses for many individuals (Maheshwari & Goyal, 2020). For instance, a study conducted by Arellana et al. (2020) found that freight trips decreased by nearly 38 percent, causing severe financial crises for transportation service providers. Furthermore, these restrictions have had a considerable impact on air travel. A study conducted in Australia revealed a drastic drop in passenger numbers, with only 69,000 passengers recorded in April 2020 compared to 3.5 million passengers in April 2019 (Munawar et al., 2021). Moreover, the effects of the pandemic extend beyond the aviation industry, significantly impacting global GDP, tourism, and the hospitality sector (Gossling, Scott & Hall, 2020; Iacus et al., 2020; Kumari et al., 2022). Consequently, the early implementation of flight restrictions by countries has proven to be an effective measure in curbing the spread of the pandemic (Zhang et al., 2020).

Recommendations

The findings of the current study and its systematic review approach have generated several recommendations that can contribute to future research in the field. Firstly, it is recommended that future scholars place greater emphasis on investigating the impact of aviation sanctions, as previous studies have primarily focused on examining the factors and types of sanctions imposed without delving into their effects. This knowledge gap regarding the consequences of aviation sanctions necessitates further empirical research to provide policymakers with a more comprehensive understanding of their outcomes. Thus, there is a need for comprehensive studies that explore the specific effects of each sanction in order to offer a more nuanced and complete assessment of their implications.

Moreover, the systematic review revealed that safety and political conflict were the most extensively studied issues among the 21 papers analyzed. This finding underscores the significance of these factors, suggesting that they are pivotal considerations in the context of aviation sanctions. Given that aviation can serve as a policy tool in international conflicts, political conflicts frequently prompt the imposition of aviation sanctions. Additionally, the high stakes involved in aviation operations, where countless lives are at risk, underscores the criticality of safety in this industry. Therefore, future research should prioritize investigations related to safety and political conflict to further advance our understanding of these key issues.

A noteworthy observation arising from this research is the paucity of studies specifically focused on aviation sanctions. This is evident from the limited number of published articles dedicated to exploring aviation sanctions, with only one paper published annually, except for the years 2008, 2015, and 2020. This dearth of research underscores the pressing need to address the topic of aviation sanctions, particularly in light of the expanding demand and supply of industrial air transportation in contemporary times. Thus, future research endeavors should pay greater attention to this crucial area to meet the growing demand for knowledge in the field of aviation sanctions.

In conclusion, this systematic review approach offers valuable recommendations for future research in the field of aviation sanctions. By emphasizing the investigation of their impact, prioritizing safety and political conflict as key factors, and addressing the research gap surrounding aviation sanctions, future scholars can contribute to a deeper understanding of this important and complex topic. Ultimately, a comprehensive body of research on aviation sanctions will provide policymakers with the necessary insights to make informed decisions, ensure the safety and resilience of the aviation industry, and promote sustainable economic growth.

Conclusions

The aviation sector plays a crucial role in stimulating economic activity and contributing to overall economic growth. It serves as a catalyst for various industries, such as tourism, trade, and business, and facilitates global connectivity and mobility. However, the rapid growth of this sector exposes it to challenges, particularly from aviation sanctions that have the potential to disrupt the industry's globalized nature. These sanctions, imposed for various reasons such as safety, environmental concerns, political conflicts, or others, pose significant risks and implications for both the aviation sector and the broader economy. In light of these challenges, the objective of this study is to investigate the factors that contribute to the imposition of aviation sanctions through a systematic literature review.

This systematic literature review has several significant contributions. Firstly, it builds upon and enhances existing research by providing insights into the most dominant or frequently observed factors that lead to the imposition of sanctions in the aviation sector. By identifying and analyzing these factors, this review serves as a valuable resource for understanding the patterns and trends found in previous studies on aviation sanctions. Secondly, the review contributes to the methodological aspects of research in this field by ensuring greater transparency, expanding the scope of studies included, promoting objectivity, and reducing implicit research bias. These methodological improvements enhance the overall quality and reliability of reviews conducted in the field of aviation sanctions. Moreover, the review emphasizes the importance of critically evaluating the quality of evidence in studies, as highlighted by Mallett et al. (2012). By encouraging researchers to engage in this critical evaluation, the review aims to enhance researchers' comprehension of the existing research landscape and contribute to the advancement of knowledge in the field of aviation sanctions.

Lastly, the findings of this systematic literature review hold valuable implications for policymakers. By gaining insights into the factors that contribute to aviation sanctions, policymakers can develop effective strategies to address the challenges associated with such sanctions in the aviation sector. This review serves as a comprehensive and valuable resource that improves our understanding of the factors influencing aviation sanctions, enhances research methodologies, and provides policymakers with valuable insights to guide their decision-making processes. Overall, this study's systematic literature review contributes to the advancement of knowledge in the field of aviation sanctions and holds practical significance for the aviation industry, policymakers, and researchers.

Acknowledgment

This research is supported by the Cabaran Perdana Research Grant, UKM [DCP-2018-002/1]

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