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OBJECTIVES

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

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

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

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Pan-Caribbean Airlines: Unlocking Regional Aviation Potential

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The Caribbean's air transport system is facing significant challenges, including operational fragmentation, excessive costs, and inadequate inter-island connectivity. These challenges limit its ability to support the region's heavily tourism-dependent economies. This research evaluates whether consolidating small Caribbean airlines into a single or virtual Pan-Caribbean carrier could transform regional air travel. Based on financial analysis, historical traffic data, and case comparisons with airline mergers in South America and the US, the paper simulates the anticipated efficiencies resulting from route consolidation, fleet standardization, and common operational services. The research concludes that consolidation may create a regional GDP impact of up to \$3.3 billion and generate over 200,000 new jobs. Research highlights regulatory harmonization, stakeholder coordination, and governance reforms as essential conditions for success. Despite transparency challenges, a unified Caribbean airline offers a compelling path to regional economic integration, improved connectivity, and long-term sustainability in aviation.

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Introduction

Air Connectivity in the Caribbean

The Caribbean is a diverse region of island states and territories and consists of independent states like Jamaica, Barbados, Trinidad and Tobago, the Bahamas, and the Dominican Republic, as well as those territories in association with other states, including Puerto Rico (USA), Martinique (France), and Aruba (Netherlands) (Richardson, 2023). In contrast to this complex geographic and political landscape, connectivity, particularly through air travel, is of the utmost importance in linking the region internally and with the rest of the world. The International Air Transport Association (IATA) reports a 7.7% year-over-year increase in Caribbean air traffic in early 2024 (Karp, 2025). Compared to 2014, seat availability has risen by 31%. However, many Caribbean islands lack direct flight options, requiring travelers to connect through major hubs like Miami or Panama City (Karp, 2025). Given the lack of land connections and tourism's growing economic importance, stronger air links are crucial for regional development and shared prosperity. However, one of the region's most considerable challenges is reaching its full air transportation potential.

Problems from the dismal financial performance of Caribbean airlines

The Caribbean airline industry faces a fundamental structural problem: fragmentation among small, inefficient national carriers that operate in a region with weak home markets and intense connectivity requirements. Burdened by high operating costs, fleet diversity, and the lack of strategic coordination, added to by government ownership and poor economies of scale, these carriers cannot compete effectively. As a result, Caribbean airlines remain unprofitable and are unable to meet the region's growing demand for reliable, affordable air transport, and the market is increasingly dominated by foreign low-cost carriers.

The necessity of research for airline consolidation

To address these issues, this paper explores a consolidated Pan-Caribbean Airline System: an ambitious undertaking to unify the region's ailing flag carriers into a coherent network, thereby rationalizing operations, efficiently utilizing fleets, and fostering regional cooperation for improved connectivity, reduced costs, and substantial economic benefits. This integration could enable Pan-Caribbean Airline System to expand its scale and network, efficiently allocating capacity, achieving cost efficiencies, and gaining regional pricing power. Government benefits would include assured interisland connectivity, increased mobility, cessation of government subsidies, and taxpayer savings. A similar concept has been successfully tested in South America with LATAM and Avianca (now Abra Group).

The possible positive impacts are immense and extend far beyond aviation. A successful Pan-Caribbean Airline System would foster regional economic integration, uniting Caribbean nations and opening new opportunities for trade, investment, and cultural exchange. Additionally, it would help in utilizing international tourism demand while simultaneously improving intraregional mobility. Unification would also minimize aviation's carbon footprint by streamlining routes and reducing redundancy, promoting greener travel.

In conclusion, this consolidation will enable Pan Caribbean Airlines to soar into the next Level of the Airline System. As the Caribbean seeks to compete in the global tourism marketplace, a unified and advanced air transport arrangement could form the basis for continued success and expansion in the years to come.

Background and context

Overview of the Caribbean airline industry

The Caribbean airline industry is fragmented, comprising a few local carriers dispersed across a vast region, which faces demanding connectivity obligations but weak home base markets. Internal inefficiencies, including high operating costs from short-range flights, external taxes/fees, and non-homogeneous fleets, strain airline finances. A lack of alignment between airline owners and management teams frequently leads to conflicting priorities: owners might concentrate on short-term financial goals, but management might aim for longer-term operating efficiency and strategic development. Such a mismatch, combined with volatile and short-term planning, weakens consistent decision-making and organizational resilience. Collectively, these issues result in high operational expenses, expensive tickets, and continuous unprofitability, preventing the region from fully capitalizing on its aviation potential for economic growth and tourism. Meanwhile, intensified foreign competition for inbound tourist traffic relegates Caribbean carriers to niche players serving home customers or limited intra-Caribbean passengers, leading to low load factors, low yields, and unprofitability.

Foreign carriers, offering superior products to foreign vacationers, have gained dominant market share at the expense of Caribbean airlines. This dominance has been further strengthened by the consolidation, entry, and expansion of Low-Cost Carriers (LCCs) and Ultra-Low-Cost Carriers (ULCCs). Conversely, Caribbean carriers, with their relatively high-cost structures (partially due to small size), face intense price competition. The relatively small and spread-out inter-Caribbean market, combined with low overall business traffic, depresses both load factors and yields. Furthermore, government ownership often results in slow responses, unstable management, and poor long-term survivability prospects.

Role of tourism and economic reliance on air transport

Air transport plays a significant role in the economies of island nations, with international and regional air travel leading to economic prosperity and cultural exchange. For these economies that depend on tourism, the airline would serve as the lifeblood of their transportation function in tourism and economic development. This calls for ensuring a stable flow of visitors through regional connections into source markets such as the United States, Canada, and Europe, achieving market diversification toward seasonality. While intraregional travel is essential for locals and visitors with multi-destination experiences, access from abroad into the region remains a headache for many Caribbean nations. Most smaller islands have no direct flights from primary international sources and depend on key regional hubs to transfer passengers from major global markets: Barbados, Trinidad, Jamaica, and Antigua.

Performance challenges facing Caribbean carriers

These systemic inefficiencies hinder the tourism sector from realizing its full potential and broader economic opportunities. In particular, the lack of proper transportation infrastructure is injurious to the tourism industry, which is the mainstay of most Caribbean economies. International visitors are often forced to take flights that do not provide direct service, and residents and tourists alike find access to the variety of the Caribbean difficult. In contrast, regions like Hawaii and the Greek Islands offer a better-integrated system due to their numerous well-integrated air systems and multi-destination travel options for tourists seeking to maximize revenues, which is not as readily available to the relatively poorly interconnected Caribbean economies.

Literature Review

Air transport and tourism interrelationships

The Caribbean airline sector is beset by numerous challenges to its viability and growth. This literature review examines the significant challenges facing Caribbean airlines. It analyzes the factors driving consolidations in the airline industry and their impacts, referencing various scholarly articles, industry reports, and studies. Over the last decade, numerous studies have highlighted the growing challenges faced by the Caribbean airline industry. The factors that have come together to influence the sector include market structure, competition, and sustainability concerns (Yarde & Jönsson, 2016). A systematic review of the literature on air transport and tourism found that the interrelationship between aviation and tourism is an area of growing interest, with a specific focus on air route and service development, passenger experiences, low-cost carriers, and the implications of new direct long-haul flights (Spasojevic et al., 2018). One of the most significant problems confronting the Caribbean airline industry is economic instability within the region. The Caribbean relies heavily on tourism, which is particularly vulnerable to global economic fluctuations, natural disasters, and pandemics (Erman et al., 2021). The COVID-19 pandemic severely impacted the aviation sector, resulting in a significant decline in passenger numbers and substantial financial losses (Cerde, 2020). High fuel, fees, and airport costs undermine Caribbean airline profitability (Alleyne et al., 2021). The market is also fiercely competitive, with regional and major international airlines. Competition culminated in price wars, which compromise service quality and operational standards (Arnell, 2024). Market consolidation trends are also seen where small airlines are struggling to compete with large ones that enjoy economies of scale (CAPA, 2024b). This consolidating environment raises questions about the long-term viability of some regional airlines. Building on this literature, this study further analyzes how these structural weaknesses hinder regional viability and explores strategic options for sustainable growth.

Governance and regulatory complexity in regional airline systems

Regulatory frameworks are largely fragmented and inconsistent throughout the Caribbean. Numerous countries implement their own set of regulations, making conducting operations rather difficult for those airlines that operate in several jurisdictions (Scott, 2023). Additionally, many issues of inadequate infrastructure at airports, including old and less-

maintained facilities, further add to the inefficiency in airline operations (Espinet et al., 2023). The regulatory environment often does not support streamlined operations or uniform safety standards, creating vulnerabilities in the industry.

The Caribbean airline industry also faces labor market issues concerning workforce stability and recruitment. Turnover rates are extremely high, and there is a shortage of adequately skilled personnel among various airlines (Arnell, 2024). Seasonality of the business, which dictates employment based on tourist seasons, amplifies these labor issues. Therefore, temporary workers are more reliant on forming a consistent workforce.

Airline mergers and consolidation

Several key factors influence the decision-making process for airline acquisitions. Man et al. (2020) identified a total of eight factors influencing airline acquisitions. These include branding, network compatibility, and business conditions. Mizutani et al. (2021) found that unified branding enhances post-merger profitability. Synergies in aviation can also be categorized into two broad groups: revenue and cost synergies (Schosser & Wittmer, 2015). Revenue synergies anticipate access to new markets, increased network, loyalty, standard pricing, and increased availability of market information. Cost synergies are typically expected to result from network, fleet, labor, sales, and marketing expense reduction, common training and maintenance, increased infrastructure availability, and lower financing costs.

Studies have shown that unless integration plans are well thought out, firms may be surprised by the resources required to cope with the problems induced by post-merger integration. A notable study was the one by Gonzalez (2024), who displayed that some mergers they studied created losses due to organizational inefficiencies of about 870 million dollars, a conservative lower bound. Antitrust authorities should pay close attention to how post-merger organizational consolidation affects the likelihood of reaping efficiency gains.

Mergers in the aviation industry can also result in several organizational complications, including the integration of the workforce, which badly affects the quality of services provided by the merged firms despite their gains in efficiency (González et al., 2024). Kim et al. (2021) analyzed US airline mergers from 1993 to 2018 and showed that large, long-run cuts in wages and fringe benefits have occurred in the merging airlines, especially in large-scale mergers. They also indicate that short-run negative employment impacts differ by occupation type.

Ponomarev (2020) examined the possible merger of the second-largest European low-cost carrier, EasyJet, and a smaller carrier with a different business model, Norwegian. It would allow both airlines to increase passenger numbers, gain access to new markets, and achieve significant revenue and cost synergies, especially on Norwegian's part, which is likely experiencing difficulties filling its planes and maintaining its margins. It would create a new, second-largest European airline.

Mizutani et al. (2023) developed a model to assess price, flight frequency, and demand, highlighting that unifying with a higher quality brand can enhance profitability post-merger. His research focuses particularly on the Delta and Northwest cases, combining model development,

empirical data analysis, and simulation techniques to thoroughly examine strategies in airline mergers. Another study, made by Khezrimotlagh et al. (2022), employed a quantitative approach that most appropriately reflects the results of any merger. Specifically, they integrated data analysis on several airline mergers, including performance measures before and after a merger, to ascertain the productivity changes and operational efficiencies.

Knowledge gaps addressed by this research

This study addresses several important knowledge gaps within the existing literature on the Caribbean aviation market. While numerous studies have explored airline mergers and industry consolidation in larger markets such as North America and Europe, there is a distinct lack of research focusing on how these processes unfold in small, tourism-dependent Caribbean economies. The region's fragmented regulatory environment, seasonal workforce, and dependence on long-haul tourism pose distinctive challenges that are not well reflected in global models. In addition, there has been relatively little focus on how irregular aviation policies among Caribbean countries undermine operating efficiency and commercial viability. Through its exploration of these understudied domains, this research adds fresh knowledge about the structural weaknesses of Caribbean airlines and offers a region-specific explanation of how mergers, governance, labor challenges, and tourism interdependencies condition the future of the industry.

Research Methodology

Data sources

The research proceeded in several stages. First, a literature review identified key issues in the Caribbean aviation industry. The literature review included journal articles, industry reports, newspaper articles, and aviation websites. The first phase focused on gathering financial statements from Caribbean airlines, despite the limited availability of up-to-date and complete data. Research utilized historical operational data (2015-2023) from Cirium® and CAPA - Centre for Aviation, including financial statements, revenue per passenger, revenue multiples, operational costs, and projected incremental traffic/revenues.

Revenue multiple valuation approach

The second phase involved developing the basic steps for using revenue multiples in company evaluations (Beltrame & Sclip, 2023). There are three basic steps to using multiples properly in an evaluation process: 1. Selecting the group of comparable companies. The first step involves selecting airlines that are similar in terms of activity and geography to the company being evaluated. Once the sector has been narrowed down, selecting companies in the same geographic area is preferable. When selecting a comparable sample, analysts should be aware of key business model differences that could impact company valuation; 2. selecting the multiple for the evaluation. Choose the multiple that can be derived from the available financial statements; 3. valuing the target company. The average multiple is applied, as the sample size is small, and outliers are excluded.

Comparative case studies

The third phase included developing a conceptual framework for the proposed Pan-Caribbean consolidated airline system. This framework was built by analyzing consolidation impacts in other regions, such as South America, where mergers like LATAM and Avianca (Abra Group) yielded positive results in efficiency, market share, and profitability. This comparative analysis informed the assessment of the potential benefits and challenges of a unified Caribbean airline network.

Fleet and operational cost analysis

During the fourth phase, the research comprehensively reviewed individual Caribbean carriers' cost profiles, including fleet compositions and operational inefficiencies. Data on existing local carrier fleets were gathered to identify cost savings from fleet standardization and greater operating coordination. The results were incorporated in a cost-benefit calculation to approximate the probable financial returns from consolidation.

Analysis

Pan-Caribbean Airline Model

Coming together into one unified pan-Caribbean air system by the region's struggling airlines could be a viable solution for the region's aviation challenges. This will eliminate inefficiencies, rationalize networks, and reduce route duplication and market cannibalization. By integrating operations, the system would be in a position to generate coherent, optimized routings that improve regional connectivity, eliminate redundant layovers, and circuitous travel. A consolidated airline system would ensure convenient schedules, enhance accessibility, and encourage tourism inflows. Further fleet standardization would improve aircraft utilization, increase crew productivity, and lower costs, allowing airlines to operate on cost-recovery models with increasingly affordable fares.

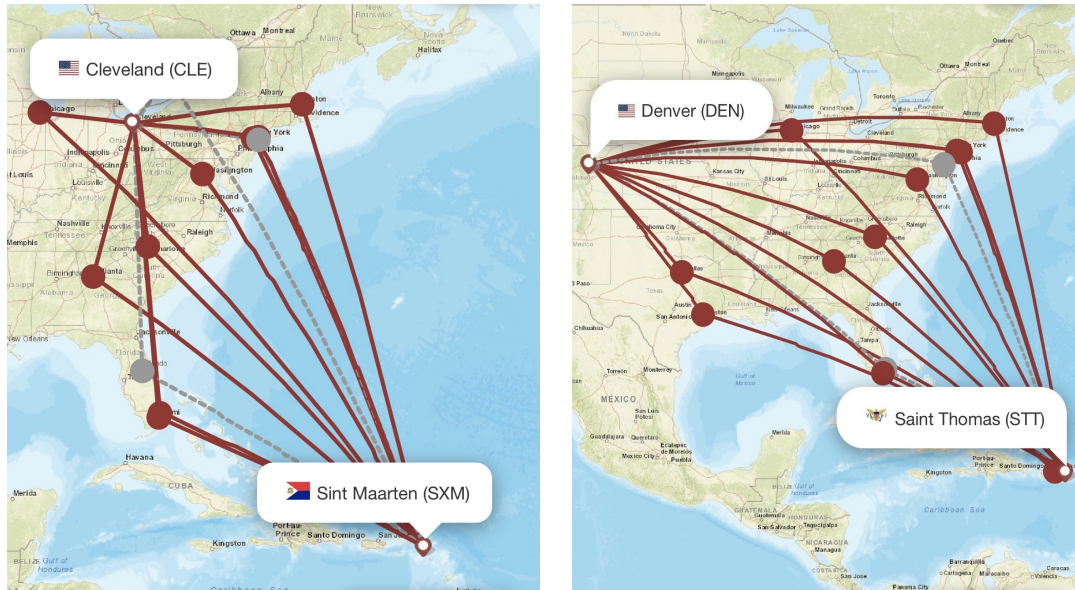
Fleet Standardization and Route Optimization

Most Caribbean countries have minimal direct international reach. Karp (2025) referred that approximately 64% of Caribbean airline traffic is to/from the US, with another 10% to/from Canada. Despite strong U.S. demand, lack of direct routes constrains growth. This limited accessibility automatically compels one toward inefficient connection, and attracting and retaining tourists is challenging. Maps (Figure 1) depict indirect flight routes from Sint Maarten (SXM) and Saint Thomas (STT) to U.S. cities, including Cleveland and Denver. The red lines illustrate current routing constraints, contributing to long travel times (6 hours 51 minutes and 9 hours 38 minutes, respectively), underscoring limited direct access from Caribbean hubs. Fleet optimization, such as deploying fuel-efficient aircraft capable of direct routes, could reduce this to 3 hours and 50 minutes for flights with A320 or A737. Similarly, the 9-hour and 38-minute journey to Denver (Figure 1) could be cut to about 5 hours from St. Thomas (STT). These

improvements would minimize layovers, lower operational costs, and enhance traveler appeal, directly addressing the region's connectivity challenges.

Figure 1

Current flight paths from Sint Maarten (SXM) (Shortest flight time: 6h 51m) and Saint Thomas (STT) (Shortest flight time: 9h 38m) to U.S. cities, illustrating indirect routes and extended travel times (flightroutes.com, n.d.)



Research has shown that regional airports are primary drivers of regional development, even if they are not profitable, as they attract investment, increase connectivity, and facilitate the economic integration of previously fragmented regions (Fornalczyk & Midera, 2025). However, there is poor intra-regional connectivity within the Caribbean. Figure 2 shows that nonstop service between San Juan (SJU) and Sint Maarten (SXM) is infrequent. Currently, this route is served exclusively by Frontier Airlines, operating three times per week with an Airbus A320neo aircraft (186-seat capacity), yielding an estimated weekly seat capacity of 558 seats. Although recent passenger volume and load factor data are not publicly available due to reporting lags, the low frequency and single-carrier operation suggest potential constraints, either from insufficient demand or operational and economic barriers to increased service. The non-stop flight duration of approximately 1 hour and 10 minutes contrasts sharply with indirect alternatives that involve 3–5-hour layovers, effectively tripling travel time (Table 1). These disparities add costs and reduce access for businesses and travelers alike, resonating deeper into structural problems of regional transportation networks. Increasing the frequency of flights, route optimization, and seamless multi-modal transit are some strategies to overcome these barriers to economic integration. By also optimizing fleets with smaller, agile aircraft tailored for short-haul routes, this flight time could be reduced to 40 minutes.

Figure 2

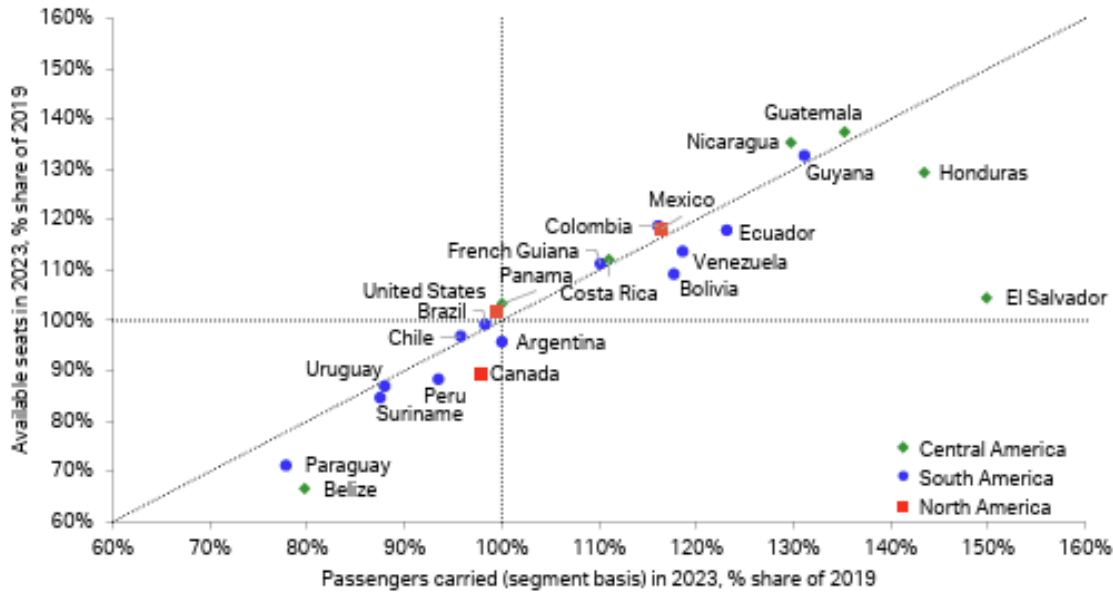
Poor intra-regional connectivity / Frequent nonstop service between San Juan (SJU) and Sint Maarten (SXM)

**Table 1**

Distance & Flight times: (SJU) to (SXM)

Via	Total flight time	Layover	Miles
Direct	1h 10 min	-	198 (309 km)
SKB Saint Kitts	4h 38 min	3h 25 min	287 (462 km)
EIS Beef Island	6h 0 min	5h 0 min	194 (312 km)

The Caribbean aviation market is also characterized by a high demand-supply imbalance, which could create excellent growth opportunities. The aviation sector in the region fails to reach its full market potential despite the high demand for air services within it. Figure 3 highlights the significant imbalance between demand and supply in Caribbean aviation, where strong travel demand is met with inadequate capacity from regional airlines. This gap has allowed foreign carriers to dominate inbound tourism traffic, while local airlines struggle with small-scale operations, high costs, and unprofitable routes. The industry's fragmentation limits connectivity and prevents Caribbean airlines from fully capitalizing on market potential. A consolidated airline system will effectively bridge this gap, providing improved connectivity, enhanced travel experiences, and increased regional tourism.

Figure 3*Market Opportunity: Caribbean demand outpaces supply (IATA, 2024)*

Cost Opportunity

Fleet heterogeneity across Caribbean carriers inflates costs due to maintenance complexity, varied pilot training requirements, and inefficient aircraft utilization. Transitioning to a standardized narrow-body fleet, such as the A320 or B737 families, could reduce operational costs by up to 30%, based on global benchmarks. In addition to narrow-body aircraft for international routes, the use of standardized regional turboprops for intra-Caribbean short-haul flights would reduce unit costs, simplify crew training, and allow greater flexibility in scheduling routes. Research (Narcizo et al., 2020; Agrawal, 2024) has shown that operational efficiency gains from regional fleet commonality can be in excess of 20% on high-frequency, short-stage-length networks. A more homogenous Pan-Caribbean airline system fleet may achieve far better economies compared to the fragmented and diverse fleets currently operating in the region. Currently, many aircraft types operate under Caribbean Airlines, which significantly increases maintenance and operational costs (Table A1).

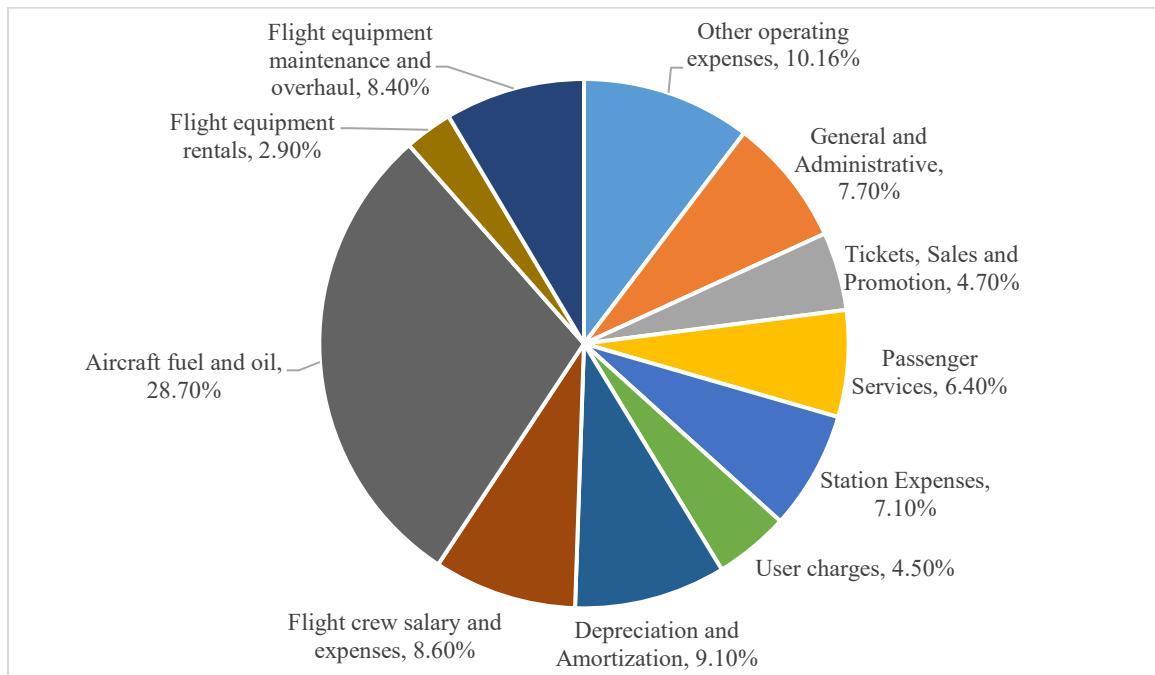
The current diversity of aircraft types within Caribbean airlines increases operational and maintenance costs. A more standardized fleet could significantly enhance cost efficiency across the region. This transition towards a homogeneous fleet could yield substantial economic benefits, as evidenced by various studies on fleet standardization. Standardizing aircraft types can reduce training and maintenance costs, as crews and technicians specialize in fewer models (Narcizo et al., 2020). Engine standardization has been shown to have a more pronounced impact on cost efficiency than airframe commonality, suggesting that focusing on engine types could yield greater savings (Merkert, 2023). Research also indicates that airlines with standardized fleets experience lower unit costs, which can enhance overall profitability despite potential trade-

offs in revenue generation (Zou et al., 2025). Empirical data from India also confirm that standardization improves operating performance and profitability, that uniform fleet types reduce complexities of scheduling and spare parts inventory, and facilitate better utilization of crew and technical manpower (Agrawal, 2024). Research in Brazil demonstrates the same results, with standardization being associated with improved operational cost control, while volatile fuel prices can lead to demand for new, more efficient models, affecting fleet composition trends (Narcizo et al., 2020).

Figure 4 analyzes airline operational cost distribution and highlights the potential impact of fleet homogeneity and shared support services on cost reduction. The Airline Cost Items Breakdown chart provides a percentage-based allocation of various expense categories, illustrating the primary cost drivers within the aviation industry.

Figure 4

Airline Cost Items Breakdown (IATA Knowledge Hub Learn, Apply, Improve, 2024)



Fleet homogeneity is projected to impact 30% of operational costs by streamlining maintenance processes, reducing spare parts inventory, simplifying crew training, and improving fuel efficiency. Standardizing an airline's fleet can lead to cost reductions in key areas such as flight equipment maintenance and overhaul (8.4%), depreciation and amortization (9.1%), and flight equipment rentals (2.9%). By minimizing variability in aircraft types, airlines can achieve economies of scale, optimize scheduling, and reduce downtime associated with maintenance and repairs.

In addition to fleet standardization, shared support services are expected to contribute to a 12% reduction in costs. This approach involves consolidating administrative, operational, and

customer service functions, leading to greater efficiency in resource utilization. Cost categories such as general and administrative expenses (7.7%), ticketing, sales, and promotion (4.7%), and station expenses (7.1%) can be optimized through centralized or shared service models. By integrating these functions across multiple locations, airlines can reduce redundancies, improve coordination, and enhance service delivery while lowering overhead costs.

Among the significant operational costs for airlines, aircraft fuel and oil account for the largest share at 28.7%, emphasizing the importance of fuel-efficient aircraft and optimized flight planning. Flight crew salaries and expenses represent 8.6% of total costs, indicating a significant labor component in airline operations. Other operating expenses constitute 10.16% of total costs, reflecting miscellaneous expenditure that could be further optimized through efficiency initiatives.

The findings suggest that fleet standardization and shared support services can reduce 42% of total operational expenses. Implementing these strategies can significantly enhance airline profitability, improve financial sustainability, and create a more competitive business model in the aviation industry.

Market and Financial Valuation

Having analyzed operational inefficiencies and the cost-saving potential of fleet standardization, we now turn to the financial dimension of consolidation. Understanding the market value of regional carriers is crucial for assessing the feasibility of a Pan-Caribbean airline model. Caribbean airlines' financial and operational consolidation presents a significant challenge due to the lack of reliable and up-to-date financial data. Among the seven airlines initially identified for analysis, excluding LIAT, Air Caraïbes, and Tropic Air, only three (Bahamasair, Caribbean Airlines, and Cayman Airways) publish financial statements, though they are outdated and incomplete.

An estimation model was developed to address this data gap using historical revenue per passenger figures and available traffic statistics. This method approximated total revenue, resulting in an estimated subtotal of approximately \$500 million for the three airlines. Valuing airlines using revenue multiples involves analyzing recent industry transactions to establish a benchmark. Let's examine two notable cases: the terminated JetBlue-Spirit merger and the completed Alaska Airlines-Hawaiian Airlines merger. In July 2022, JetBlue proposed acquiring Spirit Airlines for \$33.50 per share, totaling \$3.8 billion in cash. Including net debt, the enterprise value was approximately \$7.6 billion. At that time, Spirit's revenue was about \$5.1 billion, resulting in a revenue multiple of approximately 1.5x. In December 2023, Alaska Airlines announced its acquisition of Hawaiian Airlines for \$1.9 billion, including the assumption of approximately \$900 million in debt. This valued Hawaiian Airlines at \$18 per share. At the time of the merger, Hawaiian Airlines had reported annual revenues of around \$2.72 billion, leading to a revenue multiple of approximately 1.0x.

Based on these transactions, revenue multiples for airline valuations have ranged from approximately 1.0x to 1.5x. Applying this range to other airlines can provide a preliminary valuation estimate. For instance, if an airline generates \$3 billion in annual revenue, its valuation

might range from \$3 billion (1.0x) to \$4.5 billion (1.5x). Using the revenue multiple valuation approach, the estimated valuation for these three airlines (Bahamasair, Caribbean Airlines, and Cayman Airways) ranges from \$400 million to \$750 million. An extrapolated and highly speculative estimate places total revenue at approximately \$1 billion, yielding a valuation range of \$800 million to \$1.5 billion. However, the financial data for the remaining four airlines - Air Antilles, InterCaribbean, Winair, and SVG Air - remains unknown, making it difficult to determine a comprehensive valuation for the entire regional airline system. The lack of financial transparency severely hinders the feasibility of a consolidation effort, as essential financial due diligence cannot be conducted with the available data. Given the challenges in executing a full merger, especially due to financial opacity and political complexity, alternative models of integration deserve close attention. One such approach is the Pan-Caribbean virtual airline model, which offers a more flexible route to operational synergy.

The virtual airline model as an alternative to consolidation

While consolidation remains a key strategy for enhancing the competitiveness of Caribbean carriers, a full structural merger may not be politically or economically feasible in the region. As such, the development of a Pan-Caribbean virtual airline model offers a pragmatic and flexible alternative. Rather than requiring ownership integration, this model emphasizes coordinated operations among existing carriers through shared services, joint scheduling, and harmonized systems. A restructured LIAT, given its extensive intra-regional route network and operational footprint, could serve as the central coordinating or “host” carrier (LIAT, 2018), though this role could also be assumed by any willing and capable partner. The virtual airline model enables fleet standardization, network optimization, and resource pooling without dissolving individual airline brands or national identities. Aircraft, potentially funded by third-party investors, would be deployed strategically across participating carriers’ networks to enhance route coverage and serve underutilized or underserved markets. Common support functions such as ticketing, reservations, procurement, and maintenance would be centralized to reduce duplication and cut costs. By creating a unified customer experience and operational backbone while preserving decentralized ownership, this model allows Caribbean airlines to achieve economies of scale and improve international competitiveness in a way that is both politically viable and operationally strategic. Operational models, however, cannot succeed without robust institutional and regulatory frameworks. The following section examines the governance and implementation challenges that must be addressed to enable any form of regional airline consolidation.

Governance and Implementation Considerations

Effective governance is key to the success of any industry-wide unified program, particularly in aviation. Governance in a Pan-Caribbean airline system encompasses regulatory alignment, corporate structure, stakeholder coordination, and financial management. Caribbean governments must help, not hinder, the aviation sector’s growth. (CAPA, 2024a). Without solid governance frameworks, the proposed consolidation plans could face significant issues, such as operational inefficiency, regulatory conflicts, and financial instability. One of the significant governance challenges facing Caribbean aviation is the fragmented regulatory environment. Countries have varying aviation policies, air service agreements, and tax regimes, creating

barriers to seamless operation across borders. Financial mismanagement has existed in most of the state-owned airlines in the Caribbean for decades. Strong governance arrangements must be established to prevent fiscal inefficiencies. An integrated airline system requires close coordination among governments, investors, regulatory bodies, and labor unions. A pan-Caribbean airline system would require regional cooperation among Caribbean nations. This could mean that governments and aviation stakeholders will collaborate to address challenges and devise strategies to maximize tourism inflows. By integrating operations, countries could sell multi-destination travel packages, making regional tourism a unified experience, akin to successful models in other island regions. The Caribbean could compete more effectively in the global tourism market in this context.

Implications

Economic: GDP impact, job creation, tourism growth

Consolidating a unified brand has enormous commercial benefits by uniting dispersed marketing initiatives. The adjustment enhances global awareness of the Caribbean as a travel destination, which will appeal more to tourists. As discussed earlier, enhanced connectivity is expected to stimulate tourism inflows, with added economic value through extended stays and bundled destination offerings. This integrated approach also prepares the airline for partnerships, code-sharing arrangements, and alliances, improving its global brand recognition and airline industry competitiveness. Proposed liberalization plans—like multilateral agreements, removal of tariffs, and regional integration plans such as the Revised Treaty of Chaguaramas (Kaczorowska-Ireland, 2014) would also increase the intensity of competition, expand the range of services, and enhance passenger growth. While these changes could dramatically enhance regional connectivity and economic resilience, they must be carefully managed to avoid harming national carriers.

Table 2 analyses the projected benefits of the Pan Caribbean Air Consolidated Airline System, focusing on incremental traffic and revenue generation. The table quantifies these benefits under different operational scenarios - pessimistic, likely, optimistic, and aggressive - by evaluating three key factors: Operating Efficiency, TFCs (Total Fixed Costs) reduction, and Liberalization. The data is expressed regarding additional passenger traffic and corresponding revenue increases.

Table 2*Pan Caribbean Air Projected benefits: Incremental traffic and revenues*

		Operating Efficiency		TFCs Reduction		Liberalization		TOTAL
		Traffic	REV*	Traffic	REV	Traffic	REV	REV
Pessimistic	Assumptions	10%				12.50%		
	Amount		500		625	270		1,395
Likely	Assumptions	15%				20%		
	Amount		750		625	400		1775
Optimistic	Assumptions	20%				30%		
	Amount		1000		625	650		2275
Aggressive	Assumptions	130						
	Amount		1140		625	650		2415
BASE (2018)	46000 pax							

Expected improvements in operational efficiency translate into increased traffic and revenue, with improvements ranging from 10% (pessimistic) to 20% (optimistic). Secondly, for TFCs reduction, across all scenarios, a fixed revenue gain of \$625,000 is considered due to reductions in total fixed costs. Regulatory liberalization, estimated to bring a 12.5% to 30% increase in traffic, yields high revenue growth, particularly in optimistic and aggressive scenarios.

The pessimistic scenario foresees an incremental total revenue of \$1.395 million, with modest growth in traffic and efficiency. The probable scenario sees \$1.775 million in revenue, assuming medium efficiency and liberalization enhancements. The optimistic scenario expects \$2.275 million in revenue with significant liberalization improvements. The aggressive scenario, with more hopeful passenger growth and a larger net fare, forecasts \$2.415 million in revenue. Realizing the modeled solutions would contribute an additional \$3.3 billion to the regional GDP by 2025 and generate 207,000 extra jobs. This indicates the broader economic value of air traffic liberalization and efficiency improvements.

Environmental: Carbon footprint reduction

In addition to economic benefits, the proposed Pan-Caribbean Airline consolidation has great environmental dividends, the most prominent of which is the reduction of the region's aviation-carbon footprint. Consolidation would enable more efficient route planning, decreasing redundant flight routes that currently occur due to poor intra-regional connectivity. With efficient operations and the use of fuel-efficient, standardized planes in a consolidated system, it could have achieved lower emissions per passenger-kilometer. This would be of greatest significance

to the Caribbean, since the majority of its flights are short-haul and involve unproductive layovers, thereby contributing to total fuel use. In addition, redesigning the network and centralized planning would reduce duplicative flying of aircraft and optimize loads, both of which decrease greenhouse gas emissions. As international travel places put ever more emphasis on sustainability, this development would not only align regional air travel with worldwide environmental standards but render the Caribbean an even more appealing climate-sensitive and sustainable vacation destination.

Strategic: Global competitiveness, regional integration

In a recent study, the authors conducted analytical modeling and empirical analyses to examine whether domestic mergers can improve airlines' competitiveness in the international market. They found that a domestic airline merger can bring both "synergy" and "scale" effects to promote the merged airline's global competitiveness, reflected by an increasing route-level market share (Ma et al., 2023). Similarly, consolidating national airlines within individual Caribbean nations can create more efficient operations, with potential for resource pooling, shared fleet management, and schedule coordination. This will enable airlines to offer competitive prices, fill more seats, and enhance service reliability, reducing the need to rely on foreign carriers to provide intra-regional and international connectivity. A consolidated domestic network will also put Caribbean airlines on firmer ground to negotiate interline agreements and strategic alliances with global partners on more favorable terms, making them more competitive for long-haul traffic. Furthermore, domestic mergers can consolidate financial stability, reducing the need for government subsidies while enabling greater investment in fleet modernization.

Limitations and future research

While LATAM and Avianca consolidated into dominant airline groups, the Caribbean air transport market has factors that challenge similar consolidation. First, South American markets have larger operations, with more business-class demand and domestic connectivity opportunities. Caribbean aviation, unlike other regions, has more exposure to seasonal holiday traffic, which is more vulnerable to demand fluctuations. Second, LATAM and Avianca benefited from solid regional hubs in major economic centers like Sao Paulo and Bogota, whereas Caribbean airports operate more as point-to-point hubs. Third, with the participation of many sovereign nations, political complexity in the Caribbean introduces additional regulatory barriers compared to South America's more centralized airway systems. Although these variations do not render consolidation infeasible, they underscore the necessity for a customized plan considering the Caribbean's distinct operating environment. Last, the lack of full financial disclosure by certain airlines limits the precision of our analysis and how that may influence feasibility.

Future research could investigate the practical implementation of a virtual airline model in the Caribbean, including governance arrangements, investment channels, and regulatory harmonization. In-depth case studies of analogous models in other parts of the world might provide profound insights into best practices and possible pitfalls. Additionally, empirical examination of demand patterns, cost-sharing frameworks, and environmental impact statements would make the evidence base for informing policy choices stronger. As the region continues to

pursue sustainable and collaborative solutions to its air transport issues, such studies will be instrumental in informing both strategic planning and stakeholder coordination.

Conclusion

The Caribbean air transport industry faces fragmented operations, low intra-regional connectivity, and poor fleet management. A consolidated Pan-Caribbean airline network is a realistic solution to the abovementioned issues. Consolidation would offer the possibility of network simplification, route rationalization, and a higher frequency of service, thereby enhancing intra-regional and international connectivity.

A more integrated air transport system would yield considerable economic benefits for the Caribbean. With its greater connectivity, the system would foster tourism growth, intra-regional trade, and economic integration. Easier access to international and intra-regional destinations would make the Caribbean more competitive globally and promote higher economic resilience in tourism-dependent nations.

As previously discussed, fleet standardization could lower costs and improve operational efficiency, reinforcing the financial case for consolidation. Fleet homogeneity would enable economies of scale to support activities and purchasing, decrease operating costs, and improve profitability throughout the system. Strong public-private cooperation could drive multi-destination tourism packages. Harmonizing regional regulations would also simplify operations and provide a more efficient operating environment. Although growth and efficiency potential are obvious, realizing a Pan-Caribbean airline network requires surmounting issues of fiscal transparency, data accessibility, and political will.

Apart from economic benefits, these merger options also offer environmental benefits. Standardizing routes, eliminating duplications, and streamlining fuel consumption would lower the region's aviation carbon footprint. The consolidated system, with unified operations, would more effectively enable sustainable aviation initiatives, aligning with global progress in cleaner air travel.

Appendix A

Table A1

Current airline fleet: A mishmash of aircraft types offering huge cost economies if simplified

Airline name	ATR42	ATR72	A320	B737-8	CRJ 700	DHC-6	580	Islander	EMB -120	ERJ -145	Saab	Caravan	Citation C25B	A330 - 300/200	A350 -1000
Air Antilles		1				1									
Caribbean Airlines LIAT2020		5	12							2					
Cayman Airways Bahamasair	3	2		4		2	2				2				
Air Caraïbes	3	3		4										5	1
Winair	2					4									
interCaribbean Airways SVG Air	4	1			1	1			4	3					
						3		1					1		
Tropic Air												15			

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Implementation of VoiceThread in Online Aviation Education: A Pilot Program Towards Creating Community

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VoiceThread is an online multimedia and multimodal platform used by educational institutions across the world. The researchers in this paper implemented VoiceThread in Aviation Education to create a sense of community and decrease feelings of student isolation when taking online courses. Participants surveyed were undergraduate students majoring in a variety of degree programs in Aviation Education. All participants were enrolled in an asynchronous online Ethics & Professional Responsibility course. Enrolled students participated in VoiceThread assignments, creating original slides, recording themselves discussing the topic in an audio and visual format, and responding to their peers with video and audio comments. The researchers analyzed quantitative Likert scale items and qualitative open-ended questions. Participants reported feeling engaged and described the course as interactive when asked to describe their course environment. Additionally, they report feeling less isolated because of VoiceThread, increasing their sense of community in the course. Finally, students were asked what challenges exist for building an online community in Aviation Education, and how instructors can further support the community in their online courses. The results indicated that students were aware of the difficulty of creating community in online courses, either due to schedule restraints, motivation, and/or availability of peers, and course design limitations. Students identified VoiceThread as a good EdTech tool that helped foster community in their course and appreciated the opportunity to interact with their peers. Many students recommended that educators create an online learning environment that leaves space for community building, either in relation to the content, group work, and required course activities, or via informal interactions to create “outside-of-class” opportunities for students to spontaneously create their own community. Overall, the researchers were encouraged by the student responses and reiterate the need to create a sense of community in online Aviation Education courses.

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Introduction

Aviation Education, especially in the collegiate environment, has a long history of being multi-modal in its instruction and content delivery, including face-to-face, hybrid, and pure distance and online courses (Scarappellini & Bowen, 2001). Most well-known schools that offer aviation related curriculum in the United States have offered asynchronous online education for a variety of reasons. Additionally, undergraduate enrollment in online courses continues to grow even while overall enrollment trends downward (Bright & Vogler, 2024). While many traditional programs and students have grown accustomed to offering and taking online courses, many students have had little other choice, especially in aviation. There are countless examples of non-traditional students enrolled in online courses, such as those working full-time to fund flight training, taking night classes, serving in the military, balancing work and parenting, or graduate students seeking additional higher education from prestigious universities without needing to relocate or put their careers and families on hold.

In this paper, Aviation Education is an umbrella term that covers courses and programs in Airport Management, Air Traffic Control, Aviation Management, Dispatch, Professional Pilot, and more. While we do not sample from every facet of aviation in this research, we acknowledge that the field is wide and encompassing. This field, by its very existence, is inherently multi-disciplinary. It includes not only many topics from a variety of academic fields, such as the physical sciences like physics and chemistry, but also fields such as psychology and medical science. Aviation Education also resembles other fields that include hands-on education, such as Medicine (e.g., physicians, nurses, etc.). Both Medicine and Aviation, just as one example to illustrate the larger point, use a variety of different modalities, including lectures, simulators, and labs. Also, students in Aviation Education come with diverse skills, background knowledge, and life experiences that enrich their learning.

Educational technology has made many refinements from the first, solely pen and paper distance and correspondence courses. Gone are the days of receiving a packet of correspondence material in the mail and sending it back with the postman. Those distance courses of yesteryear were lonely and self-isolating, as even interaction with the instructor of the course was limited. Today, courses with interactive videos, assignments, and student interaction are in the education zeitgeist. The focus on the three touchpoints of engagement is now at the forefront of online course design. At the core of the development of online university courses are three questions: how do students engage with the content, how do students engage with the instructor, and how do students engage with one another.

Inherent in online Aviation Education is the idea that students come from a variety of fields to learn about aviation overall. Therefore, classes must be designed and tailored to bring many different types of people together to learn about aviation education. Research in Online Education shows that students are more engaged in courses where there is a social component (Garrison et al., 2000; Whiteside et al., 2017; Russell & Murphy-Judy, 2021). The focus on that third question, how do students engage with one another, becomes more important and valuable to students. As technology advances, there are more and more tech tools for education, sometimes referred to as EduTech or EdTech (Educational Technology) (Robinson et al., 2008) or te(a)chnology (teaching technology) (Russell & Murphy-Judy, 2021). In this paper, we

explore the use of the EdTech VoiceThread and its capacity for creating community in Aviation Education courses. This paper contributes to the pedagogy research in online Aviation Education, focusing on the implementation of VoiceThread, a specific online pedagogical tool, in online Aviation Education courses.

Research Questions

This paper centers around the following research questions: Does the implementation of VoiceThread in Aviation Education 1) positively influence students' opinions of online classes and 2) aid in limiting the sense of isolation in fully asynchronous online courses? 3) Do students view VoiceThread as a positive pedagogy tool for online courses?

This paper examines the initial implementation of VoiceThread in online distance-based Aviation Education and the student response. The researchers used questionnaires featuring Check All That Apply items, quantitative Likert scales, and open-ended qualitative prompts to address the research objectives.

Literature Review

Previous Aviation Online Research

Delivering quality Aviation Education courses has long been a goal. Scarappellini and Bowen's (2001) paper on distance education in aviation emphasized that pioneers will "recognize the constantly shifting framework surrounding distance education" (p. 158). At the time of their research on aviation distance education, more than 17 universities were known to have offered online courses. Only 6 years later, in a survey on Distance Learning in Aviation, Prather (2007) offered updated insight that 25 institutions were offering online academic courses in aviation, a 30% increase from Bowen. At the time of writing, the authors have a hard time imagining an educational institution that wouldn't have online courses at least as an option for a single course, if not many.

In recent years, since the initial peak of the COVID-19 pandemic, when higher education briefly turned its delivery model to almost entirely online, much scholarly work has been published in aviation journals regarding distance and online aviation education. A small example of authors researching online aviation education have studied a variety of perceptions and sentiments regarding online student satisfaction (Ani, 2024), effectiveness of virtual classrooms (Dattel et al., 2021), student motivation in online asynchronous courses (Wilson & Stupnisky, 2022) and many other research vectors rooted in some form of educational psychology. However, while these and other similar articles mention the types of software or platforms that are used, they are not the primary tool under investigation. As an example, Zoom or Skype are often mentioned to replace a traditional face-to-face lecture, but those tools and the students' reaction to them aren't the researcher's primary investigative focus.

VoiceThread

VoiceThread, a multimedia, multimodal web-based application, has been widely adopted by a wide variety of academic institutions (VoiceThread, 2025). The application was developed at the University of North Carolina and is an online application that allows users to create and share interactive multimedia slideshows (Brusini, 2013). Users can upload their own media slides (PDFs, PowerPoints, Canva slide decks, etc.) and then narrate those slides within the platform. Users can choose to narrate one slide at a time or flip through the slides as they narrate. There is also the option to annotate and draw on the slides as narration is being recorded, to highlight or outline important information on the slides presented. Once a slideshow is created, the application also allows others to participate, allowing for pair, group, or community discussion, transforming the educational platform into an interactive and engaging digital classroom (Features, 2025). These features and interactivity make VoiceThread “a valuable tool to support online active learning” (Zheng et al., 2017, p. 996) and an ideal tool to implement in Aviation Education courses to create a sense of community and belonging in the online asynchronous classroom.

VoiceThread in Education

The VoiceThread tool was not specifically designed as an education tool (Kent, 2017), but the company has been working in collaboration with educators to improve the tool’s features for educational use since its early days. This co-authorship with educators helped to shape what the tool is today, including its praised accessibility features (Pacansky-Brock & Ko, 2017). The educational benefits also became apparent early on (Brunvard & Byrd, 2011; Stover et al., 2015). In 2015, VoiceThread was seen as an emerging and “exemplar technology that allow[ed] readers and writers to engage with texts in multiliterate ways” (Stover et al., 2015, p. 342), demonstrating the tools capacity for applications in education.

VoiceThread is also available for pre-K-12 education and institutions internationally, such as the Southern Cross University in Australia, Open Universities Australia (OUA) (Chen & Bogachencko, 2023), and the National Aviation University in Kyiv, Ukraine note that VoiceThread is useful for teaching English for Specific Purposes (ESP) courses (Konoplianyk et al., 2021), and have adopted the tool. At the launch of New VoiceThread in 2023, the company described VoiceThread as making “interactions online warmer and more ‘human-centric’”, emphasizing the platform’s value as an educational tool that fosters connection, community, and human-centered communication (VoiceThread Blog, 2023; Bickle & Rucker, 2018).

VoiceThread in Aviation Online Education

Over 40 of the top 100 institutions have adopted the use of VoiceThread (VoiceThread, 2025), and the tool continues to be a popular choice among educators and students. A web search provided a short list of well-known aviation universities that are current users of VoiceThread. These universities are the Embry-Riddle Aeronautical University, Kansas State University, University of Nebraska at Kearney, and University of North Dakota. There is no published data on whether these universities are using them in aviation-specific courses, however. There is a dearth of scholarly research regarding online aviation education and VoiceThread in particular.

More specific research has been done on pedagogical tools in online aviation classrooms, such as synchronous chats (Walden, 2020), and utilizing a free communication platform that is used for text, voice, and video chat, such as Discord, to build an online community of scholars (Walden, 2023). Mrusek and Brito (2018) delivered a presentation on utilizing VoiceThread as a discussion board replacement in online courses and concluded that the tool can improve learner engagement and collaboration in aviation and aerospace education. After a thorough review, no published peer-reviewed articles exist regarding VoiceThread and its impact on online aviation education.

Social Presence with VoiceThread

As technology has advanced, so too have the expectations of our students and the way in which they perceive social presence. Orlando (2011) identified the benefit of improved social presence when VoiceThread was incorporated into online asynchronous classrooms, explaining that “students find that the ability to see and hear their instructors and classmates improves the sense of social presence of others in the classroom” (p. 4). Pavlou (2024) posits VoiceThread as a key tool that supported their students’ growth, both individually and as a community of learners, and enhanced research and student-instructor engagement in asynchronous activities that supported their “Arts-in-a-box” distance learning courses. Chen and Bogachenko (2021) compared text-based Discussion Board interactions to VoiceThread’s multimodal platform, finding that VoiceThread created stronger social presence, continuous and inclusive communication, more personalized communication (users identifying one another by name), and that the platform is an effective tool for online collaboration and engagement. Their study identified a Social Presence Density (SPD) (participants’ expression of emotions, use of humor, references to one another’s messages, etc.) to be more than twice as high in VoiceThreads as on text-based discussion boards (Chen & Bogachenko, 2021, p. 69). Their study reconfirms Bickle and Rucker’s (2018) findings that VoiceThread significantly contributes to students’ feeling of community, ability to learn and communicate in asynchronous online courses and Ching and Hsu’s (2013) findings that VoiceThread helped students connect with their peers and to communicate emotions and personality which allowed them to better interpret meaning and that there was a high level of preference for VoiceThread over discussion boards among students. Chen and Bogachenko’s (2021) findings also strengthen the findings of Lawrence-Benedict et al. (2019) that a drop in student perceptions of discussion boards as a viable way to create community in an online sport management graduate program between cohorts in 2014 and 2015 could have been attributed to the implementation of VoiceThread during the 2014-2015 academic year. With social media platforms like Instagram and TikTok, it comes as no surprise that students have shown a growing preference for video platforms like VoiceThread over text-based discussion boards.

The literature indicates that VoiceThread’s value is in community building, student-to-student, student-to-instructor, and student-to-content engagement, and as a foundational tool for enhancing in-person and online academic spaces, which directly contributes to creating a sense of belonging in online education programs.

Methodology

Rationale for Implementation

The instructor designed their online courses with the use of VoiceThread to encourage students to discuss and rehearse the material verbally and physically by having them record themselves and upload their recordings for other students to view. Taylor and Hinchman (2020) suggest that students are able to practice performing and teaching a skill while being recorded. Therefore, the instructor placed an extra emphasis on requiring that students use VoiceThread to record themselves with both video and audio. Finally, this VoiceThread design was selected so that the students were required to watch and comment on at least two other students' posts in an attempt to allow the students the opportunity to hear from other students' perspectives. In essence, students were listening, speaking, and practicing the course material at least three times by the end of the submission timeframe. The rationale was to allow the students the opportunity to review and critique each other as a way to increase student engagement in the cognitive and social realms (Taylor & Hinchman, 2020).

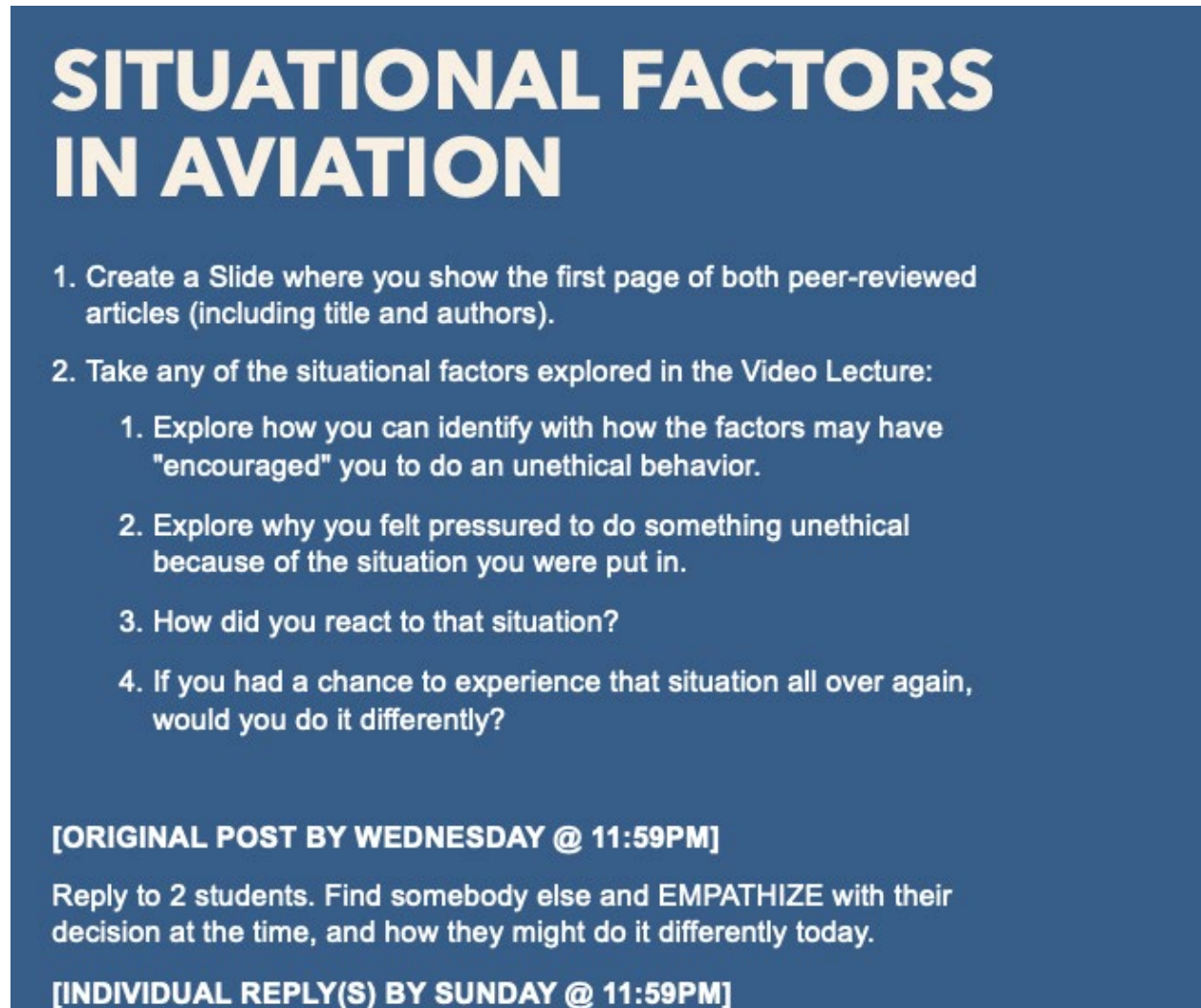
Aviation Education in particular places great value on the educational psychology principle of rehearsal. Those familiar with pilot training will understand the term chair flying, which refers to practicing and rehearsing maneuvers using mental imagery (Hudson, 2023). Research outside of aviation suggests that rehearsing material (Greene, 1987; Oberauer, 2019) and recording oneself can help with long-term memory retention (Noice & Noice, 2006). More research needs to be done on the impact of video-based discussion posts and its impact on social presence and course satisfaction (Xiu & Thompson, 2020). In concurrence with Thompson et al. (2017), the implementation of VoiceThread in this course was not intended to be the originator of learning, but simply a tool to promote learning. Recent research by Ng (2022) in online aviation education has shown that collaboration, even when asynchronous, is important in online learning environments, and tools such as flight simulators and web-conference software allow students to communicate and collaborate in an online community.

Implementation of VoiceThread in Aviation Education

The instructor chose to implement VoiceThread in a way that resembled a traditional post-and-reply format similar to those seen in discussion boards, but with the component of audio-video contributions replacing written words. Additionally, the choice to resemble traditional discussion boards was to add familiarity to the course structure, while implementing a new tech tool to help further retain the lesson (Comer & Lenaghan, 2013). Student participants were required to watch a separate video lecture and read any assigned articles. Afterwards, they were to make a video post, recording themselves in an audio and visual format each week by Wednesday, then asked to respond to other students in the class. Typically, they were asked to make a slide either from PowerPoint or Google Slides and upload it to the class VoiceThread, narrating it themselves, discussing the finer points of their assignment, such as a major theme in that week's readings. After students made their original VoiceThread posts, which included the slides and narration, they were required to view other students' VoiceThread slides and narrations and to make two replies by the Sunday following their original post. An example of the prompt is shown in Figure 1.

In this way, students who were familiar with online distance courses would be accustomed to the twice-a-week deadline and structure of the discussions, while getting used to the new platform. Additionally, this style of VoiceThread was easy to implement, as the instructor was familiar with using traditional discussion boards in their previous online courses and found it easy to adapt those discussions to this new technology and format.

Figure 1.
Example Prompt in VoiceThread



**SITUATIONAL FACTORS
IN AVIATION**

1. Create a Slide where you show the first page of both peer-reviewed articles (including title and authors).
2. Take any of the situational factors explored in the Video Lecture:
 1. Explore how you can identify with how the factors may have "encouraged" you to do an unethical behavior.
 2. Explore why you felt pressured to do something unethical because of the situation you were put in.
 3. How did you react to that situation?
 4. If you had a chance to experience that situation all over again, would you do it differently?

[ORIGINAL POST BY WEDNESDAY @ 11:59PM]

Reply to 2 students. Find somebody else and EMPATHIZE with their decision at the time, and how they might do it differently today.

[INDIVIDUAL REPLY(S) BY SUNDAY @ 11:59PM]

Participants

Participants were students enrolled as undergraduate aviation majors (e.g., professional pilot, aviation management, professional aviation) at a midwestern university. The participants were enrolled in an upper-level, asynchronous online Ethics & Responsibility course offered by

an aviation professor in the Spring 2024, Summer 2024, Fall 2024, and Spring 2025 semesters. The participants were enrolled primarily in either face-to-face, hybrid, or online undergraduate programs. Students were free to enroll in either the online course or one of the face-to-face course sections offered on campus.

The participants skewed slightly more female (52%) than male (48%). Among the participants, 2 (4.3%) were freshmen, 7 (15.2%) were sophomores, 16 (34.8%) were juniors, and 21 (45.7%) were seniors. 67 students were surveyed in total, but only 46 completed the entire survey. Those who didn't complete the entire survey were excluded from analysis for a $n = 46$. The total students who were given a chance to complete the survey was 95, with a total completion rate of 50%. See Table 1 for descriptive statistics of the demographics.

Table 1
Demographics of the sample (n = 46)

Variable	n	%
Gender		
Male	22	47.83%
Female	24	52.17%
Year in College		
Freshman	2	4.34%
Sophomore	7	15.21%
Junior	16	34.78%
Senior	21	45.65%

Procedure

For the purposes of the research survey, each class, every semester, used VoiceThread in the same way (see implementation section above for an in-depth discussion). At the end of the semester, they were asked to answer questions in an untimed, self-report survey hosted by Canvas, the university's Learning Management System. The survey asked questions regarding the general class climate related to online courses, as well as questions specifically about the implementation of VoiceThread in the course. The participants were asked to answer questions in three different formats: 1) check all that apply, multiple choice, 2) survey rating scale from 1-10, and 3) open-ended questions. The blend of quantitative and qualitative data was chosen as a deeper understanding of the student experience was desired. The data was best examined using a mixed-methods approach. Descriptive statistics utilizing frequencies and percentages were compiled and charted for the quantitative analysis, while the qualitative analysis was explored

using a Thematic Analysis paradigm to guide the research. Braun and Clarke (2006) identify Thematic Analysis as a popular and appropriate qualitative research method for analyzing data that searches across a data set to identify, analyze, and report repeated patterns. The three goals of Thematic Analysis are to identify important themes from the data, to understand how the themes relate to one another, and how themes can generate new insights about a particular phenomenon (Nowell et al., 2017). The survey, questions, and data were compiled and recorded in compliance with the Institutional Review Board at the institution.

Results

The first check all that apply style questions pertained to the online environment of the course, VoiceThread in particular, and their sense of isolation or community while taking the course.

Students were asked about new online skills that they learned after taking the course. A total of 23 (50%) enjoyed the VoiceThread discussions and lectures, while 21 (54.3%) felt that they learned how to exist in a community in an online course. 11 participants (23.9%) indicated they learned new skills and knowledge in an online setting. Interestingly, no participants (0%) reported that they did not learn anything new. See Table 2 for full descriptive statistics of the choices and responses.

Table 2
Results pertaining to Online Skills Gained After the Course

After taking this course, ... (select all that apply).	Frequency	%
I learned a lot of new skills and knowledge in an online setting	11	23.9%
I learned about new technology that I can use in my courses	25	54.3%
I learned about how to exist in a community in an online course.	21	45.7%
I enjoyed the VoiceThread discussions and lectures.	23	50%
I learned a few new things.	31	67.4%
I did not learn as much as I had hoped.	2	4.4%
I did not learn anything new.	0	0%

Note: This question has multiple responses as a Check All That Apply

Students were asked about what preferences they have for courses. A total of 20 (43.5%) indicated they would take more asynchronous online courses with VoiceThread, while 16 (34.8%) indicated they would still prefer to take in-person courses. No students (0%) chose that they would never want to take another online class again. See Table 3 for full descriptive statistics of the choices and responses.

Table 3
Results pertaining to Course Modality Preferences

This course makes me think... (select all that apply)	Frequency	%
I want to take more online courses in an asynchronous (non-scheduled) environment.	7	15.2%
that I want to take online in a synchronous (scheduled) environment.	5	10.9%
that I still prefer to take in-person courses.	16	34.8%
would take more asynchronous online courses like this one (with VoiceThread interaction)	20	43.5%
I never want to take another online class again.	0	0.00%

Note: This question has multiple responses as a Check All That Apply

Students were asked about their comfortability in the environment of this online course. 17 (36.9%) selected Yes. 10 (15.2%) indicated that after getting to know their classmates it was easy to work and participate. 8 (17.4%) said they still do not like to participate in group discussion, while 7 (15.2%) said it was easy to participate in classes. Only 1 (2.2%) checked that they were embarrassed or nervous in class because of other students. See Table 4 for full descriptive statistics of all the choices and responses.

Table 4
Results Pertaining to Online Course Environment

Did you feel comfortable in class as though the environment was easy to participate in?	Frequency	%
Yes	17	36.9%
Yes, after getting to know my classmates it was easy to work with them and participate.	10	21.7%
Yes, but it is always easy for me to participate in classes.	7	15.2%
Yes, but I still do not like to participate in group discussions	8	17.4%
No, I felt embarrassed or nervous in class because of other students.	1	2.2%
No, I felt embarrassed or nervous to participate in class because of the professor.	0	0.00%

Note: This question has multiple responses as a Check All That Apply

In the second part of the survey the participants were asked to use a Likert scale from 1-10 to rate their 1) sense of community in the class, 2) importance of community overall in online courses, and 3) if VoiceThread helped to create a sense of community in the course.

The first question using the Likert scale asked about how isolated or connected students were at the end of the class. Participants reported feeling above average ($M = 5.91$) on the connectedness aspect. The second question using the Likert scale asked participants to gauge how important it is to have a strong sense of community in the course. Participants report the importance as being slightly below the average ($M = 4.5$). The last question using the 1-10 Likert

scale positively indicated ($M = 6.9$) that respondents felt VoiceThread was helpful in creating a sense of community in the course. See Table 5.

Table 5
Likert Scale Questions

Question	Mean	Std. Deviation
On a scale of 1 to 10, where 1 is isolated and 10 is deeply connected, please rate your sense of community in the class. When thinking about this rating, think about how you feel in the class. Do you feel (1) completely isolated and not a part of the class at all, and do not know or speak to anyone within the class, or (10) like you are part of a class environment, have met new people, and have begun to create friendships with them.	5.9	2.15
On a scale of 1 to 10, where 1 is not at all important and 10 is vital or extremely important, please rate how important having a strong sense of community is in your online learning experience?	4.5	2.51
On a scale of 1 to 10, where 1 is not at all and 10 is very helpful, please rate how VoiceThread helped to create a sense of community in this course.	6.9	2.79

Additionally, open-ended questions were asked to allow student participants the ability to provide their opinion about VoiceThread. This qualitative data was collected, analyzed, and categorized by the researchers.

For results pertaining to the open-ended question “What challenges have you faced in building or maintaining a sense of community in this online class?” see Table 6.

Table 6
Student Responses Pertaining to Challenges when Building a Community

Participant Survey #	Student Responses Pertaining to Challenges when Building a Community
7	I did not see the benefit in building a [sense] of community with the other students.
8	Different time zones make it difficult for me.
10	My shyness can get in the way sometimes.
11	Easier to connect when you can record at any time.
12	Introduction slides helped me meet people.
17	I faced the challenge of not wanting to record myself for an extended time.
20	There isn't any continued conversation (like "respond to comments made on your video" or something of the like).
22	The voice threads were the only assignments where we got to interact with each other.
30	Ensuring everyone is supportive with their posts and not demeaning.
31	The aspect of the social environment in an in-person class, like before and after class, and meeting people face-to-face.
32	There simply isn't time or space for community.
35	Still hard to have a sense of community when you never actually see other people in this class other than through a screen.
40	This class is online.
45	The challenge was due to being a full online student, and this class was online. I don't go to the campus for classes anymore, so most people I meet are strangers. I enjoyed doing this class online, but I also think being in person for this class would have fostered more of a community feeling.

Note: The chart above is a selection of participant responses that highlight common themes found in the data.

As seen in Table 6, student responses to challenges they faced when building community in their online course indicated the common themes of time, motivation, format of the course, and engagement opportunities throughout the course. Many students indicated that there was no time for community building, either due to their own schedule restraints, motivation, availability

of peers in different time zones, or due to the constraints of the class structure and content design. Overall, students compared their course with face-to-face courses and a spontaneous community that is built during “hallway time”, before and after class interactions, studying with peers met in class, and meeting in person. This could indicate the need to create “hallway spaces” in an online course, such as activating the chat room on the LMS so students can chat with others who happen to be online with them at the same time, the creation of an open-ended forum for students to engage outside of class content, or the creation of a “study room” via a link to a virtual room where students can visit synchronously on their own time. Students indicated the desire for these types of elements when responding to the question “How do you think instructors can support the development of a strong community in online classes?”, as represented in Table 7 below.

For results pertaining to the open-ended question “How do you think instructors can support the development of a strong community in online classes?” see Table 7.

Table 7
Student Responses Pertaining to How Instructors Can Support Community

Participant Survey #	Student Responses Pertaining to How Instructors Can Support Community
14	I think making classes interact over videos makes it a lot better of a community vibe.
15	Group assignments and discussions help people collaborate.
18	Using apps like VoiceThread.
24	I have no idea for developing a strong online community. Maybe having extra questions, like a favorite animal, would help.
28	By creating spaces for students to converse with one another, like a Teams chat or a Discord server. Not by forcing abstract communication via discussion threads.
32	Instructors can host more Zoom meetings with other students, even just optional hangouts or group tutoring.
41	Nothing, it's the nature and purpose of an online class, so that you don't have to go, and you can do it on your own by yourself.
42	By making more assignments about personal experiences and stories.
44	It would be interesting to assign students to contact two other students to work on a project together. Or perhaps make an assignment [where] 3 students all need to voice call each other [and] record their conversation about a certain topic while answering questions. This idea only comes about because the discussion post methods always feel hollow. At least with the idea above, there's some real communication happening, not just posts and replies.
45	Maybe by having regular check-ups throughout the course with everyone, whether that is together on a Zoom call or putting people in groups for assignments. I think that could [develop] more of a stronger community for online classes.

Note: The chart above is a selection of participant responses that highlight common themes found in the data.

Students also offered ideas for how instructors can create community in online classes. Table 7 shows a sampling of student responses to this question, reflecting common themes in the data. As reflected by participant 24's comment, "I have no idea for developing a strong online community", many students opted out of answering this question on the survey. However, many students recommended optional Zoom sessions, Discord or Teams Chat threads to create an

“outside-of-class” type space for students to interact informally, group projects, live, optional study sessions, or informal hangouts via Zoom, and the use of technology to encourage the sharing of ideas. Students’ skepticism on the capacity of online classes to create community shined through this question as well, as seen in participant 41’s comment “it’s the nature and purpose of an online class so that you don’t have to go and you can do it on your own and by yourself” which can also reflect the motivations for students who choose to take their courses online. Comments like these can indicate that some students strategically choose online courses in order to avoid engaging with others and to work through the material on their own. These findings can be very useful to faculty when creating online courses, taking into account the suggestions from students to create “third spaces” for informal interaction, selecting EdTech that suits their teaching style and goals, and designing their courses with community and content in mind.

Finally, we analyzed an open-ended question on perceptions of Class Atmosphere using a generated WordCloud to gain insight into students' unscripted opinions. In Figure 2, we present a WordCloud generated from student responses to the question "In one or two words or a short phrase, how would you describe the class atmosphere and learning environment?"

Figure 2.
Word Cloud for Class Atmosphere



*Word Cloud created using www.wordclouds.com

The Word Cloud for Class Atmosphere shows students' sentiments regarding the course. Words that are larger indicate more students used those words in their responses, while smaller words signify fewer students wrote those responses, some as few as only one. The most common words indicated by the students in this response were Engaging, Comfortable, Relaxed, Important, Thoughtful, Good Learning Environment, and Challenging. These positive reflections illustrate that many students were satisfied with the course overall and found it to be meaningful and engaging.

Conclusions

Survey results found many interesting conclusions about the implementation of VoiceThread and students' desire to continue enrolling in online classes. Every student left with new knowledge, either pertaining to the course content, how to build community online, or new tech tools (as demonstrated in Table 2). Many students indicated that they enjoyed using VoiceThread and that they would be interested in taking another class utilizing VoiceThread (as demonstrated in Tables 2 and 3). This is encouraging and positions VoiceThread as a useful tool for online course instructors.

When students described their online course environment, they used words like "engaging", "creative", "encouraging", "thoughtful", and "interactive" (see Figure 2). Multiple students even indicated that there was a "good" or "great" learning environment, showing the capacity of VoiceThread to help facilitate a positive learning environment. These qualitative results also align with quantitative responses (shown in Table 4), where students responded that they were comfortable in the online environment facilitated by VoiceThread, and others felt more comfortable after getting to know their peers through the platform. These results demonstrate VoiceThread's capacity to help foster a positive learning environment where students can get to know one another, even in a fully online, asynchronous course.

When students were asked to compare this course with other courses and to identify strengths and weaknesses of community in other online courses, students continued to reflect on the lack of time and motivation for other students to invest in community building, how instructor presence impacts the sense of community, and how synchronous sessions with instructors and peers in group work helped to foster community (as reflected in Table 6). Some students also indicated that their other online classes did not encourage interaction with their classmates and that this course was their first time with a platform like VoiceThread, indicating its contribution to their sense of community. Many students commented on other online courses being text-based, lacking real-time interactions, lacking audio-video participation, and lacking instructor presence and encouragement to engage with one another. Students indicated that they appreciated when teachers attempted to foster an environment of community within their classes. These comparisons in the open-ended responses of students surveyed could indicate a desire for community building in their courses and a need for instructors to design their courses with this in mind, despite many indicating that community building was not a high priority for them in online courses (Table 5).

Many comments reflected students' skepticism in the possibility of building community in online courses (Table 3 and Table 6), one student simply responding "This class is online"

(Table 6), which seems to indicate the format of the course as being the restricting factor. However, these comments could also indicate that we as educators need to be more creative with how we use and implement EdTech, thinking strategically about elements that are for community building (i.e., welcome week VoiceThreads where students create slides about themselves and interact), elements that are for the course material (i.e., interactive VoiceThread lectures where students engage with the instructor and content), and elements that are incorporated to foster student-to-student engagement (i.e., small group discussions on VoiceThread with back-and-forth conversations over a two-week period). Students left meaningful recommendations for instructors on how to build community in online classrooms, indicating a desire for community building (as seen in Table 7).

Implications

It is interesting to the researchers that participants in this survey did not find a sense of community to be of great importance. When asked the question “How important is a sense of community in an online class?” respondents averaged 4.5, slightly less than a neither important or important rating. It is known that students choose different modalities (online, face-to-face, etc.) for a variety of reasons (O’Neill & Sai, 2014; McIntyre et al., 2023). Perhaps the students’ reasons for taking online classes mean avoiding a sense of community or being forced to participate in other students’ discussions. Or, perhaps a reason for taking online courses is to work on their own schedule (McIntyre et al., 2023), which may limit or reduce their efforts in contributing to community building or non-required elements of the course. Another possibility is that student expectations for certain types of courses are different from others. For example, students in an Ethics and Responsibilities course may not view community building—or interaction with their peers—as a necessary component of their course, while students in humanities-based courses, like Foreign Language Courses, may expect oral and peer engagement to practice the target language, a key component to American Council on the Teaching of Foreign Languages (ACTFL, 2024) guidelines for target language output opportunities in Foreign Language Classrooms (Russell & Murphy-Judy, 2021).

However, as indicated through their scalar ranking, participants reported not feeling isolated in the class, but also not feeling like they made deep connections where they made friends in class. This could be explained in many ways: the design of VoiceThread’s post once and reply to two peers method which did not simulate a back-and-forth discussion as was hoped, the need for more opportunities for students to engage spontaneously (i.e. outside of assigned participation), the need for opportunities for students to share about their personal lives and experiences, creating the opportunity to connect with other students with similar experiences, or, perhaps, very simply, that students did not desire to make deep connections in an online class and therefore did not engage in a way to foster them.

In relation to the researcher’s proposed research questions, it can be shown in this research that participants found that VoiceThread positively influenced their perceptions of online classes, students reported not feeling isolated in this class, and the participants responded that they felt VoiceThread was a useful pedagogical tool for implementation in online courses in Aviation Education. These results indicate that the implementation of VoiceThread was overall a

positive experience and motivates the researchers to continue exploring the use of VoiceThread in their courses.

Discussion / Future Directions

In the future, the instructor may decide to implement an alternative or modified version of using VoiceThread in their online courses. In future course design, the instructor would like to expand the use of VoiceThread to include stop-and-participate style slides, small group discussions, and other engagement styles of VoiceThread. For example, instead of requiring students to post based on an assignment, the instructor may design the VoiceThread interaction to make the students actively participate in an instructor-led lecture, shared via the VoiceThread platform within Canvas (the LMS). This can be accomplished by including discussion slides towards the middle to the end of the lecture, reinforcing student comprehension, encouraging Socratic dialogue to engage more deeply with the material, and to demonstrate active engagement/participation with the lecture material. One example might include a lecture on Aviation Ethics using VoiceThread in which the slide deck would have a ‘stop and discuss’ dedicated discussion question slide, requiring the students to answer questions about the ethics of the Boeing 737 MAX from an FAA regulatory standpoint.

The use of VoiceThread in these ways could unlock the potential of the platform, creating more opportunities for engagement in new ways while also providing students opportunities to engage with the instructor, the content, and one another in different ways throughout the semester. Additionally, these findings align with Chen and Bogachenko’s (2021) research, which indicated that students prefer VoiceThread discussions to traditional Discussion Boards. It could be that students will engage more deeply with other styles and implementations of VoiceThreads that do not model the classic discussion board, post-and-reply-to-two-peers method. Overall, students seemed to enjoy VoiceThread and rated it as an effective tool, indicating that more research around VoiceThread’s effectiveness as an EdTech tool is needed.

Due to the mixed bag of responses regarding a sense of community in online classes, more research might be done investigating VoiceThread and the retention of academic material past the end of the semester and the end of the course. One of the primary reasons the instructor chose to incorporate VoiceThread was because of the knowledge that students might record and re-record themselves speaking on camera multiple times, thereby creating a sense of rehearsal. As has often been said, “you never know a topic until you teach it.” In the same way that instructors have students do end-of-course presentations to summarize the material or create a culminating class project, this implementation of VoiceThread helped to accomplish these goals, on a smaller scale, in weekly VoiceThreads throughout the course. Therefore, it could be researched how much students retained information as a result of this VoiceThread implementation.

Limitations

Due to the use of a non-validated scale and limited survey participants, it can be difficult to generalize these answers about VoiceThread to the general population. Also, this population of students was mostly homogenous, being from the same school and enrolled in programs that

generally overlap. Further research might focus on expanding the sample size to a larger population at other aviation education institutions.

Other metrics of engagement could also be evaluated, such as student time spent participating on VoiceThreads compared to in-class participation in similar courses or time constraints within in-person courses. For example, if students added more digital content to the VoiceThread than the in-person course's allotted time would have allowed them to discuss/engage, it could be said that VoiceThread expanded the capacity for participation and engagement by removing those time constraints, as was found by Soto and Soto (2022) when they utilized VoiceThread in higher level math courses to extend in-class discussions that they ran out of time for.

Using VoiceThread to intentionally build community at the beginning of the semester, as Calvo and Hartle (2023) did in their Virtual Exchange program for preservice teachers in the US and Brazil, could greatly impact the students' level of engagement throughout the course. Examining how the incorporation of community-building VoiceThreads, along with content-based VoiceThreads and discussions, could be insightful to the value of community alongside learning.

Creating a sense of community in Aviation Education is important, as many students may never have a chance to come on campus, as they are working in remote locations and abroad (e.g., military service). Integrating VoiceThread may give students the ability to be both seen and heard by their instructor, but also by their peers, which may increase their longevity in the program and their affiliation with the university. The incorporation of audio-video interaction through VoiceThread could also lead to deeper student engagement and participation and result in better learning outcomes (Delmas, 2017). Other researchers have also found that VoiceThread has the capacity for higher engagement in their courses (Kent, 2017; Padilla & Kreider, 2018; D'Alessio et al., 2019; Calvo & Hartle, 2023), indicating the benefits of continuing to explore the potential of VoiceThread in Aviation Education courses.

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A Deeper Look at Part 141 Pilot School Examining Authority: The Effect of Changes to FAA Order 8900.1

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Prior research suggests that flight training providers experience delays scheduling check rides when using Designated Pilot Examiners. One potential solution to alleviate these delays is for Part 141 pilot schools to obtain examining authority. According to Rosser and Mosey (2024) many Part 141 flight schools experience challenges in attaining examining authority. This project specifically addresses recent changes to Document 8900.1 which is guidance used by Flight Standards District Offices in the examining authority application process. Part 141 Chief Flight Instructors were surveyed to provide their perceptions of the new guidance and any effect the guidance has on their intent to pursue examining authority for their pilot school. If a pilot school had already applied for examining authority, they were asked to share their experiences during the application process.

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Introduction

As the airline industry continues to demonstrate a need for large numbers of qualified pilots to fill open pilot positions, there is a corresponding need to train and certificate those pilots. The Federal Aviation Administration (FAA) Part 141 pilot schools remain a main source for training large numbers of pilots. While most of these schools train the pilots to proficiency and utilize FAA Designated Pilot Examiners (DPEs) to conduct the practical test, some have been awarded examining authority. Prior research suggests that flight training providers experience delays scheduling check rides when using DPEs (Beckman et al., 2023). One potential solution to alleviate these delays is for Part 141 pilot schools to obtain examination authority. A pilot school with examining authority has the authority to recommend its graduates for pilot certificates or ratings without further testing by the FAA (2021). Beckman et al. (2023) reported that there were 851 DPEs approved to conduct practical tests in 2021, which accounted for 87% of total practical tests administered with the remaining 13% of practical tests conducted by flight schools with examining authority. At the time of the Beckman study, only 6.5% of the responding school 14 CFR Part 141 pilot schools had received examining authority for at least one course.

Until September 26, 2023, when FAA Notice 8900.675 was released, FAA Order 8900.1, Volume 5, Chapter 12, Section 4, Examining Authority, Paragraph 5-1850 advised the Flight Standards District Offices (FSDOs) that after receiving an application for examining authority from a Part 141 pilot school, the local FSDO *should* conduct the FAA practical test for at least 50 percent of the graduates of the course for which the school applied for examining authority (FAA, 2022). According to the FAA's Terms of Reference, "should" means a procedure is recommended (FAA, 2003). The verbiage of the statement suggests that FSDO participation in practical tests was not a regulatory requirement as much as an advisement of practice, although some FSDOs may have viewed the statement as a directive from the FAA that they "must" follow. Respondents in Rosser and Mosey (2024) indicated that their FSDO of oversight was treating this guidance as regulatory which led these Part 141 pilot schools to discontinue their pursuit of examining authority. Respondents indicated that feedback from their FSDO indicated the FSDO did not have adequate manpower to complete the suggested observations.

On September 26, 2023, Notice 8900.675 was issued by the Federal Aviation Administration with a subject line of: Role of the FSDO in Conducting Practical Tests for a Pilot School Seeking Examining Authority. The Notice indicates that due to resource constraints, FSDOs are unable to conduct practical tests at the level specified in FAA guidance, and therefore have not been considering applications for examining authority. This wording in the Notice supports the findings of Rosser and Mosey (2024). According to the Notice, this has precluded Part 141 pilot schools from obtaining examining authority (FAA, 2018). The Notice further explains that 141.63(a)(5) requires the practical tests to be conducted by either an Aviation Safety Inspector (ASI) or a DPE who is not an employee of the school, but it does not indicate a percentage of practical tests that must be administered by an ASI in order to achieve examining authority. The FAA has determined that the guidance as provided is confusing, and not supported by regulations. As a result, the FAA is removing the provision that *advises* FSDOs to conduct practical tests for at least 50 percent of the graduates of the course for which the school applied for examining authority. According to the Notice, the FAA has stated that by removing this

provision, FSDOs should now be more readily able to process applications for examining authority.

This project continues the work of Rosser and Mosey (2024) and examines the effect of recent changes to Federal Aviation Administration guidance for applicants seeking examining authority. The previous study examined perceptions of the overall process of application and approval, and identified several issues associated with obtaining examining authority. This study specifically looks at the application guidance changes as presented in Notice 8900.675 and the possible effect of those changes on a pilot school's ability to achieve examining authority. Part 141 chief flight instructors were surveyed to provide their thoughts on the new guidance, specifically, any effect the guidance has on their intent to pursue examining authority for their pilot school.

Methodology

This study continues the work of Rosser and Mosey (2024) by examining the perceptions of pilot school chief flight instructors regarding obtaining examining authority in their FSDO region. The study specifically addresses Notice 8900.675 updates as they pertain to outlining the requirements for application for examining authority. The target population of this study was all Part 141 pilot school chief flight instructors in the United States. The primary research questions that directed this study were:

1. Do chief flight instructors think that having examining authority would help alleviate the backlog of practical tests under the current system using DPEs?
2. Are pilot schools more inclined to pursue examining authority now that the changes have been made?

Part 141 pilot school chief flight instructors were asked to share their thoughts on their experiences with the examining authority application process through a survey. The survey contained 24 questions. The first five questions were to address informed consent. The remaining questions consisted of fifteen yes/no type questions and three questions that were open-ended. These questions addressed whether schools had examining authority, if they planned to add examining authority, either for an initial application or application for an additional rating or certificate, and if they would apply, or re-apply, for examining authority now that the FAA has published the guidance contained in 8900.675. Other questions asked whether their school had ever been denied for examining authority, and the reason(s) given for denial. Schools were also asked how many DPEs they had access to in order to conduct practical tests for their schools, whether they experienced delays in the practical test process under the current DPE system, and if they believed having examining authority would alleviate those delays. Additionally, chief flight instructors were asked if they thought the 90% first time pass rate for two years was a hindrance to obtaining examining authority, and whether specific DPEs were utilized, or avoided, to strengthen first time pass rate. Respondents were also asked if they provided flight training for a collegiate flight program and whether their school was a member of the University Aviation Association.

To provide face validity, the survey was reviewed by two chief flight instructors and an individual with extensive experience in developing research survey questionnaires. The individuals all had knowledge of the topic and their feedback was incorporated into the survey. This study involved human participants; therefore, the researchers applied for and were awarded an exemption from the Institutional Review Board (IRB). The Aircraft Owners and Pilots Association (AOPA) Flight School Finder (2023) provided contact information for participants. The site lists flight schools that provide flight training under FAR Part 61 and Part 141, and lists fixed wing (airplane), rotorcraft (ex. helicopter) and lighter than air (ex. balloon) flight schools. The researchers were able to utilize the site filter to obtain email contact information for 457 Part 141 pilot schools and included any Part 141 flight training providers who conduct airplane, rotorcraft, or balloon flight training that were listed in the Finder. The University Aviation Association (UAA) was asked to distribute the survey to its membership since the majority of collegiate aviation program flight training is conducted under Part 141.

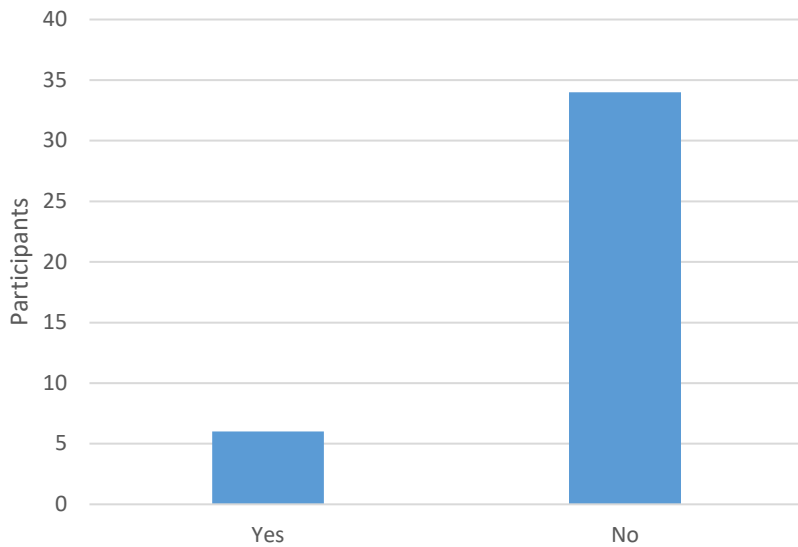
Results

The survey instrument was developed in Qualtrics XM survey software, and a link was sent to 457 Part 141 pilot schools identified in the Aircraft Owners and Pilots Association Flight School Finder. An email was sent two weeks after the initial invitation email to remind Part 141 pilot school chief flight instructors to complete the survey if they had not already. The survey was closed in Qualtrics after another two weeks, and the data was compiled. Of the 457 emails sent, 31 were returned as undeliverable, making the total of potential recipients 426. Valid responses to the survey were received from 40 participants, making the response rate 9.4%.

To address research question one, we asked the following four questions. When asked if their school currently had examining authority 6 (15%) indicated they had examining authority for at least one training course outline (TCO) offered, with 34 (85%) respondents indicating they did not have examining authority for any course offered (Figure 1). 27 (69%) respondents stated that they provide flight training for a collegiate flight program, and 12 (32%) noted that they were University Aviation Association member schools.

Figure 1

Part 141 Pilot Schools with Examining Authority



Pilot schools were asked how many DPEs are regularly available to provide practical tests for their students. When asked if they felt that the number of DPEs in their area was sufficient, 6 (15%) of respondents said yes, while 33 (85%) answered no (Figure 2). These two questions were meant to gauge what the general thoughts were on DPE staffing levels.

Figure 2

Are the numbers of available DPEs available in your area sufficient?

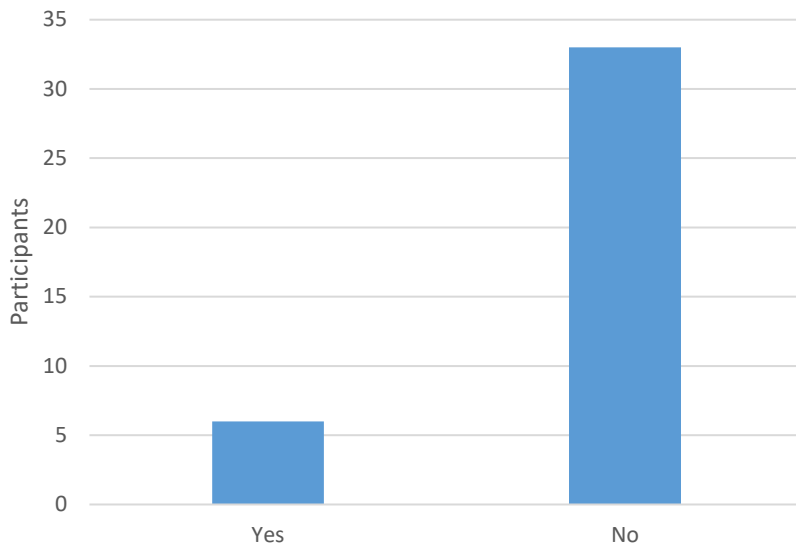


Table 1

Number of DPEs Regularly Available to Provide Practical Tests for Your Students

Number	Number of Schools
None	3
One	6
Two	13
Three	8
Four	2
Five	2
Six	1
Eight	1
Twelve	2

Note: One respondent indicated that two DPEs completed training as of 12/2023 but had not been activated by the FSDO yet.

Participants were asked if it was their experience to encounter delays scheduling a DPE for a practical test for their students; 34 (87%) answered yes, while 5 (13%) answered no (Figure 3). This was expanded into the next question which asked if they believe that having examining authority would alleviate delays they experience in scheduling of practical tests where 34 (87%) answered yes, 4 (10%) answered no, while 1 (3%) answered N/A (Figure 4).

Figure 3

Do you experience delays scheduling DPEs for practical tests?

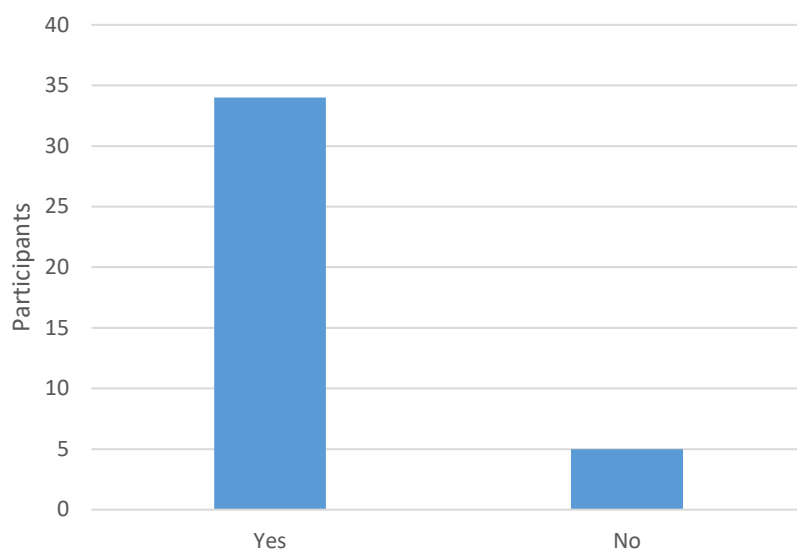
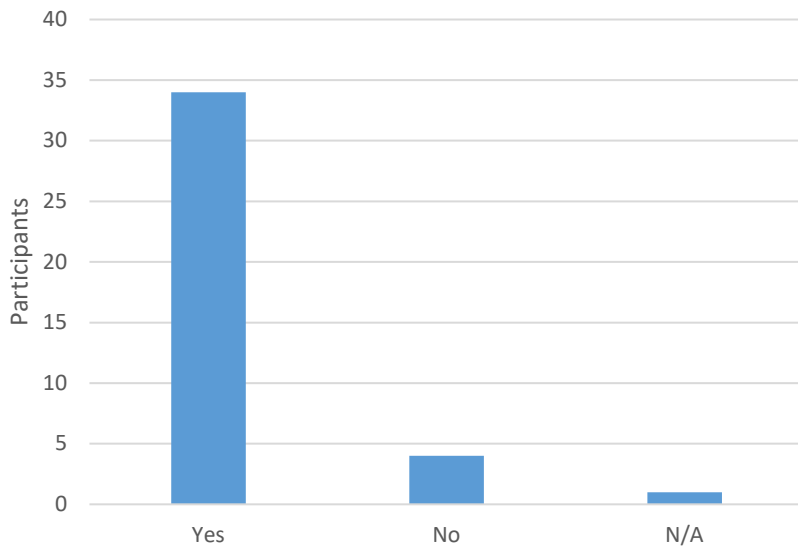


Figure 4

Do you believe that having EA would alleviate delays scheduling practical tests?



To address research question number two, we asked the following two questions: The survey then addressed where in the application process pilot schools were prior to the publication of 8900.675, and whether the changes would alter the school's intent to apply for examining authority. When asked if their pilot school was in the process of applying for examining authority before Notice 8900.675 was published, 9 (24%) answered yes, and 27 (76%) answered no (Figure 5). Participants were then asked; if they originally did not intend to pursue examining authority for either an initial application, or to add examining authority to another TCO before the publication of Notice 8900.675, would their school now pursue examining authority after the Notice came out, 23 (68%) answered yes, while 11 (32%) answered no (Figure 6). If the question was answered yes, the follow up asked if their school would be pursuing an initial application or adding to an existing TCO, 18 (55%) answered initial, 6 (18%) answered add-on, while 9 (27%) answered N/A.

Figure 5

Was your school applying for EA prior to Notice 8900.675 publication?

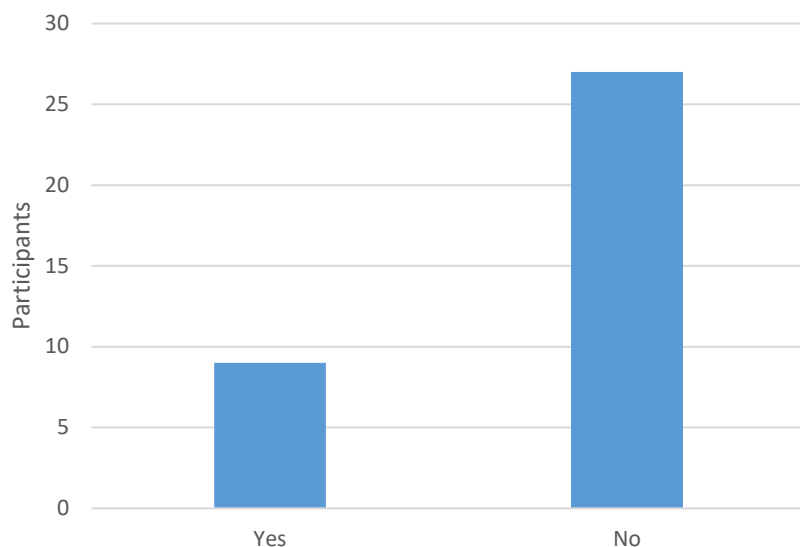
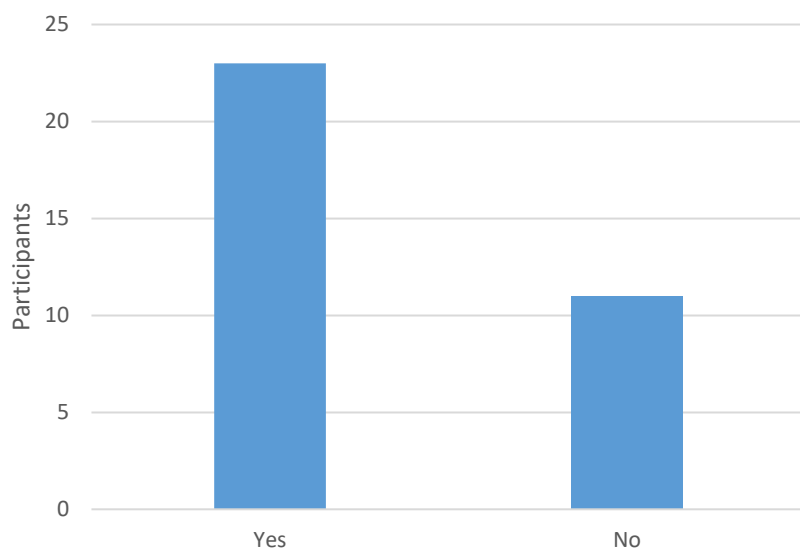


Figure 6

Do you intend to apply for EA now that Notice 8900.675 has been published?



Limitations of the Study

Several factors could be considered limitations to this study. As the study was presented by email, there is the distinct possibility that messages sent by an unrecognized source may have been ignored, deleted or even undetected if sent to a junk or spam email folder. Flight programs

that already have examining authority may have been disinterested in participating if they perceived the contents not pertinent to their operations. The same may be said for schools who were not planning to apply for examining authority at all, no matter what FAA changes were made. Another factor to consider is that some of those who completed the survey may not have completely understood the questions as the researchers may have expected. If the survey was conducted in person, it would have allowed the researchers to clarify the intent of what each question was asking.

Steps to help reduce the effects of the limitations listed included providing potential respondents an estimated timeline with the survey instruction overview. It was with hope that those reading the survey would not view the time investment as excessive and encourage participation. Additionally, in an effort to provide straightforward, understandable questions, two former Part 141 chief flight instructors familiar with pilot school operations reviewed the survey and provided feedback to help with the wording of the questions. The researchers recognize that the number of responses may be considered somewhat low and understand the limitations and possible biases associated. The surveys were only sent to Part 141 flight training schools, as the population accurately represents the study being conducted. As all the recipients fall under the same FAA regulations and requirements of application for examining authority, we feel this helped limit sampling bias, and the answers represent a true depiction of what pilot school views are towards the EA process.

Discussion and Conclusions

Most respondents do not currently hold examining authority status, so they rely on DPEs to conduct the majority of their practical tests (Figure 1). Prior research has indicated that pilot schools have shared that there are challenges to completing student practical tests due to a perceived shortage of DPEs. In this study, when asked if the numbers of DPEs in their area were sufficient (Figure 2), most respondents answered no. Answers to the follow-on question asking if their pilot school experiences delays scheduling DPEs (Figure 3), answers were also one sided, as most of the respondents answered yes (87%). These answers seem to indicate that the general perception is that there are not enough DPEs to meet the demands that pilot schools have for practical test completion.

If current numbers of DPEs cannot keep pace with the numbers of practical tests needed, then it stands to reason that an alternative means to complete practical tests needs to at least be considered. When asked if they believed that having EA would alleviate delays scheduling practical tests (Figure 4), again, respondents overwhelmingly answered yes. This directly answers research question number one; Do chief flight instructors think that having examining authority would help alleviate the backlog of practical tests under the current system using DPEs? Part 141 pilot schools have indicated that they do believe that having examining authority would accelerate the practical test process.

Participants were then asked questions on their pilot school's intent to apply for EA prior to, and after changes to Notice 8900.675 were announced (Figures 5 and 6). Results indicate that the majority of respondents were not applying for EA prior to the change. The results further indicate that most of those pilot schools now intend to apply after the change has gone into

effect. The reversal of those before and after numbers seem to indicate that pilot schools are more inclined to pursue examining authority now that changes have been made to the examining authority application process under 8900.1 than they were prior to those changes.

The purpose of this paper was to further examine the state of examining authority among Part 141 pilot schools. Specifically, the possible effects of publication of FAA Notice 8900.675, and if its contents could ease the path towards examining authority for those schools. As the results appear to show, Part 141 flight training providers may believe that examining authority would help alleviate the backlog of practical tests currently being experienced at their schools. The results also may show a new attitude towards application, or re-application, for examining authority due to the application requirement changes as outlined in the publication of FAA Notice 8900.675.

Future Research

The results of this study offer insight into perceptions of the examining authority approval process from Part 141 pilot schools' viewpoint. Specifically, any viewpoints that may have emerged after publication of FAA Notice 8900.675. It should be noted that this study examined challenges associated with the examining authority process only from the perspective of pilot schools. In an effort to establish parity, the researchers feel it important to gain insight from the FSDO's perspective also. FSDO personnel almost certainly experience different challenges to the process, and in fairness, we feel it necessary to examine the process from their perspective in order to provide balance to the research.

The recent availability of FAA Draft Order 8100.15 regarding Organization Designation Authorization (ODA) procedures has possibly opened a new path of research that appears to coincide with current study of examining authority. The ODA Program Overview (FAA, 2024) provides an explanation:

Reducing Designees. The designee system leverages the FAA's resources by authorizing individuals and organizations to perform functions for the agency...the FAA expects that an ODA applicant employing individual designees would, after being issued the organizational delegation, significantly reduce the number of individual designees performing the functions for which the applicant sought ODA. (p. 2-1)

As this appears to offer a possible alternative to examining authority for Part 141 pilot airman certification, it would stand to reason that a study into the comparisons between the two would be warranted.

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The Influence of Daylight Saving Time on US Civil Aviation Operations and Safety

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Daylight Saving Time (DST) involves biannual clock shifts, impacting various sectors, including transportation. While prior research has linked DST transitions to increased workplace injuries and automobile accidents, its effects on aviation safety remain unexplored. This study examines the relationship between DST transitions and aviation accident rates in the continental United States from 1978 to 2024 using data from the National Transportation Safety Board (NTSB). A statistical analysis was conducted to identify variations in accident frequencies surrounding DST transitions. Results indicate no significant increase in aviation accidents following DST changes, contrasting with findings in other industries. This study highlights DST's impact on aviation safety, by providing insights into its negligible impact on aviation safety. Future research should explore pilot fatigue and operational disruptions associated with DST through qualitative assessments of flight crew experiences.

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Introduction

Daylight Saving Time (DST) is the practice of setting the clocks forward one hour from standard time during the summer months, and back again in the fall, to make better use of natural daylight. As of 2025, approximately 70 countries, representing 40% globally participate in Daylight Saving Time practices (Buckle et al., 2025). The biannual time shift comprises a springtime one-hour advanced, known as a phase advance, and an autumnal one-hour delay, termed a phase delay.

Before industrialization, daily activities aligned naturally with sunrise and sunset (Fukuyama, 1992; Landes, 1998). Historical figures such as Benjamin Franklin and George Vernon Hudson proposed daylight optimization practices that later evolved into DST (Neumann & von Blanckenburg, 2025). Port Arthur, Ontario, Canada, was the first city in the world to enact DST, on 1 July 1908 to extend business hours (Reid, 2025). DST was first adopted nationwide in 1916 in Germany as an economic measure by the Imperial Office of the Interior to conserve coal during wartime (Neumann & von Blanckenburg, 2025). The United States followed suit with the Standard Time Act of 1918 during World War I as an energy-saving measure—based on the idea that moving the clock forward an hour meant one fewer evening hour during which electric lights were needed. Although repealed post-the war, DST was reinstated during World War II. The Uniform Time Act of 1966 standardized annual DST transitions federally, excluding Hawaii and Arizona (Brumage, 2016).

Although substantial research exists on DST's impact across sectors such as motor vehicles and industrial workplaces, the aviation industry remains relatively unexplored. Given aviation's high-reliability demands and susceptibility to human factors like fatigue and circadian disruption, understanding DST's influence on pilot performance and operational safety is crucial. This study addresses the research gap by evaluating the relationship between DST transitions and aviation accident counts within the continental United States from 1978 to 2024. The research intend to seek whether there are statistically significant differences between accident count before and after phase advance in spring and phase delay in fall.

In the next section, we present a literature review of the origin of DST and its impact on workplace and automobile accidents. We also review the impact of circadian rhythm on aviation operations. and DST impacts on aviation activities. Then, we discuss the methodology and statistical methods used for our analysis. Next, we present our results. Finally, we conclude the paper.

Literature Review

The implementation of DST has long been controversial due to its implications for human health, safety, and performance (Carter et al., 2022; Malow, 2022; Rishi et al., 2024). Several studies highlight potential negative impacts, including disruptions to circadian rhythms, leading to increased workplace injuries and transportation accidents (Roenneberg et al., 2019; Zhang et al., 2020). The effects have been associated with a variety of short-term physiological and cognitive impairments, as well as long-term health risks. Studies have documented increases

in sleep loss, cardiovascular incidents, emergency room visits, and declines in work performance and mental health (Ferrazzi et al., 2018; Zhang et al., 2020).

DST and Occupational Safety

Research has shown that DST can influence workplace safety, though findings are mixed across contexts. Barnes and Wagner (2009) found a statistically significant increase in both the number and severity of workplace injuries on the Monday following the spring DST transition. Their study, based on a National Institute for Occupational Safety and Health mining injury dataset from 1983–2006, also reported that workers averaged 40 minutes less sleep the night before. These results supported the hypothesis that sleep loss due to DST contributes directly to increased occupational risk.

In contrast, Lahti et al. (2011) analyzed occupational injury data in Finland between 2002 and 2006 and found no significant effect of DST on injury rates. Similarly, Robb and Barnes (2018), using over 12 million accident claims in New Zealand from 2005–2016, found that while DST had a strong impact on road accidents, it did not significantly affect workplace accidents. These findings suggest that DST-related occupational impacts may depend on regional work patterns, regulatory safeguards, and environmental factors.

In addition to accident rates, workplace performance and cognition have also been studied. Boubekri et al. (2020) found that optimized daylight and outside views positively influenced the sleep duration and cognitive performance of office workers. DST shifts, which reduce early morning light exposure, may therefore impair workplace functioning in subtle but measurable ways.

DST and Transportation Safety

The transportation sector, particularly road travel, has been a primary focus in DST impact studies. One of the earliest studies by Varughese and Allen (2001) identified an increase in fatal crashes on the Monday following the spring DST transition in the U.S., attributed to sleep deprivation. Smith (2016) extended this line of inquiry by estimating that DST-related sleep loss led to over 30 additional traffic fatalities annually from 2002–2011, with a corresponding social cost of \$275 million.

Fritz et al. (2024). using data from 732,835 fatal motor vehicle accidents recorded in the U.S. Fatality Analysis Reporting System between 1996 and 2017, found a 6% increase in fatal accidents in the week following the spring DST transition. They also observed greater risk among individuals residing in the western portions of time zones. More recently, Orsini et al. (2024) used simulator-based studies to show that DST can cause measurable and prolonged effects on driver fatigue, with performance decrements continuing for weeks post-transition.

Robb and Barnes ((2018) also found a 16% and 12% increase in road accident claims on the first and second days following the spring DST change in New Zealand, respectively. This study further highlighted the variability in DST impacts across accident categories, time of week, and regional conditions.

DST and Broader Health Impacts

DST's impacts extend beyond accidents into general health domains. Zhang et al. (2020) used large-scale computational models to show that DST transitions are associated with elevated risks for cardiovascular, behavioral, and immune-related disorders. Ferrazzi et al. (2018), analyzing hospital records in Italy, found increases in emergency room visits and repeat visits surrounding DST shifts, pointing to subtle but widespread health burdens.

Boubekri et al. (2020) underscored the importance of daylight exposure on sleep and cognition, noting that optimized lighting environments improve both outcomes for office workers. Given that DST delays sunrise in the spring, these changes could degrade alertness, productivity, and cognitive functioning in both professional and educational settings.

DST and Aviation Safety

While there are no studies that explicitly studied the impact of DST on aviation safety, previous studies have focused on the role of human factors in aviation safety (Hawkins, 1993; Jin & Lo, 2017; Jin & Lu, 2020; Majumdar, 2023; Majumdar & Marais, 2025; Wiegmann & Shappell, 2003; Yang & Mott, 2020). Aviation sector's dependence on alertness, precision, and circadian stability suggests a potential area of concern. Aviation professionals, including pilots and air traffic controllers, work in highly regulated environments where fatigue is a known safety risk. Researchers have also conducted studies to evaluate the effects of fatigue and circadian rhythms on aviation safety and pilot performance (Caldwell, 2012; Gander et al., 2013; Mendonca Mr et al., 2019, 2019; Roenneberg et al., 2019)

Caldwell (2012) outlined the consequences of sleep deprivation in pilots, emphasizing that circadian misalignment increases fatigue-related risks during early-morning or late-night shifts. Wingelaar-Jagt et al. (2020) further documented the effects of both acute and chronic fatigue on military and civilian aviators, showing that sustained performance degradation is likely when rest cycles are disrupted. Although DST-related time changes are accounted for in scheduling (Ryder, 2019), the transition can still disrupt sleep quality and biological rhythms, particularly for international or rotating crews.

The aviation industry's tight operational margins and reliance on alert decision-making mean even small circadian disruptions could have outsized effects. Fatigue reduces pilot alertness and cognitive functions in collegiate training setting (Keller et al., 2019), and it also affects decision-making in flight training (Keller et al., 2019). Therefore, there is a need to evaluate DST's influence as a contributor to fatigue and performance risk in flight operations.

DST's biannual one-hour clock shifts represent a form of circadian rhythm disruption that misaligns internal biological clocks with local time, particularly for flight crews. This acute misalignment can disturb normal sleep-wake patterns. Studies have shown that the spring DST transition shortens sleep duration and leaves individuals more fatigued and cognitively impaired during the day (Roenneberg et al., 2019). Previous research indicates that DST has wide-ranging effects across occupational, transportation, and health domains. While findings vary across contexts, consistent evidence suggests that sleep loss and circadian misalignment following the

spring shift can impair cognition and increase safety risks—especially in shift-based sectors like transportation.

In aviation, where performance is acutely sensitive to fatigue and circadian rhythms, these disruptions are an important concern. Caldwell (2012) found that sleep deprivation and circadian misalignment significantly degrade pilots' cognitive performance and essential flight skills, while Wingelaar-Jagt et al. (2021) documented sustained performance declines when rest cycles are disrupted. Such fatigue-induced impairments, such as slower reaction times, narrowed attention, and compromised decision-making, pose serious safety risks in flight operations. Even with schedule adjustments, DST can still affect crew rest quality and alignment, especially for pilots operating irregular or long-haul international routes. Though no prior studies have directly assessed DST's effects in aviation, the sector's high vulnerability to fatigue makes it a critical area for research. This study aims to address that gap by analyzing DST-related patterns in U.S. civil aviation incidents to inform future risk mitigation strategies.

Methodology

Data

The data for this study is obtained from the National Transportation Safety Board (NTSB). The data covers a period from 1978 to 2024 (47 years), in which we count the numbers of accidents in four categories: One Week Before DST Begins (OneWeekBeforeDSTBegins), One Week After DST Begins (OneWeekAfterDSTBegins), One Week Before DST Ends (OneWeekBeforeDSTEnds), and One Week After DST Ends (OneWeekAfterDSTEnds). Compared with the previous study focus on weekend before and after of DST change (Varughese & Allen, 2001), this study capture 7 days before and after the DST change.

In total, we have 188 cases ($n=188$), the number 846 is from 47 years x 4 weeks per year. Each case includes a total of aviation accidents during the week happen in the continental 48 states observing DST.

For this study, we selected starting year as 1978 because 1978 is the year Airline Deregulation Act signed into law and took effect and the US commercial aviation system has a structural change from the years before (Adrangi et al., 1997; Belobaba et al., 2016; Kuhn, 1970).

Statistical Methods

Based on the previous studies, we hypothesized that there would be an increase of accidents on the week after DST begins and ends. We used one tailed two sample t-test to test whether there is any statistically significant difference in accident counts across the DST change. We propose our hypotheses in the following:

$$H1_0: \mu_1 = \mu_2 \quad (1)$$

$$H1_a: \mu_1 < \mu_2 \quad (2)$$

$$H2_0: \mu_3 = \mu_4 \quad (3)$$

$$H2_a: \mu_3 < \mu_4 \quad (4)$$

μ_1 stands for the theoretical average for aviation accident counts of One Week Before DST Begins.

μ_2 stands for the theoretical average for aviation accident counts of One Week After DST Begins.

μ_3 stands for the theoretical average for aviation accident counts of One Week Before DST Ends.

μ_4 stands for the theoretical average for aviation accident counts of One Week After DST Ends.

Finally, we performed a time-series analysis on the average accident count across the time frame (1978–2024).

Results

This section presents the findings of our analysis of U.S. civil aviation accidents from 1978 to 2024. Table 1 shows summary statistics for aviation accidents recorded on different event days around DST transitions. The sample size includes all 47 years. The number of accidents ranges from 11 to 98, indicating the minimum accident count is 11, while the maximum accident count is 98.

Table 1

Descriptive Statistics for Week

Week	N	Mean	Std. Dev	Minimum	Maximum
OneWeekBeforeDSTBegins	47	37.47	20.42	13	98
OneWeekAfterDSTBegins	47	37.91	19.21	11	97
OneWeekBeforeDSTEnds	47	31.45	14.04	11	70
OneWeekAfterDSTEnds	47	29.94	13.10	12	69

The mean number of accidents varies across the Week, with the highest accident count observed during One Week Before DST Begins (OneWeekBeforeDSTBegins). Conversely, the lowest mean accident count is found during One Week After DST Ends (OneWeekAfterDSTEnds).

Table 2

Power Calculation for Two Sample T-Test

T-Test Groups	Mean Difference	Std. Dev	α two-sided	Group Sample Size	Power
μ_1 vs. μ_2	15	19.82	0.05	47	0.9771
μ_3 vs. μ_4	15	13.57	0.05	47	0.9996

We set the mean difference at 15, that is 15 accidents difference for DST transition. The statistical power for both comparisons exceeds the commonly accepted threshold of 0.80, which indicates a high probability of detecting a true effect if one exists. μ_1 vs. μ_2 has a power of 0.9771, meaning a 97.71% chance of correctly rejecting the null hypothesis if the true mean difference is 15. μ_3 vs. μ_4 has an even higher power of 0.9996 due to a smaller standard deviation, making the test more sensitive to differences.

Table 3

Tests of Homogeneity of Variances for OneWeekBeforeDSTBegins and OneWeekAfterDSTBegins

Levene's Test (F)	Levene's sig
0.238	0.627

Levene's test resulted in a p-value of 0.627, which is greater than the conventional alpha level of 0.05. This indicates that the null hypothesis of equal variances cannot be rejected. Therefore, we can assume equal variances between the two groups and proceed with the t-test under the assumption of homogeneity of variance.

Table 4

T-test for Equality of Means of OneWeekBeforeDSTBegins and OneWeekAfterDSTBegins

t	df	Sig. (1-tailed)	Mean Difference	Std. Err Difference	95% CI Difference Lower	95% CI Difference Upper
-0.109	92	0.4565	-0.447	4.09	-8.569	7.676

The one-tailed two independent samples t-test yielded a p-value of 0.457, which is greater than the conventional significance level of 0.05. This result suggests that the observed difference between the group means is not statistically significant in the hypothesized direction. Therefore, we fail to reject the null hypothesis. There is no sufficient evidence to suggest a statistically significant difference in mean counts between OneWeekBeforeDSTBegins and OneWeekAfterDSTBegins.

Table 5

Tests of Homogeneity of Variances for OneWeekBeforeDSTEnds and OneWeekAfterDSTEnds

Levene's Test (F)	Levene's sig
0.607	0.438

Levene's test resulted in a p-value of 0.438, which is greater than the conventional alpha level of 0.05. This means the assumption of equal variances is not violated. Therefore, we can

assume equal variances between the two groups and proceed with the t-test under the assumption of homogeneity of variance.

Table 6

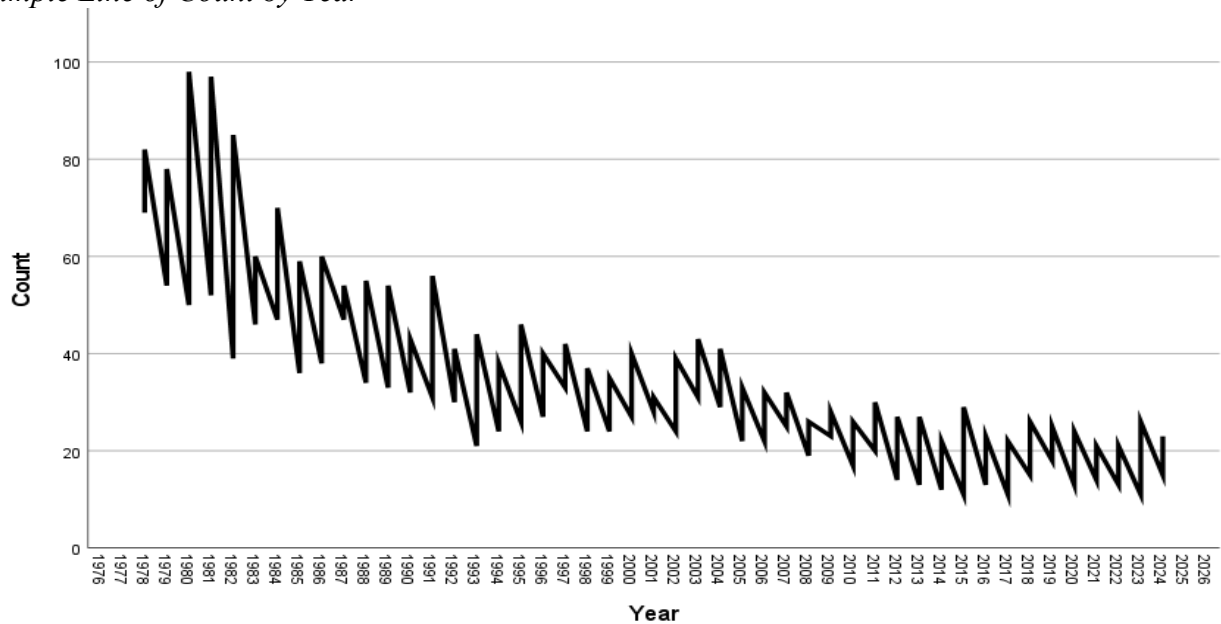
T-test for Equality of Means of OneWeekBeforeDSTEnds and OneWeekAfterDSTEnds

t	df	Sig. (1-tailed)	Mean Difference	Std. Err Difference	95% CI Difference Lower	95% CI Difference Upper
-0.539	92	0.2955	-1.511	2.801	-7.074	4.052

The one tailed two sample t-test returned a p-value of 0.296, which is greater than the typical alpha level of 0.05. This means the observed difference in means is not statistically significant in the expected direction. Therefore, we fail to reject the null hypothesis. There is no sufficient evidence to conclude that the mean count in the week before DST ends is different (specifically lower) than the week after DST ends.

Figure 1

Simple Line of Count by Year



The chart above reveals a consistent and sharp downward trend, suggesting accidents happened during each year has substantially decreased over time. This trend likely reflects a steadily improving aviation safety record, attributable to multiple factors, including:

- advancements in aviation technology,
- improved understanding of human factors,

- the implementation of Safety Management Systems (SMS), and
- more effective organizational and regulatory practices.

These improvements have been widely documented in the literature (Bowen & Lu, 2004; Cusick et al., 2017; Perrow, 2011; Stolzer, 2016; Wiegmann & Shappell, 2003).

Conclusion

This study examined the potential relationship between Daylight Saving Time (DST) transitions and aviation accident rates across the continental United States from 1978 to 2024. In contrast to other sectors, such as road transportation and occupational safety, our findings did not reveal statistically significant differences between accident count before and after phase advance in spring and phase delay in fall. As for the practical difference in term of accident count change between two weeks of DST transition, there is 0.34 increase in spring (you lose one hour) and there is 1.51 decrease in fall (you gain one hour). That generally complies with our experience, most of us feel happy with extra hour of sleep in the morning!

Future research should explore these subtler impacts using natural language processing techniques to analyze unstructured narrative accident reports. Additionally, qualitative studies examining flight crew and ground crew experiences could offer valuable insights into how DST affects fatigue and operational performance. As for policy discussions about the permanence or abolition of DST continue, such evidence-based insights will be vital to guide aviation scheduling and fatigue management practices.

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Fostering Active Learning through AI-Integrated Platforms: Student Perceptions from a Large Enrollment Professional Education Course

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This study investigates how AI-integrated online learning platforms influence student engagement and learning experiences in a large enrollment, foundational course within a professional education program. Drawing on survey responses from 109 undergraduate students enrolled in an introductory aviation course, we assess student perceptions of an AI-supported classroom platform and examine whether these perceptions differ between students on flight and non-flight academic pathways. Most students reported positive experiences, particularly valuing features such as live polls and real-time feedback that supported interaction and knowledge reinforcement. Although no statistically significant differences were found between pilot and non-pilot students, pilot students expressed a stronger preference for collaborative and communicative functions. Open-ended feedback also identified areas for platform improvement, including enhanced integration with learning management systems and expanded AI functionalities. The findings offer practical implications for educators seeking to adopt AI-enhanced tools to support active learning and provide insights into how such technologies can be effectively implemented in structured, high-enrollment courses across disciplines.

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Introduction

Digital learning platforms have become widely integral to modern higher education, enhancing knowledge retention, increasing student engagement, and minimizing distractions from electronic devices in classrooms. Their significance has grown substantially during and after the COVID-19 pandemic, as educational institutions have increasingly adopted blended and hybrid learning approaches to provide flexible and adaptive educational experiences (Guppy et al., 2022). The widespread implementation of such platforms has prompted educators to examine how these platforms influence student engagement, learning outcomes, and classroom dynamics across various disciplines. Previous studies indicate that digital tools in the classroom can significantly enhance student engagement (Byon, 2005; Stavitskyi & Urazgaliyeva, 2018). More recent studies also suggest that AI-integrated educational technologies may foster student creativity and contribute to more interactive and supportive learning environments (Hwang et al., 2022).

While substantial research has been conducted on digital platforms in general education contexts, there is limited empirical evidence concerning their use in structured, professional education domains where high cognitive load and procedural knowledge are emphasized. One such domain is aviation education, which demands rapid information processing, strict adherence to safety protocols, and highly structured training environments. The insights drawn from such settings can inform broader applications in similarly intensive disciplines, such as engineering and healthcare. This study investigates the effectiveness of AI-integrated online platforms within a large-enrollment, introductory aviation course at a U.S. base university. In doing so, it contributes to the scholarship of teaching and learning by offering evidence-based insights into how digital platforms can enhance student engagement and learning experiences in classroom settings that present challenges for interactivity and personalization. The study further explores whether differences exist between students on distinct academic pathways. Specifically, between those training to become professional pilots and those pursuing aviation-related non-flight majors. The study seeks to answer the following questions:

Q1: How do students perceive the use of AI-integrated online learning platforms in their learning experience?

Q2: Which features best support in-class engagement and learning outcomes, and what improvements do students suggest?

Q3: Do pilot and non-pilot students perceive in-class online platforms differently?

Understanding the impact of AI-integrated online classroom platforms is critical for helping aviation educators make informed decisions about the adoption and integration of these technologies into their instructional practices. Given the distinct learning needs and performance expectations in aviation education, such insights are especially valuable for ensuring that technological tools align with pedagogical goals. Student feedback can offer practical guidance for the ongoing development and refinement of digital platforms, ensuring they are responsive to user needs and capable of enhancing both engagement and learning outcomes. Moreover, these findings may contribute to broader discussions on the role of AI in specialized professional education and inform future research and policy in this area.

The remainder of this paper is organized as follows. The next section reviews prior research on online learning platforms, the application of AI in education, and existing studies focused on aviation students. The Methodology section outlines the study context, describes the AI-integrated platform used, and details the survey instrument and data analysis procedures. The final sections present the findings and offer a discussion of the results in light of existing literature.

Literature Review

The adoption of digital learning platforms has become increasingly prominent in modern education, with a recent trend of incorporating AI-based functions (Ikedinachi et al., 2019; Luo & Hsiao-Chin, 2023). While the COVID-19 pandemic catalyzed significant growth in remote learning research, this study focuses on the use of digital tools in face-to-face classrooms settings. This section synthesizes current literature on digital learning technologies, their effectiveness in fostering engagement and learning experiences, and the role of AI-driven features in shaping modern educational practices.

Classroom Technology Tools and Student Engagement

Technology tools in the classroom have demonstrated the potential to increase student engagement, though their effects on academic performance and attendance remain less conclusive. For example, Young (2008) noted that while these tools enhance engagement, they do not consistently translate to improved grades or attendance, and their impact on self-study remains uncertain. Successful integration relies heavily on continuous teacher training and support. Interactive tools, such as those used in computer graphics education, can motivate students and reinforce learning. However, the Think-Pair-Share (TPS) model received mixed feedback, as many students preferred individual tasks, underscoring the need for strategic implementation (Schweitzer et al., 2011).

Several studies highlight the role of digital platforms in enhancing engagement. The Student Response System (SRS), for instance, significantly boosts classroom participation, although student preferences vary (Malandrino et al., 2014). Additionally, Classroom Assessment Techniques (CATs) also support instructional improvement and student satisfaction despite initial resistance to adopting new technologies (Byon, 2005).

Another commonly used category is digital learning platforms, which influence student engagement and activity differently. For example, Google Classroom has been linked to improved cognitive activity and motivation (Stavytskyi & Urazgaliyeva, 2018), while Quizizz, with its gamified interface, was favored for encouraging greater participation (Ramadhan, 2022). Similarly, platforms like Edmodo and Quipper promote independent learning and language skills practice, even though they sometimes face technical challenges such as slow internet speeds (Cakrawati, 2017).

While technology tools in the classroom improve motivation and engagement, their impact on academic performance and self-study effectiveness needs more exploration. Effective implementation relies on comprehensive teacher training and support and thoughtful

consideration of appropriate methodologies to maximize student engagement and learning outcomes.

Artificial Intelligence in Education

Ng et al. (2023) analyzed the evolution of AI in education over two decades, focusing on applications in teaching and learning. Key advancements include Intelligent Tutoring Systems (ITS), adaptive learning systems, natural language processing (NLP), learning analytics, and AI-driven robotics and virtual assistants. These tools support personalized learning, data-informed decision-making, and improved student engagement. Rincon-Flores et al. (2020) emphasized the promise of predictive analytics in enhancing outcomes, predicting individual student performance accurately remains challenging. Although AI seems good to both students and teachers, it should only complement rather than replace traditional teaching methods. While AI can enhance assessments and mentoring, it cannot substitute the human elements of teaching, such as character development and interpersonal communication (Fitria, 2021).

As AI tools are increasingly embedded in online learning platforms, a range of features that directly support teaching and learning are offering. These include automated summarization of student posts, intelligent tutoring systems, adaptive or personalized learning paths, chatbots and virtual assistants, real-time feedback mechanisms, and automated assessments (Chen et al., 2020; Zawacki-Richter et al., 2019). Collectively, such features can automate routine administrative tasks, reduce instructor workload, and enable personalized learning experiences that enhance system quality, information quality, and service quality (Hamzah et al., 2025). For instance, AI-powered assistants and chatbots can provide students with immediate support, although their success depends on proper training and ongoing support for both students and instructors (Chen et al., 2023; Singh & Hiran, 2022). Similarly, studies show that AI-generated learning materials and adaptive pathways foster deeper engagement, active learning, and improved knowledge retention, though barriers to adoption remain (Aluko et al., 2025). Within this broader landscape, our study underscores the role of AI-driven summarization, which helped students in a large lecture course quickly synthesize peer contributions from discussion boards. By condensing dozens of responses into concise takeaways, the summarization feature reduced cognitive load, improved accessibility of collective insights, and created new opportunities for active engagement with course material.

In addition, from the instructor's perspective, AI tools also help to enhance teaching efficiency by providing personalized learning experiences and automating routine tasks, but challenges such as potential biases, low-quality information, and the risk of learner isolation need to be managed to ensure effective AI integration in education (Edali et al., 2024). Research also highlights that while AI systems can strengthen learner-instructor interactions and deliver in time and personalized support, they may raise concerns regarding responsibility, agency, and surveillance, pointing to the importance of explainability and human oversight (Seo et al., 2021). Thus, ethical considerations and teacher training are essential for effective implementation (Bozic, 2023). Involving teachers in the design process ensures AI tools meet their needs and enhances their willingness to integrate AI. Co-designing fosters a better understanding of AI's capabilities and limitations among educators (Nazaretsky et al., 2022). These points highlight that ethical and practical considerations are crucial for the successful adoption of AI in

education. The most existing studies on the integration of classroom technology tools and AI in education, such as those by Bozic (2023), Cakrawati (2017), and Singh & Hiran (2022), have explored the general educational landscape, highlighting the benefits and challenges of AI and digital platforms in primary, secondary, and higher education settings.

Personality and Cognitive Performance of Pilot Students

Within aviation education, the critical importance of safety in flight training has driven research on pilot students' personality traits, cognitive abilities, and learning styles, as well as the differences between pilot and non-pilot students.

Research has consistently shown that pilots exhibit distinct features compared to the general population. Pilot students tend to have superior stress management and cognitive performance. Dillinger et al. (2003) found that pilot students demonstrate enhanced stress-coping abilities and cognitive processing abilities distinguish them from non-pilots, while Barkhuizen et al. (2002) reported faster information processing and reaction times, with a classification accuracy of 92.3% distinguishing them from non-pilots.

Personality studies have revealed that pilot students score higher on Agreeableness and Conscientiousness compared to other traits (Gao & Kong, 2016). These traits reflect cooperation and task diligence. Neuroticism was the only trait showing a statistically significant difference between pilot and non-pilot groups, suggesting that pilots are generally more emotionally stable. Cognitive preference assessments using the Myers-Briggs Type Indicator (MBTI) show that pilot students often exhibit the ISTJ profile, favoring logical, structured problem-solving (Fussell et al., 2018). They also value collaboration and diverse perspectives in group settings.

Research into pilot students' learning styles has demonstrated that they prefer structured, systematic, and goal-oriented learning. The Kolb Learning Style Inventory identifies them as predominantly Converging and Assimilating learners, favoring abstract conceptualization and logical analysis (Gao et al., 2013; Kanske & Brewster, 2001). These preferences align with the rigorous and procedural nature of flight training. Reesman and Birdsong (2023) also emphasized that pilots benefit from visual and active learning strategies, reflecting their hands-on training environments.

In summary, integrating digital platforms and AI into classrooms can enhance learning efficiency and engagement when implemented with careful planning and sufficient support. However, in aviation education, particularly for pilot students, the structured and discipline-driven nature of training necessitates tailored learning technologies. Despite increasing interest in digital and AI-enhanced learning, there remains limited research on how these tools align with the unique cognitive and personality traits of aviation students. Few studies have examined how such platforms are perceived by pilot versus non-pilot students. This study aims to fill that gap by evaluating the impact of AI-driven classroom platforms in an introductory aviation course, offering insights into how these technologies can be optimized for aviation education.

Methodology

Research Setting

This study was conducted within the aviation department of a U.S. based university that offers a range of collegiate aviation programs, including flight, aeronautical engineering, unmanned aerial systems, and aviation management. The curriculum selected for this study is an introductory 3-credit hours course that is a required component across four undergraduate aviation programs. As a foundational course, it provides students with a broad overview of the aviation industry, covering its historical development, regulatory framework, and the roles of key stakeholders. By the end of the course, students are expected to develop a broad understanding of the aviation industry's historical development, connect past trends to contemporary challenges, and synthesize diverse sources of information to interpret critical topics in the field.

Major assessments in the course include ten online quizzes, three exams, and one group presentation. In addition, in-class activities conducted through the CampusKnot platform provided opportunities for extra credit. Prior to this study, the course primarily followed a traditional lecture-based format, with limited opportunities for student-driven or interactive learning, largely due to its enrollment size of more than 100 students per semester. This practical challenge made the course an ideal setting to investigate the impact of integrating active, technology-supported instructional strategies.

Students enrolled in the course primarily came from aviation-related programs, which diversely consist of both academic focus and technical experience. For the purposes of this study, students in the flight program who have received structured flight training are referred to as “pilot students”. Those enrolled in other non-flight majors are categorized as “non-pilot students”. This distinction allowed for a comparative analysis of how different career pathways may influence student engagement and perceptions of digital learning platforms.

CampusKnot Integration

Throughout the selected semester, we integrated a specific online learning platform, CampusKnot, into classroom activities to enhance class engagement and participation. CampusKnot is an AI-enhanced teaching assistant that helps faculty increase engagement by gathering real-time feedback and streamlining classroom interactions. From driving participation to eliminating the upkeep of engagement, Campusknot transforms the learning environment into an exciting hub of active student involvement. The platform offers a variety of features. Table 1 below outlines the primary functions, Polls and Feeds, and how they applied.

Table 1

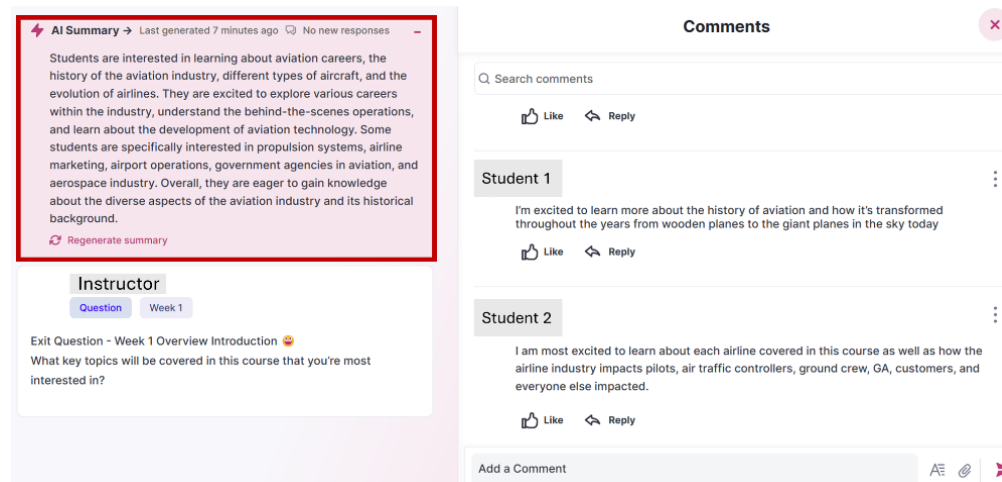
CampusKnot Functions for In-class Activities

Functions	Description
Polls	<i>Multiple-choice Questions:</i> Assess students' understanding of content in real time. <i>Open-ended Questions:</i> Encouraged deeper reflection and creative responses. <i>Word Cloud:</i> Captured a collective snapshot of students' perspectives.
Feeds	Served as a forum for students to post and reply to peers and instructors, promoting active discussion. Frequently used for lecture exit questions and reflection prompts. Included an AI-generated summary feature (see Figure 1).

The Polls feature engages students through multiple-choice and open-ended questions, helping assess prior knowledge and real-time understanding. An optional word cloud function helps to visualize common themes from student responses. Feeds functioned as a discussion forum where students could ask questions, share ideas, and reflect on lecture content, providing an outlet for those less comfortable speaking in class. They also featured an AI-generated summary tool (Figure 1), which offered concise recaps of student contributions.

Figure 1

AI Summary Function in Feed



Over the semester, 13 discussion prompts were posted through CampusKnot Feeds, align with lecture topics such as aviation careers, historical milestones, aircraft development, and general aviation, etc. These prompts invited students to comment on key ideas, connect concepts, and exchange perspectives with peers. Table 2 presents participation patterns from the first eight lectures that show consistently high levels of engagement. The AI summary function was particularly valuable in this large-class setting where the volume of responses could otherwise be challenging to synthesize.

Table 2*Summary of Student Discussion Board Activities (First Eight Lectures)*

Lectures	Lecture / Discussion Prompt	Views	Comments
1	Overview & Introduction – key topics of interest	136	83
2	Aviation Careers – future career interests	121	73
3	Aviation Milestones – reflection discussion	112	23
4	Aircraft Development – favorite aircraft	101	54
5	Milestones of Airlines – key takeaways	95	43
6	Pan American Airways – reflection discussion	88	23
7	General Aviation – thoughts/questions	79	24
8	Aerospace Industry – reflection discussion	64	26

Survey Design and Data Collection

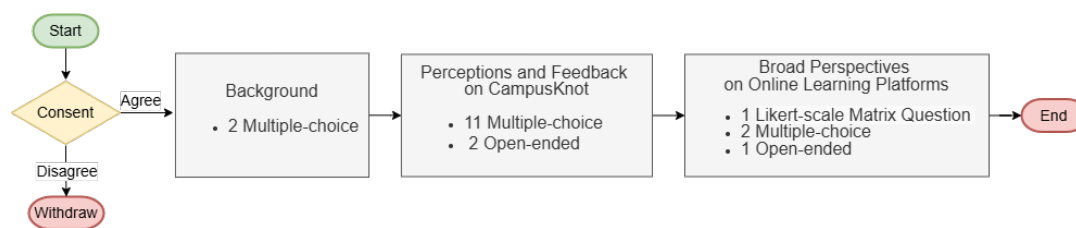
The survey instrument was developed using established design strategies informed by prior studies on student perceptions of online learning platforms, including but not limited to study of Cakrawati (2017), Byon (2005), and Ramadhan (2022), etc. Our survey include mixture of multiple question formats, including Likert-scale items, matrix questions, and open-ended questions. These widely used approaches is easy to measure levels of agreement or satisfaction, also capture nuanced attitudes and provide richer data for analysis and interpretation. To ensure content validity and clarity, the draft questionnaire was reviewed by two faculty experts in aviation education and two representatives from CampusKnot, the platform partner. The external reviewers brought extensive experience in education and technology, particularly in faculty onboarding, product feature testing, and classroom engagement strategies. Their feedback, together with the disciplinary expertise of aviation faculty, was instrumental in refining both the design and wording of survey items, ensuring the instrument was methodologically sound, research-based, and practically applicable.

We utilized a Qualtrics-based online survey to capture students' perceptions of CampusKnot and their broader attitudes toward online learning platforms. Participants were recruited from a course already using the CampusKnot platform, representing a convenience sample of enrolled students. An Institutional Review Board (IRB) approval was secured prior to conducting the survey. Students' participation was completely voluntary, and informed consent was obtained from all participants, and confidentiality is maintained by anonymizing data and securely storing materials.

Following consent, students provided background information such as their major and academic standing. The survey is divided into two main sections and took approximately 10–15 minutes to complete (Figure 2 illustrates the survey flow).

Figure 2

The Survey Flow



The first section of the survey examined students' classroom experiences using CampusKnot, assessing its perceived impact on engagement and learning outcomes. Students were asked about their motivation for participation, perceived benefits for engagement and academic performance, preferred platform features, and suggested improvements. This section consisted of multiple-choice and open-ended questions (Table 3 lists the questions in the first section).

Table 3

Survey Questions on Student Perceptions of CampusKnot

Category	No	Question
Overall Experience	Q2.1	How would you rate your overall experience using CampusKnot during this semester?
	Q2.2	How easy is it to navigate CampusKnot's interface and access its features?
Motivation	Q2.3	What are your primary reasons for participating in CampusKnot activities?
	Q2.4	How often do you participate in CampusKnot activities?
Features	Q2.5	What types of CampusKnot activities do you find most engaging?
	Q2.6	How do you feel about the "AI Summary" feature in the Feed discussions, which provides a summary of all the comments?
Learning Experience and Perceived Benefits	Q2.7	How do you feel that using CampusKnot influences your in-class learning experience?
	Q2.8	Has using CampusKnot motivated you to be more active in other areas beyond platform activities, such as participating in discussions, contributing to group projects, or reaching out for help?
	Q2.9	Do you feel that participating in activities on CampusKnot helps you better understand the course material?
	Q2.10	Do you think participating in CampusKnot activities positively influences your academic performance in this course (e.g., on quizzes and exams)?
Integration with Learning	Q2.11	Do you feel that CampusKnot (used for in-class activities) effectively complements Brightspace (used for quizzes, exams, and announcements)?

Management System		
Additional Feedback	Q2.12	What did you like the most about the CampusKnot activities and why?
	Q2.13	Any additional comments or feedback about CampusKnot?

The second section explored students' overall perceptions of digital learning tools beyond CampusKnot. It featured a 5-point Likert scale matrix designed to assess general attitudes, with response options ranging from "Strongly agree (5)" to "Strongly disagree (1)". Additional follow-up questions further gather insights into platform preferences and engagement. The responses from this matrix question enabled a comparative analysis of attitudes and experiences between pilot and non-pilot students, shedding light on how program affiliation may influence students' perception on digital learning engagement.

Data used in this study was collected through an online survey distributed at the end of the Fall 2024 semester, between November 13 and December 16, 2024, to all 147 students enrolled in the course. By the time of data collection, students had engaged with CampusKnot consistently, providing sufficient exposure to offer informed feedback. A total of 115 submissions were received, with a response rate of 78.2%. After filtering out incomplete responses, 109 valid responses remained, resulting in a validity rate of 94.7%.

Data Analysis

Qualitative Analysis

Qualitative coding is a systematic method used to analyze textual data by identifying key themes and patterns through labeled segments of information. This approach helps researchers organize unstructured responses while preserving the contextual depth of qualitative insights (Auerbach & Silverstein, 2003). The coding process can follow a deductive approach, where predefined codes are applied based on existing theories, or an inductive approach, where themes emerge directly from the data (Williams & Moser, 2019). Given its iterative nature, qualitative coding often involves multiple rounds of refinement to ensure accuracy and relevance (Elliott, 2018). Researchers may conduct coding manually or use qualitative analysis software such as NVivo or ATLAS.ti to manage large datasets efficiently. Regardless of the method, the interpretative nature of coding ensures that the process remains human-centered (Williams & Moser, 2019).

This study employs an inductive coding approach to analyze open-ended survey responses, allowing key themes to emerge naturally from student feedback. Qualitative data is first reviewed to identify recurring keywords related to the question's purpose, such as platform usability, influence on engagement level, and feature preferences. These initial codes are refined and categorized into broader themes, and the frequency at which particular themes appear is recorded. Given the moderate dataset size, manual coding was chosen to maintain deep engagement with the data while leveraging R for efficient frequency counting. This approach ensured that the textual data is systematically analyzed, offering a rigorous reflection of students' feedback about online learning platforms.

Quantitative Analysis

For multiple-choice questions, descriptive statistics are employed to provide a summary of the responses. Frequency distribution, means, and standard deviations were computed to assess overall patterns in student perceptions. Bar charts are utilized to visualize response patterns and facilitate an intuitive understanding of the data distribution.

To examine whether pilot and non-pilot students differ in their perceptions of online learning platforms (Q3.1, matrix question using the Likert scale), a Chi-square test is performed. This test assesses the association between two categorical variables by comparing observed and expected frequencies under the null hypothesis:

H_0 : There is no association between student type (pilot students vs. non-pilot students) and their perceptions of online learning platforms.

The Chi-square statistic is calculated as:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

where O_i is the observed frequency of responses in each category and E_i is the expected frequency assuming no relationship (Rana & Singhal, 2015; Swinscow et al., 2002). Degrees of freedom (df) are computed as:

$$df = (r - 1) \times (c - 1)$$

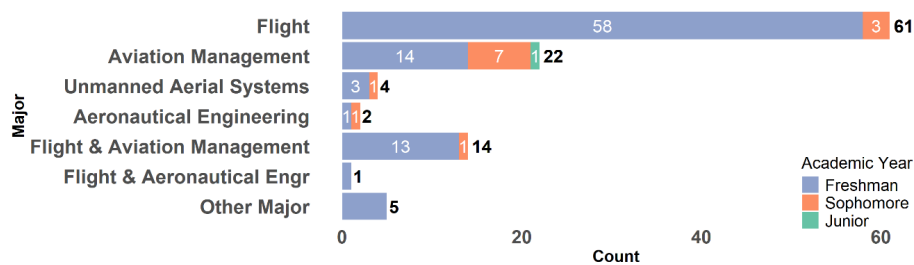
where r is number of categories in one variable and c is the number of categories in the second variable. The resulting Chi-square value is then compared to a critical value with a statistical significance at $\alpha=0.05$. If the calculated Chi-square value exceeds the critical value, the null hypothesis is rejected, indicating a significant association between student type and their perceptions of online learning platforms. Otherwise, the null hypothesis is retained, suggesting no meaningful relationship.

Results and Discussions

This section presents survey findings. Using descriptive statistics and thematic coding of open-ended responses, we first report participant demographics, examine student feedback on CampusKnot, compare perceptions between pilot and non-pilot students, and highlight student perspectives on the overall future role of AI related and desired platform features.

Demographics

The survey initially gathered background information from students. First-year students comprise the largest group, with 95 respondents (Figure 3). Sophomores account for a smaller proportion, with 13 participants, while Juniors have the least representation, with only one respondent. No Seniors participated in the survey.

Figure 3*Demographic of Survey Participants*

Regarding majors, the majority of students are in aviation-related fields. The largest group of respondents comes from the flight program with 61 pilot students, followed by students from the aviation management. Fewer students came from the aeronautic engineering and unmanned aerial systems programs. Some participants working on double majors within aviation department, including flight along with aviation management or unmanned aerial systems, showed comparatively smaller distributions, mainly made up of Freshmen. Furthermore, 5 first-year students are from other departments, such as psychological science and exploration program.

Feedback about CampusKnot

The first part of the survey explores students' perceptions of using CampusKnot in class, covering various categories including overall experience, motivation, engagement with platform features, and perceived learning benefits. The final two questions let students share open-ended feedback, providing a deeper understanding of their experiences and potential areas for improvement.

Overall Experience

Regarding students' satisfaction with CampusKnot in class (Q2.1 & Q2.2), nearly 90% of students rate their overall experience as extremely or somewhat satisfied and find the interface and features easy to navigate. A small group of students expressed a neutral attitude, while only about 5% provided negative feedback regarding the platform's usability and overall experience. The specific concerns raised by this group will be addressed later in the open-ended responses.

Motivation

Given that we offer extra credit for some activities, one of our goals was to understand what motivates students to participate, whether they are primarily driven by extrinsic rewards or if other factors, such as enhancing learning, also play a role. Question 2.3 asks students about their motivations for using CampusKnot. There are 96.3% of respondents selected earning extra credit as their primary motivation, highlighting the strong influence of extrinsic incentives. Staying engaged with the class (48.6%) is the second most selected reason, followed by interacting with classmates or the instructor (22.0%) and reinforcing course material to deepen

understanding (20.2%). A smaller portion of students (8.3%) indicate personal interest in the topics.

Question 2.4 explores how frequently students use CampusKnot. About 27.5% reported participating almost every time the instructor posts a question, regardless of whether it offers extra credit. Another 34.9% said they primarily engage in activities that offer extra credit, though some also participated in non-credit activities that interested them. These findings suggest that while extra credit was the dominant motivator, many students are involved to fostering class engagement and enhancing learning experiences.

Features

As discussed earlier, various in-class activities were implemented with different objectives in mind, and the following questions examined which activities they found most compelling, as well as their perceptions of AI-powered features.

Question 2.5 shows that multiple-choice questions stand out as the most engaging activity, with 87.2% of students selecting this option, suggesting that students prefer quick assessment activities that offer instant responses. Discussion activities were the second most engaging (32.1%), followed by open-ended questions (21.1%) and word cloud activities (17.4%). These results indicate a strong preference for structured, concise prompts like multiple-choice questions, while a smaller but notable group values open-ended formats that encourage deeper interaction.

The feedback is mixed from responses about "AI Summary" function that automatically generates a summary of feed discussions (Question 2.6). A significant portion (33.9%) found it "very useful", stating that it helped them quickly grasp the main points without reading through every comment. Another group (28.4%) considered it "somewhat useful", acknowledging its convenience but still preferring to review the entire discussion for added context. A smaller segment (7.3%) did not find the feature beneficial, expressing a preference for reading all comments themselves. Moreover, the remaining students reported being unaware of this function, suggesting that a portion of users may not fully explore the platform on their own and that more explicit guidance or demonstrations could improve adoption.

Learning Experience and Perceived Benefits

The following questions explore how the platform influences students' classroom learning experiences and their perceptions of its impact on academic performance. Since actual grades are unavailable, the findings rely entirely on students' self-reported experiences.

In terms of the platform's effect on in-class learning experience (Question 2.7), the majority indicates that it has significantly or somewhat improved their learning experience (79.8%). Some students (20.2%) feel that it has had no impact, and no respondents feel it has negatively affected their learning. The role of CampusKnot in enhancing engagement beyond platform activities (Question 2.8), such as discussions, group work, or seeking help, is also worth considering. About 57.8% of students feel at least somewhat more motivated to participate in

these broader academic activities after using the platform, suggesting that its interactive features may encourage greater involvement beyond the structured tasks. On the other hand, a smaller group does not experience this effect (25.7%), indicating that while the platform supports engagement for many, its impact may depend on individual learning preferences and habits.

Regarding the effect on understanding course material (Question 2.9), most students (83.5%) strongly or somewhat agree that the platform's activities help them grasp the course more effectively. A smaller group of students (15.6%) remains neutral, while only one student disagrees with the helpfulness of the platform. A similar pattern can be observed in response to Question 2.10, which asks for the platform's influence on academic performance, including quizzes and exams. The majority of students believe it has a positive impact (78%). There are 18.3% respondents remain neutral, and 3.7% students express disagreement, indicating that while many find it beneficial, its effect on performance may vary based on individual study habits and learning preferences.

Effectiveness of Integration with Learning Management System

During the study period, CampusKnot was used exclusively for in-class activities, while Brightspace hosted all other materials and assessments. When asked about CampusKnot's effectiveness (Q2.11), 82.57% of students reported a positive experience, noting it enhanced their learning. However, 7.4% cited technical issues like lag and suggested improvements. Open-ended feedback (Table 4) praised interactive features like live polls but also reflected a desire for greater platform integration to streamline course access.

Table 4

Key Themes and Frequency of Open-ended Responses for Q2.11 "Do you feel that CampusKnot effectively complements Brightspace?"

Theme	Count	Example Quote
Technical Issues	7	"Sometimes it would lag, causing distraction."
Improve Engagement and Interactivity	4	"I found live poll effective and engages students."
Perceived Added Value	3	"Didn't feel like anything extra, though the extra credit was nice."
Integration Concerns	2	"I would be much more satisfied if Brightspace was used for everything."

Additional Feedback

The analysis of responses asking what students like most shows that students most frequently appreciated the platform's ability to enhance engagement and promote interactive learning, with 26 respondents emphasizing its role in fostering active participation (Table 5). They also value its ease of use and intuitive navigation, as mentioned by 21 respondents, underscoring the importance of a user-friendly interface. Additionally, 18 respondents noted that the platform effectively reinforced course material and provided valuable real-time feedback

through live polls, while external motivators such as extra credit were highlighted as key drivers of participation.

Table 5

Key Theme Frequency of Open-ended Responses for Q2.12 “What did you like the most about the CampusKnot activities and why?”

Theme	Coding Keywords	Count	Example Quote
Engagement & Interactive	Engage, interaction, fun, motivating, active learning, participation, immersive experience, class involvement	26	“Engagement features: Campus knot helps me to interact with instructor and other students.”
Knowledge Reinforcement & Study Aid	Understand, learn, quiz, review, practice, apply knowledge, reinforce, study tool	18	“Helps reinforce some of the more important things we just learned.”
Ease of Use & Intuitive Navigation	Easy to use, navigate, accessible, user-friendly, simple, clean, straightforward, modern, convenient, intuitive, interface	21	“Clean and user-friendly interface. Easy to navigate.”
Live Polls & Real-Time Feedback	Live polls, pop-up, real-time, interactive questions, instant feedback, immediate results, gauge understanding	18	“To get real time feedback so that I can know whether I was correct or not right after I submit.”
Extra Credit & Incentives	Extra credit, bonus, reward, incentive, earning points	17	“Live Polls. It is interesting to get extra credit and also know information.”
Interaction with Classmates & Peer Collaboration	Responses, ideas, discussion, classmates, collaboration, peer feedback, shared insights	11	“I think learning more about my classmates’ opinions was interesting.”
Accessibility Across Multiple Devices	Cross-device, multiple platforms, anywhere access, available on the phone	1	“I liked that I could get it on many devices.”

In response to the open-ended question (Q2.13) inviting any additional comments about CampusKnot, many students offered positive feedback, highlighting the platform's usefulness, interactivity, and ease of use. However, several students also raised concerns, particularly related to technical issues such as lag, slow loading, and connectivity problems. In addition, some respondents expressed a desire for better integration with the university's existing learning management system, Brightspace, to streamline their learning experience. Other suggestions

included interface improvements, such as the addition of a dark mode or more robust server capacity to handle higher user loads.

Table 6

Key Theme Frequency of Open-ended Responses for Q2.13 “Any additional comments or feedback about CampusKnot?”

Theme	Keywords	Count	Example Quote
Positive Feedback	Good, useful, positive, nice, love, like, great	10	“I like Campusknot.”
Technical Issues	Lag, slow, connectivity, loading, server, WiFi	6	“Experienced connectivity issues throughout the class.”
Integration with Brightspace	Brightspace, integrate, replacement	3	“It would be amazing if CampusKnot was (ever) integrated into Brightspace.”
Suggestions & Improvements	Dark mode, improve, new feature	2	“Need a better server to hold more students online at the same time. And UI needs improvement.”

General Perception of In-class Online Learning Platforms

The second part of the survey focused on students' general perceptions of in-class online learning platforms. A Likert-scale matrix question (Table 7) using a 5-point Likert scale to assess various dimensions of the online platform's influence on the learning experience, including engagement, focus, motivation, understanding of course material, confidence in subject knowledge, anticipated academic impact, and discussion participation.

To compare the differences between pilot and non-pilot students, Chi-square tests were performed on each sub-question. For consistency, students pursuing a double major or belonging to other majors are excluded from this analysis. Although the Likert-scale data are ordinal, the chi-square tests provided valuable insights into whether the distribution of responses differed significantly between the two groups. Table 7 below summarizes the descriptive statistics (mean and standard deviation) for both pilot and non-pilot students, as well as the chi-square test results for eight sub-questions.

For most of the sub-questions, the descriptive statistics indicated similar central tendencies between the groups. With mean ratings generally above four, indicating positive experiences with online learning platforms. Pilot students tend to have higher scores with higher standard deviation, indicating that pilot students tend to have overall higher recognition but more different perceptions about online platforms used in class.

The Chi-square tests suggest that there are no statistically significant differences between both groups for all the statements we asked. Both pilot and non-pilot students have similar positive perceptions of in-class online learning platforms.

Table 7

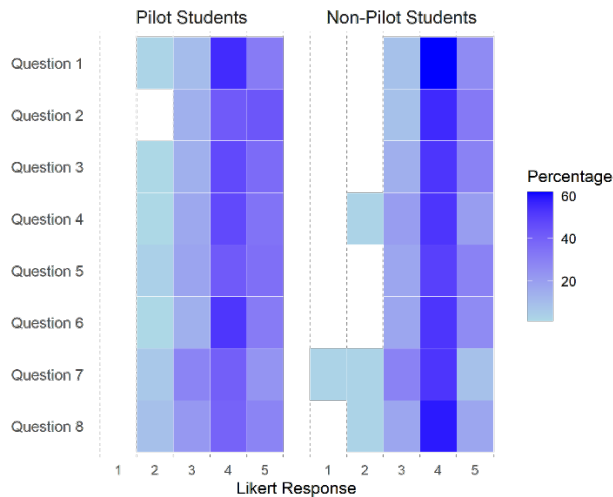
Student Perceptions of the Usage of In-class Online Platforms (Q3.1)

No	Question	Pilot Students (Mean±SD)	Non-pilot Students (Mean±SD)	χ^2 Statistic	P value
1	Using an online learning platform during class usually makes me feel more engaged in the course content.	4.16 ± 0.71	4.18 ± 0.58	1.34	0.72
2	I find it easier to stay focused during class when interactive online activities are used.	4.29 ± 0.71	4.24 ± 0.61	2.28	0.32
3	I feel more motivated to participate in class when interactive activities are available online.	4.20 ± 0.73	4.15 ± 0.67	0.96	0.81
4	Online activities in class often enhance my understanding of the course material.	4.14 ± 0.74	3.94 ± 0.75	2.10	0.55
5	I feel more confident in my knowledge of the course material when I regularly participate in online platform activities.	4.09 ± 0.84	4.12 ± 0.70	1.94	0.58
6	I believe participating in activities on online platforms will positively influence my academic performance.	4.14 ± 0.71	4.09 ± 0.68	0.79	0.85
7	Online learning platforms make it easier for me to connect with other students and the instructor.	3.82 ± 0.88	3.64 ± 0.82	6.36	0.17
8	Online learning platforms encourage me to engage in discussions or ask questions that I may not participate in otherwise.	3.88 ± 0.94	3.94 ± 0.70	4.67	0.19

Although the Chi-square results indicate no statistically significant difference between the two groups at the $\alpha=0.05$ level, the p-value of Questions 7 and 8 is the lowest, suggesting notable discrepancies between pilot and non-pilot students. To provide a clearer comparison, Figure 4 illustrates the percentage distribution of responses for each sub-question. Notably, more pilot students reported that online learning platforms encouraged them to connect with others and participate in discussions they might otherwise avoid. This suggests that pilot students may place greater value on the social and collaborative features of online platforms. This finding aligns with existing literature highlighting pilot students' distinct personality traits and preferences, such as a tendency toward teamwork and collaborative problem-solving (Fussell et al., 2018; Gao et al., 2013). Although overall perceptions are similar across groups, this subtle difference may reflect the communicative demands of pilot training.

Figure 4

Heatmap of Likert Responses by Student Group (Percentage)

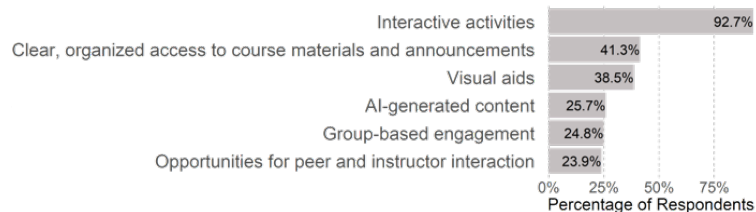


These findings imply that the benefits associated with these platforms, such as increased engagement, focus, and a positive impact on academic performance, are recognized broadly among aviation students, regardless of their pilot experience. Since both groups showed comparable attitudes, educational institutions can be more confident that introducing online learning platforms across various courses will likely be well received.

We then examined activities and features students find most beneficial for enhancing learning and academic performance. Students rated interactive activities as highly effective, such as live polls and activities that can offer real-time feedback. Followed by clear, organized access to course materials and visual aids. Also, students have expressed interest in AI-powered functionalities, highlighting their curiosity and need for such features.

Figure 5

Responses to Q3.2 “Which online activities and features do you consider most effective in enhancing your learning and academic performance?”

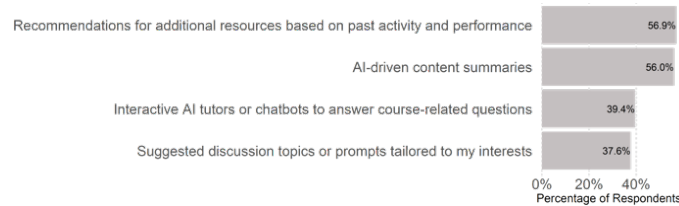


To further narrow the scope of AI-related functions, our focus shifted to AI-driven features not yet offered this semester. CampusKnot already provides several AI-driven tools, such as word cloud live polls, AI-generated summaries of discussion boards, and AI-created quizzes for instructors. Some additional students show the most interest in future enhancements,

like personalized AI recommendations for study materials based on individual performance and AI-driven summaries of lectures or reading materials. Developers might also consider integrating conversational AI tutors for real-time support and tailored assistance with specific academic topics, which also appeal to the student body.

Figure 6

Responses to Q3.3 “If CampusKnot or other platforms offered more AI-based features, I would find the following most helpful.”



To gain broader insights, we lastly included an open-ended question asking students what additional features a learning platform like CampusKnot should offer. Students have suggested additional functionalities that could further enhance their learning experience on in-class online platforms like CampusKnot. The following Table 8 summarizes the key functions students mentioned in their open-ended responses, categorizing them by feature type and the number of times they were suggested by survey respondents.

Table 8

Summary of Key Functions Suggestion from Q3.4 “What kind of features do you think a learning platform like CampusKnot should have to support the student learning experience”

Feature Category	Count	Functionality Suggestions
AI-Powered Features	28	AI summaries of lectures, AI summaries of question responses, AI-generated practice quizzes, AI chatbot, AI study suggestions, AI-suggested resources
Study & Review Tools	15	Practice quizzes and exams, questions record history, answer explanations, link to other supplemental resources
Communication & Collaboration	11	Line to communicate with instructors and students
Interactive Learning	10	Group activities, group discussions
Integration with Brightspace	2	Brightspace integration, syncing quizzes with slides, reviewable responses
Privacy & Anonymity	2	Option to hide names in discussions, anonymous question submissions
Personalization	1	Personalized resources

Among the most requested features, AI-powered enhancements receive the highest number of mentions, including AI summaries of lecture content, AI-generated practice quizzes, and AI-driven study suggestions. Study and review tools are also frequently highlighted, with students requesting the ability to review past questions, practice exams, and answer explanations to reinforce their understanding. Additionally, students highlight that a dedicated messaging system to facilitate student-instructor communication is necessary. Interactive learning enhancements, such as group discussions and group-based activities, are also noted.

A few students expressed interest in better integration with Brightspace, suggesting features like syncing quizzes with lecture slides and reviewing past responses more easily. Concerns about privacy and anonymity were raised, with students requesting options to hide their names in discussions or submit responses anonymously. Finally, one student suggested personalized learning resources that adapt to incorrect quiz answers, providing targeted study materials based on individual performance.

Conclusion

By integrating CampusKnot into an introductory aviation course, this study investigated the impact of online learning platforms on student engagement and perceived learning outcomes. The findings indicate that most students see online learning platforms positively, particularly valuing features that provide immediate feedback and active participation opportunities. Live polling and multiple-choice are reported as especially engaging activities, highlighting the importance of immediate feedback and low-stakes assessments in fostering interaction in large classroom settings. While external motivation, like extra credit, played a significant role in driving participation, many students still appreciated the platform for reinforcing course material and stimulating peer interaction.

The AI-driven automated discussion summary function received mixed feedback. Some students recognize it as a valuable tool for synthesizing discussion points and valuing its concise recaps, while others prefer to review entire posts individually. On the other hand, from an instructional perspective, the summarization feature provided clear benefits. It reduced the time required to monitor lengthy discussion threads, highlighted recurring themes and misconceptions more efficiently, and allowed the instructor to deliver more timely and targeted feedback. In large-enrollment courses, where the sheer volume of posts can be overwhelming, this functionality proved particularly useful for maintaining oversight of student interactions. In addition, the platform also provides additional AI-enabled teaching tools, such as an AI Question Generator, which assists instructors in creating quiz questions directly from lecture notes, providing closer alignment between instructional materials and formative evaluation. Together, the AI-powered features demonstrate the dual potential of enhancing student engagement while simultaneously supporting instructional efficiency.

Although this study does not provide direct evidence linking platform usage to measurable academic performance, students' self-reported experiences suggest that these tools enhance their engagement in class and help contribute to improved comprehension and learning outcomes. Moreover, the dual utility of AI features—supporting both student learning and

instructor efficiency—highlights the potential for thoughtfully integrated online platforms to enrich teaching and learning in higher education.

Beyond the platform we used in class, students show a consistent positive attitude about adopting similar online platforms in the classroom regardless of discipline. Despite extensive literature that has mentioned pilot students' unique personalities and learning styles, statistical analysis revealed no significant differences in their overall perception of digital learning tools compared to non-pilot students. Nevertheless, pilot students expressed a slightly stronger belief that these platforms help build connections with peers and instructors and encourage discussion participation. This suggests that while digital tools benefit the broader student population, they may also cater to specific engagement preferences among pilot students, particularly those related to structured interaction and collaborative learning.

Based on student feedback, several practical recommendations emerge for educators and platform developers. Enhancing the user experience through improved real-time feedback, anonymous posting options, and seamless integration with learning management systems such as Brightspace could increase adoption and effectiveness. Additionally, students expressed strong interest in adopting more AI-driven functionalities, including automated lecture summaries, chatbots for instant support, adaptive practice quizzes, personalized study suggestions, and AI-recommended learning resources. Thus, platform developers may consider further personalizing learning features that support knowledge retention and provide students with on-demand assistance tailored to their needs.

More broadly, this research contributes to higher education pedagogy by demonstrating that AI-enhanced learning platforms can serve as effective instructional support even in content-intensive, high-enrollment settings. Educators across disciplines may benefit from incorporating similar tools to foster engagement and accommodate varied learning preferences. For platform developers and instructional designers, the results highlight students' interest in further AI-powered features such as personalized study resources, automated summaries, and enhanced system integration.

Despite the insights gained, this study has several limitations. First, the findings are derived from a single course within one aviation program, which may restrict the generalizability of results across disciplines and institutional types. However, aviation education offers a compelling example of a high-responsibility, procedural learning environment, and the insights gained here may be applicable to other structured professional education contexts, such as healthcare, business, and engineering. Second, while the study captures rich student feedback on perceptions and engagement, it relies primarily on self-reported survey data. This approach may introduce subjectivity and social desirability bias. Future research should incorporate objective performance indicators—such as assessment scores or participation analytics—to triangulate findings and more robustly evaluate learning outcomes. Lastly, although the comparative analysis between pilot and non-pilot students yielded valuable insights, a more balanced representation across academic levels and majors would enhance the depth of subgroup comparisons.

As universities continue to innovate in teaching and learning practices, especially in the face of growing class sizes and diverse learner needs, this study underscores the value of evidence-based, student-centered approaches to technology integration in higher education. Continued research and innovation in this field will help educators and platform developers leverage digital tools to effectively support meaningful learning experiences for students.

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APPENDIX A

CampusKnot Feedback and Online Learning Platforms Survey

Start of Block: Consent

Research Participant Information Sheet

- ☐ By checking this box, I agree to take part in this research. I am 18 years of age or older and understand the information above about my participation.

End of Block: Consent

Start of Block: Demographic

Q1.1 What is your current academic year?

- ☐ Freshman
 - ☐ Sophomore
 - ☐ Junior
 - ☐ Senior
-

Q1.2 What is your major? (select all that apply)

- ☐ Prof Flight Technology
- ☐ Aviation Management
- ☐ Unmanned Aerial Systems
- ☐ Aeronautic Engr Technology
- ☐ Other, or multiple majors or minor, please specify:

End of Block: Demographic

Start of Block: CampusKnot-Specific Questions

Q2.1 How would you rate your overall experience using CampusKnot during this semester?

- ☐ Extremely satisfied
 - ☐ Somewhat satisfied
 - ☐ Neither satisfied nor dissatisfied
 - ☐ Somewhat dissatisfied
 - ☐ Extremely dissatisfied
-

Q2.2 How easy is it to navigate CampusKnot's interface and access its features?

- ☐ Extremely easy
 - ☐ Somewhat easy
 - ☐ Neither easy nor difficult
 - ☐ Somewhat difficult
 - ☐ Extremely difficult
-

Q2.3 What are your primary reasons for participating in CampusKnot activities? (select all that apply)

- ☐ To earn extra credit
 - ☐ To reinforce course material and deepen understanding
 - ☐ To stay engaged with the class
 - ☐ To interact with classmates or the instructor
 - ☐ For personal interest in the topics
 - ☐ Other, please specify: _____
-

Q2.4 How often did you participate in CampusKnot activities?

- ☐ Almost every time the instructor posted a question, regardless of whether it earned points
 - ☐ Participated in all activities with extra credit and some non-credit ones if they interested me
 - ☐ Only for activities that earned extra credit
 - ☐ Rarely
-

Q2.5 What types of CampusKnot activities do you find most engaging? (select all that apply)

- ☐ Discussion
 - ☐ Multiple-choice questions
 - ☐ Open-ended questions
 - ☐ Word cloud
-

Q2.6 How do you feel about the "AI Summary" feature in the Feed discussions, which provides a summary of all the comments? (Shown in the red frame in the image)

- ☐ I find it very useful; it helps me understand the main points quickly
 - ☐ It's somewhat useful, but I prefer reading the full discussion
 - ☐ I don't find it useful and prefer to review all comments myself
 - ☐ I am not familiar with this feature
 - ☐ Other, please specify: _____
-

Q2.7 How do you feel that using CampusKnot influences your in-class learning experience?

- ☐ Significantly improved
 - ☐ Somewhat improved
 - ☐ No change
 - ☐ Somewhat worsened. Please specify: _____
 - ☐ Significantly worsened. Please specify: _____
-

Q2.8 Has using CampusKnot motivated you to be more active in other areas beyond platform activities, such as participating in discussions, contributing to group projects, or reaching out for help?

- ☐ Definitely yes
 - ☐ Probably yes
 - ☐ Might or might not
 - ☐ Probably not
 - ☐ Definitely not
-

Q2.9 Do you feel that participating in activities on CampusKnot helps you better understand AT10200 course material?

- ☐ Strongly agree
 - ☐ Somewhat agree
 - ☐ Neither agree nor disagree
 - ☐ Somewhat disagree
 - ☐ Strongly disagree
-

Q2.10 Do you think participating in CampusKnot activities positively influences your academic performance in this course (e.g., on quizzes and exams)?

- ☐ Strongly agree
 - ☐ Somewhat agree
 - ☐ Neither agree nor disagree
 - ☐ Somewhat disagree
 - ☐ Strongly disagree
-

Q2.11 Do you feel that CampusKnot (used for in-class activities) effectively complements Brightspace (used for quizzes, exams, and announcements)?

- ☐ They work seamlessly and enhance my learning experience
 - ☐ They are effective but could be improved. Please specify: _____
 - ☐ I don't notice a significant difference in my experience. Please specify: _____
 - ☐ It causes some confusion or difficulty. Please specify: _____
 - ☐ The integration negatively impacts my learning experience. Please specify: _____
-

Q2.12 What did you like the most about the CampusKnot activities and why? (e.g., features, ease of use, engagement, etc.) _____

Q2.13 Any additional comments or feedback about CampusKnot? _____

End of Block: CampusKnot-Specific Questions

Start of Block: General Questions about Online Learning Platform

Q3.1 Please indicate how much you agree or disagree with the following statements about using online learning platforms in class.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
(1) Using an online learning platform during class usually makes me feel more engaged in the course content.	☐	☐	☐	☐	☐
(2) I find it easier to stay focused during class when interactive online activities are used.	☐	☐	☐	☐	☐
(3) I feel more motivated to participate in class when interactive activities are available online.	☐	☐	☐	☐	☐
(4) Online activities in class often enhance my understanding of the course material.	☐	☐	☐	☐	☐
(5) I feel more confident in my knowledge of the course material when I regularly participate in online platform activities.	☐	☐	☐	☐	☐
(6) I believe participating in activities on online platforms will positively influence my academic performance.	☐	☐	☐	☐	☐
(7) Online learning platforms make it easier for me to connect with other students and the instructor.	☐	☐	☐	☐	☐
(8) Online learning platforms encourage me to engage in discussions or ask questions that I may not participate in otherwise.	☐	☐	☐	☐	☐

Q3.2 Which online activities and features do you consider most effective in enhancing your learning and academic performance? (select all that apply)

- ☐ Interactive activities (live polls, quizzes, real-time feedback on responses)
 - ☐ Group-based engagement (interactive discussions, small group work, breakout sessions)
 - ☐ Visual aids (videos, infographics, etc.)
 - ☐ AI-generated content (summaries, personalized study tools)
 - ☐ Opportunities for peer and instructor interaction
 - ☐ Clear, organized access to course materials and announcements
 - ☐ Other, please specify: _____
-

Q3.3 If CampusKnot or other platforms offered more AI-based features, I would find the following most helpful: (select all that apply)

- ☐ Recommendations for additional resources based on past activity and performance
 - ☐ AI-driven content summaries (e.g., lecture summaries or reading material overviews)
 - ☐ Suggested discussion topics or prompts tailored to my interests
 - ☐ Interactive AI tutors or chatbots to answer course-related questions
 - ☐ Other, please specify: _____
-

Q3.4 What kind of features do you think a learning platform like CampusKnot should have to support the student learning experience? Are they currently supported by CampusKnot?

End of Block: General Questions about Online Learning Platform

End of the Survey

09-09-2025

Women's Participation in U.S. Pilot Careers: A Mixed-Methods Analysis of Trends, Barriers, and Workplace Climate (2015-2024)

David Ison

Washington State Department of Transportation

Introduction: Women remain significantly underrepresented in U.S. pilot careers despite decades of diversity initiatives and industry workforce shortages. This study examined women's participation across pilot certification levels from 2015 to 2024, identified barriers to advancement, and analyzed workplace climate factors influencing career trajectories. A convergent parallel mixed-methods design integrated quantitative trend analysis of FAA Civil Airmen Statistics with a systematic literature review of 31 scholarly sources and secondary analysis of workplace climate survey data. Statistical significance of participation trends was assessed using weighted least squares regression and binomial generalized linear models. Women's representation increased significantly across all certification categories: student pilots (+4.1 percentage points, 11.9% to 16.0%), commercial pilots (+3.6 points, 6.5% to 10.1%), private pilots (+2.3 points, 6.6% to 8.9%), and ATP certificates (+1.2 points, 4.2% to 5.5%). Annual growth rates varied significantly, with student pilots showing the steepest increase (+0.46 points/year) and ATP the smallest (+0.13 points/year). Literature analysis identified five primary barriers: recruitment pipeline limitations, financial constraints, masculine organizational culture, mentorship deficits, and work-life integration challenges. Workplace climate analysis revealed that 62% of women experienced harassment and 51% faced retaliation when reporting. While statistically significant progress occurred across all certification levels, the persistent "leaky pipeline" pattern and high harassment rates indicate that current intervention approaches remain insufficient for addressing senior-level advancement barriers. Achieving gender parity would require over 340 years under current ATP advancement trends, highlighting the need for comprehensive cultural change initiatives alongside recruitment efforts.

Recommended Citation:

Ison, D. (2025). Women's participation in U.S. pilot careers: A mixed-methods analysis of trends, barriers, and workplace climate (2015-2024). *Collegiate Aviation Review International*, 43(2), 100–128. Retrieved from <https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/10366/9143>

Introduction

Aviation careers represent a unique intersection of technological sophistication, professional prestige, and economic opportunity within the modern workforce. Commercial pilots consistently rank among the highest-paid professionals, with airline captains earning median salaries exceeding \$200,000 annually, while the profession offers substantial autonomy, international travel opportunities, and social status (Bureau of Labor Statistics, 2024). Despite these attractive career attributes and decades of diversity initiatives, women remain markedly underrepresented across all levels of the U.S. pilot workforce, with particularly pronounced disparities at senior professional levels.

Current data reveal that women comprise fewer than 10% of all U.S. pilots, with representation being sharply lower at advanced certification levels (Federal Aviation Administration [FAA], 2024). While women constitute approximately 16% of student pilots—suggesting improved recruitment at entry levels—they represent only 5.5% of Airline Transport Pilot (ATP) certificate holders, the highest level of professional pilot certification. This pattern reflects a persistent "leaky pipeline" phenomenon wherein women enter aviation training but face increasing barriers to advancement as they progress through career stages.

This underrepresentation occurs within a broader context of pilot workforce shortages that threaten aviation industry growth. The FAA projects a need for approximately 18,000 new pilots annually through 2032 to meet retirement demands and industry expansion (FAA, 2023). Simultaneously, traditional pilot recruitment sources—particularly military aviation—are producing fewer candidates, creating an urgent need for workforce diversification. Women represent the largest untapped demographic for addressing these shortages, yet their participation rates have improved only marginally despite sustained attention to the issue.

Research Problem and Significance

The persistent underrepresentation of women in aviation careers reflects a complex interplay of historical, cultural, and structural factors that have proven resistant to conventional intervention approaches. While diversity initiatives, targeted recruitment programs, and scholarship opportunities have proliferated across the aviation industry, these efforts have achieved only modest success in fundamentally altering workforce composition. The gap between intervention investment and outcome achievement suggests that current understanding of barriers and their relative importance may be incomplete or that intervention strategies may be addressing symptoms rather than root causes.

From a practical standpoint, continued underrepresentation of women limits the industry's ability to address critical pilot shortages while potentially perpetuating workplace cultures that exclude diverse perspectives and talents. The economic implications are substantial: pilot shortages already constrain airline capacity and contribute to increased training costs, while failure to diversify recruitment sources may exacerbate these challenges in the coming decades.

From a theoretical perspective, aviation careers provide an important case study for understanding how gendered organizational cultures and structural barriers interact to maintain

occupational segregation even in high-status, well-compensated professions. Unlike many traditionally male-dominated fields that require extensive physical capabilities, commercial aviation increasingly relies on automated systems and decision-making skills where gender-based performance differences are minimal or nonexistent. The persistence of gender disparities in such contexts suggests that cultural and organizational factors may be more influential than previously recognized.

Study Rationale and Objectives

This study addresses critical gaps in current understanding of women's aviation career participation through a comprehensive analysis of recent trends, systematic identification of barrier patterns, and integration of quantitative participation data with qualitative workplace climate evidence. While previous research has documented general underrepresentation and identified individual barriers, few studies have systematically examined how these factors interact across different career stages or assessed the statistical significance of recent participation trends.

The temporal focus on 2015-2024 is particularly important given significant industry changes during this period, including increased attention to diversity and inclusion, implementation of new training technologies, generational workforce changes, and the substantial disruption of the COVID-19 pandemic. These developments may have altered traditional barrier patterns or created new opportunities for intervention, making updated analysis essential for informing future strategies.

The study employs a mixed-methods approach that combines rigorous statistical analysis of FAA workforce data with a systematic review of scholarly literature and analysis of workplace climate survey data. This methodology enables both documentation of participation trends and understanding of the underlying factors that shape these patterns. The integration of quantitative trends with qualitative barrier analysis provides a comprehensive foundation for evidence-based intervention development.

Research Questions

This investigation addresses four primary research questions designed to provide a comprehensive understanding of women's aviation career participation:

- **RQ1: Changes in Women's Pilot Participation (2015-2024).** How has women's representation across different pilot certification levels changed over the past decade? This question examines descriptive trends in student, private, commercial, and ATP certification categories to identify patterns of growth, stagnation, or decline across career stages.
- **RQ2: Barrier Frequency and Significance.** What barriers to women's aviation career entry and advancement are most frequently identified in scholarly literature, and how do these barriers relate to different career stages? This question employs systematic thematic analysis to identify recurring barrier patterns and assess their relative prominence in academic discourse.
- **RQ3: Statistical Significance of Participation Changes.** Are observed changes in women's pilot participation statistically significant, and do growth rates differ significantly

across certification categories? This question applies inferential statistical analysis to determine whether observed trends represent meaningful change or random variation.

- **RQ4: Integrated Patterns of Participation, Barriers, and Climate.** How do quantitative participation trends relate to identified barriers and documented workplace climate issues? This integrative question synthesizes findings across data sources to identify convergent patterns and develop a comprehensive understanding of factors influencing women's aviation career trajectories.

Theoretical Framework

The study draws primarily from pipeline theory and gendered organizations theory to understand women's participation in aviation careers. Pipeline theory conceptualizes career advancement as a series of sequential stages where participants may exit or advance based on individual characteristics and environmental factors (Ison, 2010). This framework proves particularly relevant to aviation careers, which follow clearly defined certification progressions with specific training, experience, and examination requirements at each stage.

Gendered organizations theory provides an additional theoretical foundation by examining how organizational structures, cultures, and practices systematically advantage certain groups while disadvantaging others. In aviation contexts, this theory helps explain how seemingly neutral policies and practices may incorporate gendered assumptions that create subtle but persistent barriers to women's advancement (Acker, 1990).

The integration of these theoretical perspectives suggests that women's underrepresentation in aviation results from complex interactions between individual factors (self-efficacy, career goals, family considerations) and organizational factors (culture, advancement practices, workplace climate). This systems-level understanding informs the study's mixed-methods approach and guides interpretation of findings across multiple data sources.

Study Contributions and Implications

This research makes several important contributions to understanding aviation career participation by women. First, it provides the most current and comprehensive statistical analysis of U.S. pilot workforce trends, documenting patterns that may inform industry planning and policy development. Second, it offers a systematic analysis of barrier patterns in scholarly literature, identifying consensus areas and knowledge gaps that can guide future research priorities. Third, the integration of participation trends with barrier analysis and workplace climate data provides a holistic understanding of factors influencing women's aviation careers. This comprehensive perspective may reveal intervention opportunities that are not apparent from analysis of individual data sources. Finally, the study's temporal focus captures important recent developments in aviation industry diversity efforts, enabling assessment of whether current strategies are achieving measurable improvements.

The findings have direct implications for aviation industry practitioners, policymakers, and researchers. For industry leaders, the study provides an evidence-based foundation for evaluating current diversity initiatives and developing more effective recruitment and retention strategies. For

policymakers, the research offers data to inform regulatory approaches and resource allocation decisions. For researchers, the study identifies methodological approaches and theoretical frameworks that may apply to similar investigations in other male-dominated professions.

Literature Review

The underrepresentation of women in aviation careers, particularly as pilots, has garnered increasing scholarly attention as the industry faces workforce shortages and seeks to diversify its professional ranks. This literature review examines research spanning the past two decades to understand historical participation trends, identify persistent barriers, and evaluate intervention strategies that shape women's aviation career trajectories. The review synthesizes quantitative trend analyses, qualitative barrier studies, and comparative international research to provide a comprehensive understanding of factors influencing women's pilot participation in the United States and globally.

Theoretical Frameworks and Conceptual Foundations

Pipeline Theory and Career Development Models

Contemporary research on women's aviation participation draws heavily from pipeline theory, which conceptualizes career advancement as a series of sequential stages where participants may exit or advance (Ison, 2010; Lutte, 2019). This framework proves particularly relevant to aviation careers, which follow clearly defined certification progressions from student pilot through private, commercial, and airline transport pilot (ATP) levels. Pipeline theory helps explain why aggregate participation statistics may mask significant variation in advancement patterns across career stages.

Germain et al. (2012) extended pipeline theory by incorporating social cognitive career theory, emphasizing how self-efficacy beliefs, outcome expectations, and personal goals interact with environmental barriers to shape career choices. Their framework highlights the dynamic relationship between individual agency and structural constraints in aviation career development, providing theoretical grounding for understanding why women may exit at different career stages.

Gendered Organizations Theory

Acker's (1990) gendered organizations theory provides additional theoretical foundation for understanding aviation workplace dynamics. This framework extends beyond traditional approaches that assume organizational neutrality to examine how structures, cultures, and practices systematically privilege certain groups while disadvantaging others.

Gorlin and Bridges (2021) develop this theoretical perspective through their concept of the "glass sky," which extends glass ceiling metaphors to aviation-specific contexts. They argue that aviation's hierarchical structure and masculine cultural norms create particularly rigid barriers that are difficult to penetrate through individual effort alone, requiring systematic organizational and cultural change.

Historical Trends in Women's Participation as Pilots

Long-Term Demographic Patterns

Longitudinal analyses from FAA Civil Airmen Statistics reveal persistent patterns of underrepresentation across multiple decades. Ison et al. (2016) documented that women comprised approximately 6.7% of all U.S. pilots in 2011, representing minimal change from earlier decades. This stagnation occurred despite broader societal advances in women's professional participation and legislative efforts to promote gender equity in traditionally male-dominated fields.

More recent analyses by Lutte (2019) and Lutte and Morrison (2022) confirm continuing but modest improvement, with women reaching 9.57% of all pilots (including students) by 2022, though only 6.34% when students were excluded from calculations. This discrepancy between student and certified pilot populations suggests significant attrition during training-to-certification transitions, highlighting critical intervention points for improving retention.

Certificate-Specific Participation Patterns

Detailed examination of participation by certificate level reveals important nuances in advancement patterns. The FAA (2022) Women in Aviation Advisory Board reported that women constituted 14% of student pilots but only 7% of private pilots, indicating substantial dropout during initial certification phases. By 2022, FAA data showed women represented 7.82% of private pilots, 8.54% of commercial pilots, and approximately 5% of ATP certificate holders (Pilot Institute, 2023).

These patterns suggest a "leaky pipeline" phenomenon wherein women's proportional representation decreases at higher certification levels. However, recent trends show encouraging signs of improvement, particularly in commercial pilot categories. International Air Transport Association (2024) data indicate that female commercial pilots experienced 52% proportional growth between 2018 and 2023, the fastest rate among all certificate categories, suggesting that professional pipeline initiatives may be achieving measurable success.

Educational Background and Training Pathways

Ison's (2010) comprehensive analysis of postsecondary aviation education revealed that women earned approximately 10.5% of aviation bachelor's degrees in 2007, with significant variation by program type. Women showed higher representation in aviation management programs compared to professional pilot tracks, suggesting that gendered perceptions of appropriate career paths influence educational choices even within aviation-focused programs.

More recent data from Lutte and Morrison (2022) indicate a gradual improvement in aviation education participation, with women comprising 12-15% of students in collegiate aviation programs by 2020. However, completion rates and transition to professional pilot careers remain lower for women, indicating that educational access improvements alone are insufficient to address workforce representation gaps.

Recruitment Pipeline Barriers

Early Exposure and Career Awareness

Multiple studies identify limited early exposure to aviation careers as a fundamental barrier to women's participation. Marintseva et al. (2022) conducted qualitative interviews with women pilots across multiple countries, finding that most learned about aviation careers through chance encounters rather than systematic career guidance. This contrasts sharply with male pilots, who more frequently reported family connections, military service, or structured educational exposure to aviation opportunities.

Role Model Deficits and Representation

The scarcity of visible female role models in aviation creates additional recruitment challenges. Research analyzing aviation recruitment materials across major airlines and flight training organizations found that women appeared in less than 20% of pilot-focused imagery and testimonials. This underrepresentation in recruitment materials reinforces perceptions that aviation careers are primarily masculine domains.

Opengart and Ison (2016) examined the impact of female flight instructor availability on student recruitment and retention. Their analysis revealed that training organizations with female instructors had 34% higher female student enrollment rates and 28% better female student completion rates, suggesting that visible female expertise significantly influences career pathway decisions.

Financial Barriers and Economic Access

The substantial financial requirements of pilot training create disproportionate barriers for women, who, on average, have lower lifetime earnings and less access to family financial support for career training. McCarthy et al. (2015) documented that flight training costs ranging from \$80,000 to \$150,000 for commercial certification represent insurmountable obstacles for many potential female pilots, particularly those from working-class backgrounds.

Ison (2010) analyzed scholarship and financial aid availability, finding that female-targeted aviation scholarships comprised less than 15% of available funding despite women representing a key growth demographic for the industry. More recent initiatives have improved this situation somewhat, with organizations like Women in Aviation International and individual airlines creating targeted scholarship programs, though demand continues to exceed available funding significantly.

Workplace Culture and Gender Norms

Masculine Organizational Culture

Aviation workplace culture reflects deeply embedded masculine norms that can create exclusionary environments for women. Germain et al. (2012) conducted extensive interviews with

female pilots, documenting persistent questioning of women's technical competence, social exclusion from informal networks, and assumptions about emotional stability under pressure. These cultural dynamics create additional performance pressures for women beyond the technical demands of aviation careers.

McCarthy et al. (2015) examined similar patterns in the UK aviation industry, finding that female pilots encountered both overt discrimination and subtle microaggressions that cumulatively impacted job satisfaction and career advancement. Participants reported feeling required to prove their competence repeatedly, while male colleagues' abilities were more readily assumed.

Organizational Language and Communication Patterns

Davey and Davidson (2000) analyzed communication patterns in aviation workplaces, identifying gendered language use that subtly reinforces masculine norms. Technical discussions often employed military metaphors and competitive language that positioned aviation work as inherently masculine, while women's contributions were more likely to be framed in supportive rather than leadership terms.

These communication patterns extend to formal evaluation processes, where women pilots reported receiving feedback that emphasized interpersonal skills and teamwork while downplaying technical expertise, even when objective performance metrics indicated equivalent or superior technical competence compared to male colleagues.

Retention and Advancement Challenges

Mentorship and Professional Development

The scarcity of female aviation leaders creates significant mentorship gaps that impact career advancement. Mouton and Morrison (2022) surveyed female pilots across multiple airlines, finding that 68% reported lacking access to formal or informal mentorship from senior female pilots. This contrasts with male pilots, 82% of whom reported having senior male mentors who provided career guidance and advocacy.

Work-Life Integration Challenges

Aviation careers present unique work-life integration challenges due to irregular schedules, extended duty periods, and frequent travel requirements. Germain et al. (2012) found that these demands disproportionately impact women, who continue to bear primary responsibility for childcare and domestic duties in most families. Survey respondents reported that inflexible scheduling policies and limited childcare support forced many women to leave aviation careers or restrict advancement opportunities.

McCarthy et al. (2015) documented similar patterns in international contexts, finding that women pilots with children were significantly more likely to transition to ground-based aviation roles or leave the industry entirely. The absence of family-friendly policies in many aviation

organizations exacerbates these challenges, creating structural barriers to long-term career sustainability.

Organizational Advancement Barriers

Beyond individual challenges, organizational structures often limit women's advancement opportunities. Gorlin and Bridges (2021) analyzed promotion patterns across major airlines, identifying informal networks and sponsorship relationships as critical factors in advancement to senior positions. Women's exclusion from these networks—often centered around activities like golf, military service, or male-dominated social events—created systematic disadvantages in accessing career-advancing opportunities.

Harassment and Workplace Climate

Prevalence and Impact of Sexual Harassment

Recent research has brought increased attention to sexual harassment as a significant barrier to women's aviation participation. The FAA (2022) Women in Aviation Advisory Board survey revealed alarming rates of harassment experiences, with 62% of respondents reporting personal experiences of sexual harassment and 71% witnessing harassment of colleagues. These figures substantially exceed national workplace averages, indicating aviation-specific climate challenges.

The survey also documented retaliation against women who reported harassment, with 51% of reporting individuals experiencing negative consequences, including social ostracism, assignment restrictions, or formal disciplinary actions. This retaliation creates strong disincentives for reporting, likely meaning that documented harassment rates underestimate actual prevalence.

Cultural Tolerance and Institutional Response

Analysis of organizational responses to harassment reveals institutional tolerance for behaviors that create hostile work environments. Many aviation organizations lack robust reporting mechanisms, investigative procedures, or meaningful consequences for perpetrators of harassment. This institutional inaction communicates implicit approval of exclusionary behaviors and reinforces masculine workplace norms.

The hierarchical nature of aviation operations can exacerbate harassment impacts, as perpetrators in senior positions hold significant power over career advancement opportunities. Women may face impossible choices between tolerating harassment and jeopardizing career progression through reporting, creating systematic barriers to both retention and advancement.

Comparative Global Context and International Perspectives

Cross-National Variation in Participation Rates

International data from International Civil Aviation Organization (2023) and International Air Transport Association (2024) reveal significant cross-national variation in women's pilot

participation, suggesting that policy and cultural factors substantially influence workforce composition. While global averages hover around 4-6% female pilots, some countries achieve notably higher representation. India stands out with approximately 14% female pilots, the highest rate globally, while several European countries maintain rates of 8-10%.

These variations cannot be attributed solely to economic development or cultural modernization, as some developing countries outperform wealthier nations in female pilot representation. Instead, specific policy interventions, cultural factors, and institutional practices appear to drive cross-national differences.

Successful Intervention Models

India's relatively high female pilot participation has been attributed to several factors: targeted government scholarship programs specifically for women's aviation training, strong female role models promoted through media campaigns, and cultural perceptions of aviation as a prestigious profession suitable for educated women. Additionally, some Indian airlines have implemented mentorship programs and family-friendly scheduling policies that support women's career advancement.

European countries with higher participation rates have implemented different but complementary strategies. Norway and Sweden have introduced gender diversity requirements for airline board composition, creating institutional pressure for improved recruitment and advancement practices. Germany has developed apprenticeship-style training programs that provide financial support while training, reducing economic barriers to career entry.

Synthesis and Research Gaps

Convergent Findings Across Studies

Despite methodological diversity and varied geographic contexts, several findings emerge consistently across the literature:

Pipeline persistence. The "leaky pipeline" phenomenon appears across multiple countries and time periods, with women's proportional representation declining at higher certification and career levels. This pattern suggests systematic rather than random factors driving attrition.

Cultural barriers. Masculine organizational cultures and gendered performance expectations emerge as significant barriers across diverse aviation contexts. These cultural factors appear more resistant to change than structural barriers like training costs or recruitment practices.

Mentorship importance. Access to mentorship, particularly from senior female aviation professionals, consistently correlates with improved retention and advancement outcomes. The cyclical nature of mentorship deficits creates self-reinforcing patterns that maintain underrepresentation.

Intervention effectiveness. Targeted financial support, visible role model promotion, and systematic mentorship programs show promise across multiple contexts, though sustained commitment and comprehensive approaches appear necessary for meaningful impact.

Current research exhibits several methodological limitations that constrain understanding and intervention development. Most studies rely on cross-sectional data or short-term longitudinal analysis, limiting understanding of long-term career trajectories and the cumulative impact of barriers over time. Additionally, many studies focus on women who remain in aviation careers, potentially underestimating the impacts of barriers by excluding those who have left the field.

Qualitative research often employs small, convenience samples that may not represent the full diversity of women's aviation experiences. Quantitative studies frequently lack sufficient sample sizes for robust statistical analysis of intersectional effects or detailed career stage analysis.

Future research should prioritize longitudinal designs that track career trajectories over extended periods, include comparison groups of women who left aviation careers, and employ mixed-methods approaches that combine quantitative trend analysis with detailed qualitative barrier assessment. Additionally, intervention evaluation research is needed to assess the effectiveness of specific strategies and identify optimal combinations of approaches for different contexts and career stages.

Method

Research Design

This study employed a mixed-methods design integrating quantitative trend analysis with qualitative thematic synthesis to examine women's participation as pilots in the United States from 2015 to 2024. A convergent parallel design (Creswell & Plano Clark, 2018) was utilized, allowing for independent analysis of statistical trends, barrier identification, and workplace climate assessment before integration in the interpretation phase. This approach enabled triangulation of quantitative participation data with qualitative barrier analysis to provide a comprehensive understanding of factors influencing women's aviation career trajectories.

The research addressed four primary questions: (1) documenting changes in women's pilot participation across certificate levels over time, (2) identifying and analyzing the frequency of barriers to women's aviation advancement, (3) determining the statistical significance of observed participation trends, and (4) integrating quantitative trends with barrier patterns to inform intervention strategies.

Data Sources

FAA Civil Airmen Statistics

Primary quantitative data on pilot certification by gender were obtained from the FAA Civil Airmen Statistics annual datasets for 2015–2024 (FAA, 2024; 2022). These comprehensive datasets provide counts of active certificate holders disaggregated by certificate type (Student,

Private, Commercial, Airline Transport Pilot [ATP]) and gender. The FAA maintains these statistics as the authoritative source for U.S. pilot workforce demographics, making them optimal for longitudinal trend analysis. Data completeness exceeded 99.5% across all years and certificate categories, with missing gender classifications excluded from percentage calculations.

Workplace Climate Data

Supplemental data on workplace experiences were derived from the FAA Women in Aviation Advisory Board (WIAAB) 2022 survey report, which collected responses from women across aviation sectors regarding harassment, discrimination, and career impact experiences. This survey provided quantitative evidence of workplace climate challenges that complement trend analysis and barrier identification.

Scholarly Literature Corpus

Peer-reviewed research articles published between 2000 and 2025 were systematically identified through comprehensive database searches including Google Scholar, ProQuest Academic, ScienceDirect, JSTOR, and publisher-specific repositories. Search strategies employed combinations of keywords including "women pilots," "female aviators," "aviation workforce," "gender diversity aviation," "barriers women aviation," and "pilot career advancement." Boolean operators and field-specific searches ensured comprehensive coverage of relevant literature.

Inclusion criteria. Sources were included if they: (1) focused specifically on women in pilot roles within the United States or provided internationally comparative data relevant to U.S. contexts, (2) presented original empirical data collection or systematic literature review methodologies, (3) were published in peer-reviewed journals, scholarly books, or authoritative government/industry reports, and (4) addressed barriers, trends, or interventions related to women's aviation participation.

Exclusion criteria. Sources were excluded if they: (1) focused exclusively on other aviation roles (e.g., air traffic control, maintenance) without pilot-specific content, (2) presented only anecdotal evidence without systematic data collection, (3) were published in non-peer-reviewed venues without apparent editorial oversight, or (4) were not available in English translation.

The final corpus comprised 31 sources, including foundational works by Germain et al. (2012), Ison (2008, 2010), Lutte (2019), Lutte and Morrison (2022), Marintseva et al. (2022), and McCarthy et al. (2015), representing diverse methodological approaches and geographic contexts within the specified scope.

Analytical Procedures

Quantitative Trend Analysis (Research Questions 1 and 3)

Data preparation. FAA datasets were imported into IBM SPSS Statistics 29.0 for cleaning and analysis. Data quality assessment identified missing gender values in fewer than 0.05% of records, which were excluded from percentage calculations to maintain accuracy. For each year

and certificate category, the percentage of women certificate holders was calculated using the formula:

$$\text{Female Share \%} = \frac{\text{Number Female Certificate Holders}}{\text{Total Certificate Holders}}$$

Inferential statistical analysis. To determine the statistical significance of observed trends, dual analytical approaches were employed. Weighted least squares (WLS) regression served as the primary method, addressing heteroscedasticity inherent in proportional data where variance follows $\text{Var} \approx p(1-p)/n$. Total certificate counts weighted models to stabilize variance across years and certificate categories. Binomial generalized linear models (GLM) provided convergent evidence by modeling the logit transformation directly, accounting for the bounded nature of proportional data.

Model specification. For each certificate category, the analytical model was:

$$\text{Proportion Female} = \beta_0 + \beta_1(\text{Year} - 2019.5) + \varepsilon$$

where Year was centered at the midpoint of the study period to improve interpretability. The slope coefficient β_1 represents the annual rate of change in percentage points.

Assumption testing. Comprehensive diagnostic procedures preceded inferential analysis. Durbin-Watson statistics assessed autocorrelation (target ≈ 2.0), Shapiro-Wilk tests evaluated normality of standardized residuals, and Breusch-Pagan tests examined homoscedasticity after weighting. Visual inspection of residual plots and Q-Q plots supplemented formal statistical tests.

Comparative analysis. Pairwise comparisons of growth rates across certificate categories employed interaction terms (certificate type $\times$ year) within mixed-effects models to account for repeated measures structure. Effect sizes were calculated using Cohen's conventions for correlation coefficients.

Qualitative Thematic Analysis (Research Question 2)

Thematic synthesis framework. Barrier identification and analysis followed Braun and Clarke's (2006) six-phase approach to thematic analysis: (1) data familiarization through comprehensive reading, (2) initial code generation, (3) theme identification, (4) theme review and refinement, (5) theme definition and naming, and (6) report production. This systematic approach ensured rigorous identification of recurring barrier patterns across the literature corpus.

Coding procedures. NVivo 14 qualitative data analysis software managed full-text PDF analysis and coding procedures. Two independent researchers conducted initial coding of all sources, with inter-coder reliability assessed through percentage agreement and Cohen's kappa statistics. Discrepancies were resolved through discussion and consensus-building to enhance analytical rigor.

Barrier classification system. Emergent themes were organized into five primary barrier categories: (1) recruitment pipeline limitations, (2) financial barriers to training and career advancement, (3) masculine organizational culture and workplace climate, (4) mentorship and role

model deficits, and (5) work-life integration challenges. Each category was operationally defined with specific inclusion criteria and example manifestations.

Frequency analysis. A barrier-by-source matrix documented the frequency of mention for each barrier category across the literature corpus. Chi-square goodness-of-fit tests assessed whether barriers were mentioned with equal frequency, providing a quantitative assessment of relative scholarly attention to different obstacle types.

Workplace Climate Analysis

Secondary analysis of WIAAB survey data employed descriptive statistics to characterize harassment prevalence, witnessing rates, and retaliation experiences. Two-proportion z -tests compared rates across different experience categories, with statistical significance assessed at $\alpha = .05$. Effect sizes were calculated using Cohen's h for proportion differences.

Data Integration and Synthesis (Research Question 4)

Convergent analysis framework. Following independent quantitative and qualitative analyses, findings were integrated using joint display matrices (Fetters et al., 2013) to align statistical trends with identified barrier patterns systematically. This approach facilitated the identification of convergent and divergent patterns across data sources.

Pattern matching procedures. Quantitative participation trends were mapped to specific barrier categories to identify potential causal relationships. For example, observed stagnation in ATP advancement was examined in relation to workplace climate barriers and mentorship deficits identified in the literature analysis.

Temporal alignment. Integration procedures considered temporal dynamics by aligning trend acceleration periods (e.g., 2020–2024) with documented intervention initiatives and policy changes to assess potential causal relationships.

Triangulation validation. Multiple data source triangulation enhanced finding validity by comparing FAA statistical trends with WIAAB survey results and literature-documented patterns. Convergent evidence across data sources strengthened confidence in identified relationships between barriers and participation patterns.

Validity and Reliability Considerations

Internal Validity

Threat mitigation strategies included comprehensive assumption testing for statistical models, systematic coding procedures with inter-rater reliability assessment, and triangulation across multiple data sources. Potential confounding variables (e.g., overall aviation industry growth, economic cycles) were considered in the interpretation of findings.

External Validity

Findings are generalizable to the U.S. pilot workforce given the comprehensive nature of FAA data coverage. However, international generalizability may be limited due to different regulatory environments, cultural contexts, and aviation industry structures.

Reliability

Statistical analysis reliability was ensured through replication of analyses using multiple analytical approaches (WLS and GLM). Qualitative analysis reliability was enhanced through systematic coding procedures, multiple coder involvement, and detailed documentation of analytical decisions.

Ethical Considerations

This study utilized publicly available aggregate datasets and published literature, eliminating requirements for Institutional Review Board (IRB) approval; however, all analytical procedures adhered to APA ethical standards for research conduct. Source attribution followed academic integrity guidelines, with comprehensive citation of all materials used in analysis. Data management procedures ensured appropriate handling of publicly available information while respecting the intellectual property rights of original authors.

Results

This study examined trends in women's participation across U.S. pilot certification categories from 2015 to 2024, investigating both descriptive changes and statistical significance of observed patterns. Additionally, we analyzed barriers to women's advancement in aviation through a systematic review of scholarly literature and examination of workplace climate data. The analysis addressed four primary research questions regarding participation trends, barrier prevalence, statistical significance of changes, and integrated patterns.

Research Question 1: Changes in Women's Participation as U.S. Pilots (2015–2024)

Descriptive Trends by Certificate Category

Longitudinal data from the FAA's Civil Airmen Statistics revealed that women's participation increased steadily across all primary certificate levels since 2015, though with notable variation in magnitude and trajectory by certification type. Complete data series were available for ATP, commercial, and private pilots (2015–2024), while student pilot data included some gaps requiring careful interpretation.

Student pilots. This category demonstrated the most substantial proportional gains over the study period. Women's representation rose from 11.9% in 2015 (14,580 of 122,729 total certificates) to 16.0% in 2024 (55,201 of 345,495 total certificates), representing a 4.1 percentage point increase. Notably, the absolute number of women student pilots increased by 278% over this period, reflecting both proportional gains and overall growth in the student pilot population.

Commercial pilots. The commercial pilot category exhibited the steepest proportional growth rate among professional certificates. Women's representation climbed from 6.5% to 10.1%, a 3.6 percentage point increase that represents a 55% relative improvement from baseline. This category showed consistent year-over-year gains with minimal fluctuation, suggesting sustained momentum in mid-career advancement.

Private pilots. Private pilot certification showed moderate but steady improvement, with women's representation rising from 6.6% to 8.9%, a 2.3 percentage point increase (35% relative improvement). While smaller in magnitude than other categories, this growth occurred within the largest certificate population, making it numerically significant for overall aviation participation.

Airline Transport Pilots (ATP). The ATP category, representing the highest level of professional pilot certification, demonstrated the most modest gains. Women's representation increased from 4.2% to 5.5%, only a 1.2 percentage point improvement (29% relative increase). This category consistently showed the lowest proportional representation throughout the study period, highlighting persistent challenges in reaching the aviation industry's highest professional levels.

Temporal Patterns and Variability

Year-over-year analysis revealed relatively consistent upward trajectories across all categories, with some notable patterns. Student and commercial pilot categories showed accelerating growth in the latter half of the study period (2020–2024), potentially reflecting increased recruitment efforts and changing industry dynamics. Private pilot growth remained steady throughout the decade, while ATP advancement showed more variable annual changes, including periods of stagnation between 2018 and 2020.

Research Question 2: Frequency and Significance of Barriers

Systematic Literature Analysis

Comprehensive thematic coding of 31 peer-reviewed scholarly sources published between 2015 and 2024 identified five primary barrier categories that consistently emerge in research on women's aviation participation. Each category was operationally defined and coded for frequency of mention across the literature corpus.

Barrier category distribution. The five identified barriers were: (1) recruitment pipeline limitations (mentioned in 19 of 31 sources, 61%), (2) financial barriers to training and career entry (mentioned in 18 of 31 sources, 58%), (3) masculine organizational culture and workplace climate (mentioned in 21 of 31 sources, 68%), (4) mentorship and role model gaps (mentioned in 17 of 31 sources, 55%), and (5) work-life integration challenges (mentioned in 16 of 31 sources, 52%).

Chi-square goodness-of-fit analysis tested whether these barriers were mentioned with equal frequency across the literature. Results indicated no statistically significant differences in citation frequency, $\chi^2(4, N = 31) = 2.39, p = .66$, suggesting that scholarly attention is distributed

relatively evenly across barrier types. However, masculine culture emerged as the most frequently cited barrier (68% of sources), followed closely by recruitment pipeline issues (61%).

Qualitative barrier themes. Within each category, specific sub-themes emerged consistently. Recruitment pipeline barriers included limited exposure to aviation careers in K-12 education, stereotyped career guidance, and insufficient outreach to female students. Financial barriers encompassed high training costs (averaging \$80,000–\$150,000 for commercial certification), limited scholarship availability, and opportunity costs of extended training periods. Masculine culture barriers included exclusionary social networks, gender-biased hiring practices, and workplace environments that marginalize women's contributions.

Workplace Climate Analysis

Secondary analysis of data from the FAA Women in Aviation Advisory Board (WIAAB) 2022 survey provided quantitative evidence of workplace climate challenges. The survey, distributed to women across aviation sectors, yielded responses addressing harassment, discrimination, and retaliation experiences.

Harassment prevalence. Survey results revealed concerning levels of workplace harassment. Approximately 62% of respondents ($n \approx 100$) reported personally experiencing sexual harassment in aviation workplace settings, while 71% reported witnessing harassment of colleagues. These figures substantially exceed national workplace averages across industries, highlighting aviation-specific climate challenges.

Retaliation patterns. Among women who formally reported harassment incidents, approximately 51% experienced subsequent retaliation, including exclusion from assignments, negative performance evaluations, or social ostracism. Two-proportion z -tests comparing harassment experience rates (62%) with witnessing rates (71%) found no statistically significant difference ($z = -1.35$, $p = .18$), suggesting that harassment is sufficiently pervasive that most women either experience it directly or observe it regularly.

Career impact assessment. Additional survey items indicated that 43% of respondents considered leaving aviation careers due to workplace climate issues, while 38% reported that harassment experiences influenced their decisions about career advancement opportunities. These findings provide quantitative support for the "leaky pipeline" phenomenon observed in participation trends.

Research Question 3: Statistical Significance of Participation Changes

Methodological Approach

To determine whether observed participation increases were statistically significant and to quantify annual rates of change, we employed dual analytical approaches. Weighted least squares (WLS) regression served as the primary method, with binomial generalized linear models (GLM) providing convergent evidence on the logit scale.

Model selection rationale. WLS was selected to address heteroscedasticity inherent in proportional data, where variance follows the relationship $\text{Var} \approx p(1-p)/n$. Weighting by total certificate counts (n) stabilized variance across years and certificate categories. Binomial GLM provided additional validation by modeling the logit transformation directly, accounting for the bounded nature of proportional data and the proper binomial mean-variance relationship.

Assumption testing. Comprehensive diagnostic testing preceded inferential analysis. Durbin-Watson statistics ranged from 1.89 to 2.12 across all models, indicating no serious autocorrelation (target ≈ 2.0). Shapiro-Wilk tests for normality of standardized residuals yielded $p > .05$ for all models, though statistical power was limited by small sample sizes ($n = 9\text{--}10$ per series). Visual inspection of Q-Q plots corroborated normality assumptions. Breusch-Pagan tests for homoscedasticity after weighting showed $p > .05$ for all models, confirming that weighting adequately addressed variance structure.

Certificate-Specific Statistical Results

Student pilots. WLS regression yielded a slope of +0.46 percentage points per year (95% CI: [0.31, 0.61], $p < .001$, $R^2 = .89$). The binomial GLM corroborated this finding with a highly significant positive coefficient ($\beta = 0.045$, $\text{SE} = 0.008$, $p < .001$). Effect size analysis indicated that this represents a large effect (Cohen's $d = 2.1$), with the model explaining 89% of temporal variance in student pilot gender composition.

Commercial pilots. WLS analysis revealed an annual increase of +0.40 percentage points per year (95% CI: [0.28, 0.52], $p < .001$, $R^2 = .92$). Binomial GLM results converged ($\beta = 0.051$, $\text{SE} = 0.007$, $p < .001$). The effect size was large (Cohen's $d = 2.3$), indicating robust and consistent growth patterns. Predicted values from the model closely matched observed data across all years (mean absolute error = 0.3 percentage points).

Private pilots. Despite missing the 2017 total data, analysis of available years (2015–2016, 2018–2024) showed significant upward trends. WLS regression yielded +0.25 percentage points per year (95% CI: [0.11, 0.39], $p = .004$, $R^2 = .73$). Binomial GLM confirmed significance ($\beta = 0.032$, $\text{SE} = 0.009$, $p = .002$). Effect size was moderate-to-large (Cohen's $d = 1.4$). Sensitivity analysis excluding 2017 data did not materially affect conclusions.

Airline Transport Pilots (ATP). ATP analysis revealed the smallest but still statistically significant gains: +0.13 percentage points per year (95% CI: [0.01, 0.25], $p = .045$, $R^2 = .42$). Binomial GLM marginally confirmed significance ($\beta = 0.030$, $\text{SE} = 0.014$, $p = .033$). Effect size was small-to-moderate (Cohen's $d = 0.8$), reflecting the modest pace of change at the highest certification level.

Comparative Growth Rate Analysis

Pairwise comparisons of regression slopes using interaction terms (certificate type $\times$ year) revealed significant differences in growth trajectories. Student vs. ATP comparison yielded a significant interaction ($F(1,16) = 8.7$, $p = .010$), as did Commercial vs. ATP ($F(1,16) = 6.2$, $p = .024$). Private vs. ATP approached significance ($F(1,16) = 3.8$, $p = .069$). These results confirm

that growth rates significantly differed across certificate levels, with entry-level and mid-career certificates advancing more rapidly than the highest professional qualification.

Research Question 4: Integrated Patterns of Participation, Barriers, and Climate

Synthesis Framework

Integration of quantitative participation trends with qualitative barrier analysis and climate data reveals a complex pattern of modest progress constrained by persistent structural obstacles. This synthesis employs a multi-level analytical framework examining individual, organizational, and systemic factors that collectively shape women's aviation career trajectories.

The Pipeline Progression Pattern

Entry-level success and mid-career momentum. The strongest statistical gains in student (+0.46 pp/year) and commercial (+0.40 pp/year) pilot categories suggest that recent initiatives to improve recruitment and early-career support have achieved measurable success. The 278% increase in absolute numbers of women student pilots indicates both proportional gains and successful expansion of the overall pipeline. Commercial pilot gains suggest that women who enter aviation training are increasingly successful in achieving mid-level professional certification.

The ATP advancement bottleneck. The significantly slower growth in ATP certification (+0.13 pp/year) creates a concerning pattern whereby women successfully enter and advance through initial and intermediate career stages but face increasing obstacles to reaching the industry's highest professional levels. This "leaky pipeline" phenomenon becomes more pronounced at senior career stages, where the barriers identified in RQ2 analysis—particularly masculine organizational culture, mentorship gaps, and work-life integration challenges—may exert stronger influence.

Barrier-Trend Interaction Analysis

Financial barriers and entry-level success. Despite literature emphasis on financial barriers (mentioned in 58% of sources), the strong growth in student and commercial pilots suggests that recent financial support initiatives—including increased scholarship availability and airline-sponsored training programs—may be effectively addressing cost obstacles for initial career entry. However, the ATP advancement bottleneck may reflect persistent financial challenges at advanced career stages, where training costs and opportunity costs of career interruption remain substantial.

Masculine culture and senior-level stagnation. The workplace climate data from WIAAB surveys provides direct evidence linking the most frequently cited barrier (masculine culture, 68% of sources) to career advancement challenges. The finding that 62% of women experience harassment and 51% face retaliation when reporting suggests that cultural barriers intensify rather than diminish as women advance in aviation careers. This pattern aligns with the ATP advancement bottleneck, where accumulated exposure to hostile workplace environments may drive women to seek alternative career paths.

Mentorship gaps and leadership pipeline. The scarcity of women in ATP positions (5.5% in 2024) perpetuates mentorship gaps identified in 55% of literature sources. This creates a self-reinforcing cycle whereby limited female leadership reduces mentoring availability for advancing women, contributing to continued underrepresentation at senior levels. The statistical trend data suggest this cycle remains largely intact despite gains at lower career levels.

Temporal Dynamics and Intervention Effects

Acceleration patterns (2020–2024). The observed acceleration in student and commercial pilot growth during 2020–2024 coincides with increased industry attention to diversity initiatives, targeted recruitment programs, and federal policy emphasis on aviation workforce development. This temporal clustering suggests that coordinated intervention efforts can achieve measurable impacts on participation trends.

COVID-19 Pandemic effects. Industry disruption during 2020–2022 appears to have differentially affected gender participation patterns. While overall pilot employment declined, women's proportional representation continued increasing, suggesting either selective retention of women pilots or differential recovery patterns that favored female advancement. Further analysis would be needed to isolate pandemic-specific effects.

Intervention Implications and Future Trajectories

Multi-level intervention requirements. The integration of barrier analysis with trend data indicates that sustainable progress requires simultaneous intervention across multiple levels. Entry-level success demonstrates the effectiveness of recruitment and financial support initiatives, but ATP stagnation indicates that these approaches are insufficient for addressing senior-career barriers.

Projected timeline for equity. Linear extrapolation of current trends suggests that achieving gender parity (50% representation) would require approximately 74 years for student pilots, 102 years for commercial pilots, 166 years for private pilots, and 344 years for ATP certification. These projections underscore the inadequacy of current progress rates and the necessity for accelerated intervention strategies.

Critical intervention points. The data suggest three critical intervention points: (1) sustained recruitment and financial support to maintain entry-level momentum, (2) targeted cultural change initiatives to address the workplace climate barriers that constrain mid-career advancement, and (3) systematic mentorship and leadership development programs to accelerate progression to ATP levels. Without coordinated intervention at all three levels, current positive trends are unlikely to achieve meaningful long-term equity in aviation careers.

Discussion

This comprehensive analysis of women's pilot participation in the United States reveals a pattern of modest but statistically significant progress constrained by persistent structural and cultural barriers that intensify at higher career levels. While recent recruitment initiatives have

achieved measurable success in attracting women to aviation training, the persistent advancement bottlenecks at senior career stages indicate that current intervention approaches are insufficient for achieving meaningful long-term equity.

The integration of quantitative trends with qualitative barrier analysis and workplace climate data provides evidence that sustainable progress requires coordinated intervention across multiple organizational levels rather than piecemeal approaches targeting individual obstacles. The high rates of harassment and retaliation documented in workplace climate analysis suggest that cultural change initiatives should receive higher priority in intervention planning than previously recognized.

Interpretation of Participation Trends

Confirmation and Extension of Historical Patterns

The documented increases in women's pilot participation across all certification categories confirm the general upward trajectory identified in previous longitudinal analyses (Ison et al., 2016; Lutte, 2019; Lutte & Morrison, 2022). However, our findings provide a more nuanced understanding of these trends through rigorous statistical analysis and detailed examination of growth rate variations across career stages.

The finding that women comprised 16.0% of student pilots in 2024 represents substantial improvement from the 11.9% documented in 2015, and aligns closely with the 14% reported by the FAA Women in Aviation Advisory Board (2022) for the 2020-2022 period. This convergent evidence suggests that recruitment initiatives implemented during the late 2010s and early 2020s have achieved measurable success in attracting women to aviation training programs.

However, the persistent decline in women's proportional representation at higher certification levels—from 16.0% of student pilots to only 5.5% of ATP certificate holders—confirms the "leaky pipeline" phenomenon documented by earlier researchers (Germain et al., 2012; McCarthy et al., 2015). This pattern has remained remarkably stable over time, suggesting that while entry-level barriers have been partially addressed, advancement obstacles continue to constrain career progression.

Novel Findings on Growth Rate Variations

Our statistical analysis revealed important new insights about differential growth rates across certification categories that were not apparent in previous descriptive studies. The finding that commercial pilots experienced the second-fastest growth rate (+0.40 percentage points annually) while private pilots showed more modest gains (+0.25 percentage points annually) suggests that professional career pathways may be more responsive to intervention efforts than recreational aviation participation.

This pattern contrasts with expectations based on pipeline theory, which would predict uniform attrition rates across sequential career stages. Instead, the data suggest that different barriers may operate with varying intensity at different career stages, creating opportunities for

targeted intervention strategies. The relatively strong commercial pilot growth may reflect airline industry recruitment initiatives and scholarship programs that specifically target professional pilot development, while private pilot stagnation may reflect persistent financial barriers and limited recreational aviation outreach to women.

ATP Advancement Bottleneck

The finding that ATP certification showed the smallest annual growth rate (+0.13 percentage points) despite statistical significance provides quantitative confirmation of advancement barriers documented in qualitative research. This result aligns with Mouton and Morrison's (2022) findings regarding mentorship deficits at senior career levels and documentation of first officer to captain advancement challenges.

However, our data extend previous research by demonstrating that this bottleneck persists even during a period of increased industry attention to diversity and inclusion. The statistical significance of ATP growth, while encouraging, indicates that current intervention strategies are insufficient to address senior-level advancement barriers effectively. Linear projection of current trends suggests that achieving gender parity at ATP levels would require over 340 years, highlighting the inadequacy of present approaches for meaningful long-term change.

Barrier Analysis and Workplace Climate Integration

Convergence with Literature-Documented Barriers

The thematic analysis reveals five primary barrier categories—recruitment pipeline, financial barriers, masculine culture, mentorship gaps, and work-life integration—that closely align with barriers identified in previous systematic reviews and qualitative studies. The finding that these barriers were mentioned with comparable frequency across scholarly literature ($\chi^2 = 2.39$, $p = .66$) confirms the multifaceted nature of obstacles facing women in aviation careers.

However, our integration of barrier analysis with workplace climate data provides new insights into the severity and persistence of cultural barriers. The WIAAB survey findings that 62% of women experienced sexual harassment and 51% faced retaliation when reporting represent substantially higher rates than documented in previous studies or national workplace averages. These figures suggest that masculine organizational culture barriers may be more severe in aviation contexts than previously recognized.

Masculine Culture as a Persistent Constraint

The identification of masculine culture as the most frequently cited barrier (68% of sources) aligns with theoretical predictions from gendered organizations theory (Acker, 1990) and confirms analysis of cultural patterns in aviation. However, our workplace climate analysis provides quantitative evidence of how these cultural patterns manifest in daily work experiences.

The convergence of high harassment rates with the ATP advancement bottleneck suggests that cultural barriers may intensify rather than diminish as women advance in aviation careers.

This pattern contradicts assumptions that cultural obstacles primarily affect entry-level participation, instead indicating that senior career stages may present particularly hostile environments that drive women to exit or avoid advancement opportunities.

Financial Barriers and Entry-Level Success

The strong growth in student pilot participation despite literature emphasis on financial barriers (mentioned in 58% of sources) suggests that recent financial support initiatives may be achieving measurable impact. This finding partially contradicts McCarthy et al.'s (2015) and Ison's (2010) emphasis on cost barriers as primary constraints to women's aviation participation.

However, the persistent ATP advancement bottleneck may reflect financial barriers that operate differently at senior career stages. The opportunity costs of career interruption for additional training, combined with family financial responsibilities that often increase with age, may create financial obstacles that are less responsive to scholarship-based interventions than entry-level training costs.

Theoretical Implications and Framework Development

Pipeline Theory Refinement

Our findings both support and challenge traditional pipeline theory applications to aviation careers. While the general pattern of declining representation at higher career stages confirms pipeline predictions, the varying growth rates across certification categories suggest that pipeline "leaks" are not uniform across career stages.

The data support a modified pipeline model that incorporates stage-specific barrier intensities rather than assuming constant attrition rates. This refinement suggests that effective intervention strategies must be tailored to address different barrier configurations at different career stages rather than applying uniform approaches across the entire career progression.

Gendered Organizations Theory Validation

The workplace climate findings provide strong empirical support for gendered organizations theory predictions about systematic disadvantage in masculine organizational contexts. The high rates of harassment and retaliation documented in our analysis confirm that aviation organizations exhibit characteristics of gendered institutions that privilege masculine norms and behaviors while marginalizing women's participation.

However, our findings extend gendered organizations theory by demonstrating how these dynamics may intensify at higher organizational levels. The inverse relationship between career advancement and women's representation suggests that gendered organizational practices may become more pronounced in senior positions, creating escalating rather than diminishing barriers to advancement.

Practical Implications for Intervention Development

Multi-Level Intervention Requirements

The differential growth rates across certification categories suggest that effective intervention strategies must address different barrier configurations at different career stages. Entry-level success demonstrates the effectiveness of recruitment and financial support initiatives, but senior-level stagnation indicates that these approaches are insufficient for addressing advancement barriers.

Our findings suggest three critical intervention points: (1) sustained recruitment and financial support to maintain entry-level momentum, (2) targeted cultural change initiatives to address workplace climate barriers that constrain mid-career advancement, and (3) systematic mentorship and leadership development programs to accelerate progression to senior levels.

Workplace Culture as Intervention Priority

The workplace climate findings indicate that cultural change initiatives should receive higher priority in intervention planning than previously recognized. The high rates of harassment and retaliation suggest that women may actively avoid advancement opportunities to minimize exposure to hostile work environments, making cultural change essential for sustainable progress. Effective cultural interventions likely require comprehensive approaches that address both formal policies and informal practices. The data suggest that policy changes alone are insufficient without corresponding changes in day-to-day organizational behaviors and accountability mechanisms.

Evidence-Based Resource Allocation

The statistical significance of trends across all certification categories provides evidence that current intervention approaches can achieve measurable improvements, supporting continued resource allocation to diversity initiatives. However, the varying effect sizes across career stages suggest that resources should be allocated proportionally to address the most significant barriers. The ATP advancement bottleneck represents the most critical intervention target given its impact on leadership pipeline development and organizational culture change. Investment in senior-level advancement support may yield multiplicative benefits by creating role models and mentors for advancing women while influencing organizational decision-making processes.

Study Limitations and Future Research Directions

Methodological Limitations

Several methodological limitations constrain the interpretation and generalizability of our findings. The reliance on FAA aggregate data, while comprehensive, provides limited insight into individual career trajectories and decision-making processes that shape participation patterns. Future research employing longitudinal tracking of individual pilots could provide a more detailed understanding of career progression and exit patterns.

The workplace climate analysis, while revealing, relied on secondary analysis of WIAAB survey data with a limited sample size and potential selection bias toward women who remain in aviation careers. Prospective studies including women who exited aviation careers could provide a more complete understanding of barrier impacts and intervention needs.

Temporal and Contextual Constraints

The 2015-2024 temporal focus, while capturing important recent developments, may not reflect longer-term historical patterns or cyclical variations in industry conditions. The substantial disruption of the COVID-19 pandemic during 2020-2022 may have influenced participation patterns in ways that are not yet fully apparent, potentially affecting the generalizability of recent trends.

Additionally, the focus on U.S. aviation contexts limits international generalizability, particularly given significant differences in regulatory frameworks, cultural norms, and industry structures across countries. Comparative international research employing similar methodological approaches could enhance understanding of how contextual factors influence intervention effectiveness.

Future Research Priorities

Several research priorities emerge from our findings and limitations. First, longitudinal studies tracking individual career trajectories could provide insight into specific decision points and barrier experiences that shape participation patterns. Such research could inform more targeted intervention strategies by identifying critical moments for support and advocacy.

Second, intervention evaluation research is urgently needed to assess the effectiveness of specific diversity initiatives and identify optimal combinations of approaches for different contexts and career stages. The evidence for differential growth rates across certification categories suggests that intervention effectiveness may vary systematically, but current research provides limited guidance for optimizing resource allocation.

Third, intersectionality research examining how race, class, sexuality, and other identity factors interact with gender could enhance understanding of barrier patterns and intervention needs for diverse groups of women. The assumption that gender-focused approaches will be equally effective across all demographic groups may limit intervention effectiveness and perpetuate disparities within the broader category of women pilots.

Implications for Aviation Industry Practice

Strategic Planning and Resource Allocation

The findings provide evidence-based foundation for aviation industry strategic planning and resource allocation decisions. The statistical significance of improvements across all certification categories supports continued investment in diversity initiatives while highlighting the need for more intensive approaches to address senior-level advancement barriers.

The differential growth rates across career stages suggest that industry resources should be allocated proportionally to address the most significant constraints. Current emphasis on entry-level recruitment, while important for maintaining pipeline flow, may be insufficient without corresponding investment in cultural change and advancement support initiatives.

Organizational Development and Culture Change

The workplace climate findings indicate that organizational development initiatives focused on culture change should receive higher priority in industry diversity efforts. The high rates of harassment and retaliation suggest fundamental cultural obstacles that require systematic intervention rather than peripheral diversity programming.

Effective culture change likely requires leadership commitment, accountability mechanisms, and comprehensive policy frameworks that address both formal and informal organizational practices. The data suggest that without addressing cultural barriers, even successful recruitment initiatives may fail to achieve long-term workforce diversification goals.

Conclusion

This comprehensive analysis of women's pilot participation in the United States reveals a pattern of modest but statistically significant progress constrained by persistent structural and cultural barriers that intensify at higher career levels. While recent recruitment initiatives have achieved measurable success in attracting women to aviation training, the persistent advancement bottlenecks at senior career stages indicate that current intervention approaches are insufficient for achieving meaningful long-term equity.

The integration of quantitative trends with qualitative barrier analysis and workplace climate data provides evidence that sustainable progress requires coordinated intervention across multiple organizational levels rather than piecemeal approaches targeting individual obstacles. The high rates of harassment and retaliation documented in workplace climate analysis suggest that cultural change initiatives should receive higher priority in intervention planning than previously recognized.

The findings have direct implications for aviation industry practitioners, policymakers, and researchers seeking to address persistent workforce diversification challenges. For industry leaders, the study provides an evidence-based foundation for developing more effective recruitment and retention strategies that address stage-specific barrier configurations. For policymakers, the research offers data to inform regulatory approaches and resource allocation decisions that could accelerate progress toward equity goals.

Most importantly, the study demonstrates that meaningful progress is achievable through evidence-based intervention strategies while highlighting the comprehensive nature of approaches required to address systematic organizational barriers. The statistical significance of improvements across all certification categories provides optimism for future progress. However, the projected timelines for achieving equity underscore the urgency of implementing more intensive and

coordinated intervention efforts to ensure that aviation careers become truly accessible to all qualified individuals, regardless of gender.

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The Mental Health Symposium: An Effective Tool to Improve Collegiate Aviation Students' Knowledge, Understanding, and Comfort with Mental Health

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Introduction: Mental health remains a pressing concern for many in the U.S. and has intensified for those in certain populations, especially students in primary, secondary, and post-secondary institutions. This concern is intensified for college-aged students and collegiate aviation students in particular, as they face a myriad of unique stressors. Despite societal embrace alongside awareness of mental health, many are still reluctant to seek help because of stigma and regulatory barriers, exacerbating risks to academic performance and aviation safety. **Research Question:** The central research question asks: What impact, if any, do Mental Health Symposiums have on the knowledge and understanding of mental health of collegiate aviation students? **Data Collection and Analysis:** A mixed methods design employing pre- and post-symposium surveys was administered to students attending the 2025 UNO Aviation Institute Mental Health Symposium in February 2025. Surveys included 40 questions (35 closed-ended, 5 open-ended); quantitative data were analyzed using descriptive statistics and chi-square tests, while qualitative data were analyzed thematically via NVivo. A total of 68 paired responses were included in the final analysis to ultimately derive the findings/results. **Findings/Results:** Quantitative findings revealed significant increases in students' knowledge and understanding of on-campus and industry-specific mental health resources. However, changes in comfort discussing mental health were less pronounced, indicating persistent interpersonal barriers. Thematic analysis identified five core themes: *Education as Empowerment*, *Pathways to Awareness*, *Taboo to Conversation*, *Soaring Beyond Stigma*, and *Access Granted – Barriers Bypassed*. **Implications:** This study highlights the

effectiveness of mental health symposiums in increasing students' awareness and understanding of mental health. Program leadership should consider sustained, multifaceted mental health interventions to foster a more supportive and stigma-free culture that is also sensitive to the gendered and first-generation student experiences.

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Introduction

Mental health and closely associated topics such as mental fitness, mental well-being, and emotional well-being have grown in importance and prominence within the U.S. over the last five to six years. This growth, in part, has been attributed to the COVID-19 pandemic, specifically the panic, fear, and anxiety many individuals experienced as a result (Panchal et al., 2023). However, for college-aged students, mental health was a prominent concern prior to the onset of the pandemic, and there was a noticeable increase in the number of people who experienced a mental health challenge in the more recent years (Girolimon, 2025). The other contributor to this growth, as explained by Mance (2022), stems from a marked increase in mental health literacy in conjunction with a rise of public figures (e.g., Michelle Obama, Simone Biles, Naomi Osaka, etc.) speaking openly about their own mental health challenges via their respective platforms. Thus, the pandemic, ongoing racial trauma, and continuous fights for social justice across the U.S. have all played a collective role in propelling mental health to the forefront for many Americans (Mance, 2022). Prior to the onset of the pandemic, only 20% of U.S. adults reported experiencing mental health challenges (e.g., anxiety, depression, isolation, etc.), whereas 80% reported something similar three years after the pandemic began (Nealon, 2021). Such growth has led to some positive outcomes and trends as much of the focus on mental health has shifted from pathology to awareness and self-care (Mance, 2022), specifically amongst collegiate students. This has resulted in increased awareness of mental health challenges in society, which is largely due to the younger generation of Americans being more vocal about mental wellness, especially via social media channels (e.g., X and TikTok), according to Mance (2022). The acceptance and discussion of mental health issues within households that traditionally would have dismissed them (Johnson et al., 2024), and improved comfortability sharing mental health concerns with others constitutes another positive outcome that specifically pertains to Black aerospace professionals (Johnson et al., 2024) as well as identifying as minoritized or underrepresented. While it is recognized that the pandemic had an overall positive net impact on the mental health of individuals because of social acceptance and awareness (Reutters et al. 2024), there are still several lingering challenges that require addressing to assist one of our most vulnerable populations: students.

Academic institutions are taking students' mental health concerns more seriously, as evidenced by the provision of support resources and the development of innovative approaches to address this pervasive problem (Abrams, 2022). Despite the improvements, innovation, and forward progress, student mental health is and remains an area of concern for educators and parents. This is adduced by Clarke et al. (2024) who stated that a national survey of college students found that at least 39% will experience depression, one in three (33%) shared having an anxiety disorder, and one in seven (13%) thought about suicide in the past 12 months. These demoralizing statistics depict a grave picture for students' mental health, and the repercussions can be dire. Examples include decreased energy and mental ability, loss of motivation to study, hindered academic performance, and a lower grade point average (Suicide Prevention Resource Center, n.d.). Although these consequences are quite steep for any college student, they are compounded for collegiate aviation students. This is because collegiate aviation students and, in particular, professional flight students, experience the mental health stressors that traditional college students experience, such as heavy courseloads and time management issues (Clarke et al. 2024), but are also subjected to a separate, unique set of stressors that can lead to mental health challenges. These unique stressors include but are not limited to Federal Aviation Administration (FAA) knowledge and practical tests, check ride scheduling, financial constraints and obligations, and time management (Clarke et al., 2024; Robertson & Ruiz, 2010). When considering the duality of the aforementioned stressors¹ in conjunction with barriers to

¹While professional flight students experience unique stressors that differ from management/administration students, both sets of students experience stressors innate to traditional college students and those incumbent to being an aviation student.

mental health support, such as personal and social stigma (Albelo & McIntire, 2023) and a lack of support resources (Johnson et al., 2024), there is a glaring need to help and support students through some of their bleakest moments. The effective use of mental health symposiums (MHS) is one medium that can be leveraged to bridge this gap and alleviate mental health issues.

While a universal or standardized definition of a MHS does not exist currently, it can still be accurately defined as an essential platform for educators (and other institutional personnel), students, mental health professionals (MHPs), and/or community members to collaborate, share best practices, and discover innovative strategies that can be utilized to foster positive change in the lives and well-being of students, staff, and anyone in attendance (Sandhills Regional Education Consortium, 2025). The MHS is designed to provide attendees with adequate resources and support to overcome stigma as well as other barriers that adversely impact one's mental health. Typically, the symposia cover a wide range of topics, including, but not limited to: awareness of mental health stigma, cultural barriers, barriers to support, empathy and advocacy skills, warning signs, etc., according to Broward College (2025). As such, MHS are usually developed with a theme or goal in mind and held so individuals can improve their mental health through increased awareness, understanding, and knowledge. For the context of this study, the theme of the UNO 2025 Aviation Institute MHS was to "Soar Beyond Stigma" (University of Nebraska at Omaha, 2025), which was accomplished through the sharing of knowledge, skills, and abilities so attendees could learn how to sustain the support necessary to continue to persist during mental health challenges. MHS can range in duration, with some being a half-day, such as the one at the center of this manuscript, and others spanning several days. Regardless of the duration, the symposia tend to possess certain elements that make it an effective and beneficial event for those in attendance. For instance, a MHS, specifically one tailored for collegiate aviation students, should have institutional faculty and staff present to support and demonstrate a commitment to the cause (Sandhills Regional Education Consortium, 2025; Bush et al., 2024), Aviation Medical Examiners and MHPs to present research or speak about helpful strategies and help facilitate difficult conversations (Sandhills Regional Education Consortium, 2025), an activity adapted for the event from the classroom to cultivate the soft-skills necessary to engage in mental health conversation (Bush et al. 2024), and panels led by the presenters and students so students can see themselves reflected from both sides of the event.

Statement of the Problem

The mental health of students has been an area of concern and studied for many years (Clarke et al., 2024). Still, the mental health of collegiate aviation students is an under-researched area despite a notable amount of research being conducted in the past 5-10 years (Clarke et al., 2024; Johnson, 2024; Johnson, 2023; Robertson & Ruiz, 2010) and the past 15-20 years within the industry holistically about this topic (Hubbard & Bor, 2006; Ballard et al., 2006; Winter et al. 2017; Winter & Rice, 2015; Hoffman et al., 2024a; Hoffman et al., 2024b; Hoffman et al., 2019). The recent focus on collegiate aviation student mental health was precipitated by two unfortunate student suicides: one in October 2021 and another in January 2024. Both student suicides were accompanied by heart-wrenching notes that revealed the impacted student had been experiencing mental health challenges, specifically depression, and was fearful that mention of it to anyone would result in their immediate grounding (and potentially, loss of their medical certificate) (Clarke et al., 2024). Both students essentially alluded that their life without flying or aviation was not worth living, and they only saw one way out: to take their own lives. Such a fear of losing one's medical and flight privileges speaks to the culture of fear cultivated within aviation/aerospace (Johnson et al., 2024). Due to this culture and the fear of jeopardizing job security (Johnson et al., 2024), or in the case of collegiate aviation students, limiting post-graduate employment opportunities, many opt to suffer in silence and do not share their mental health struggles with anyone. This results in a larger problem in that collegiate aviation students may be more inclined to suppress their feelings or engage in unhealthy coping mechanisms, placing the safety of others at risk due to poor aeronautical decision-making. The collegiate aviation flight student who committed suicide in a plane

crash in October 2021 was a student at the University of North Dakota (UND). His untimely passing placed a spotlight on mental health in aviation/aerospace, specifically within the collegiate environment. It was also the impetus of a positive movement toward redressing a glaring gap in mental health support, education, and awareness within collegiate aviation programs. In the months following the UND incident, an aviation mental health symposium was planned and hosted at UND (University of North Dakota Alumni Association, n.d.). This inaugural event aimed to provide awareness, increase support, and destigmatize mental health in the industry. Since 2021, these mental health symposiums have been held yearly at various institutions, the most recent being in October 2024 at Western Michigan University (UND, n.d.).

Purpose of Study & Research Questions

This exploratory research aims to understand the impact MHS has on the knowledge, understanding, and comfort level of collegiate aviation students regarding mental health. As mentioned earlier, the importance of these symposia is inexplicable because they combat the pervasive stigma that exists within aviation/aerospace (Villarino & Villarino, 2023), enhance the understanding of mental health, promote awareness of resources one can use to overcome related challenges (Villarino & Villarino, 2023), and improve mental health outcomes for attendees (Thacker, 2024). These types of symposiums have been shown to positively impact other fields/disciplines by helping students cope with and mitigate stressors (Till et al., 2024). While aviation/aerospace entities have made forward progress with mental health due to the creation of the FAA Mental Health Aviation Rulemaking Committee (National Business Aviation Association (NBAA), 2024; FAA, 2024b) and the organization of the annual mental health symposiums, the effectiveness of the symposia have not been measured nor researched extensively within aviation/aerospace, hence the need for this study. As such, the authors contend their incorporation into collegiate aviation programs may be an effective and robust way to improve collegiate aviation student mental health and lessen the likelihood of student suicides (and self-harm). The usage of these symposia may inform collegiate aviation program leadership of techniques and/or resources they can leverage to increase mental health support within their program and improve the mental health of aviation students.

The following research questions were addressed by conducting pre- and post-surveys of the collegiate aviation students at the University of Nebraska at Omaha (UNO), a four-year midwestern institution, during their 2025 Aviation Institute Mental Health Symposium (MHS). The surveys included a range of questions designed to assess students' knowledge, awareness, and comfort levels related to mental health. Given the salient purpose of this study, the following central (or primary) research question (CQ) was developed to guide this study:

CQ: What impact, if any, do Mental Health Symposiums have on the knowledge and understanding of mental health of collegiate aviation students?

There are also three secondary research questions (RQs) guiding this study:

- RQ#1: What is the overall perception (positive, negative, or indifferent) that collegiate students have about symposiums relative to mental health?
- RQ#2: Are collegiate aviation students more comfortable or inclined to discuss mental health-related topics as a result of attending a mental health symposium?
- RQ #3: What barriers or impediments, if any, exist that may deter or prevent collegiate aviation students from seeking help, support, and/or resources to resolve their mental health challenges/issues?

Significance of the Study

Although the extant mental health research on collegiate aviation students offers valuable insights into their perceptions and attitudes toward this issue (Clarke et al., 2024; Albelo & McIntire, 2023), there is limited research that specifically focuses on the effectiveness of mental health symposia regarding students' knowledge, understanding, and comfort with mental health. This study is significant because it yields insights into how students perceive the usefulness of the knowledge gained and resources obtained from the MHS. More importantly, the study may inform collegiate aviation program leadership about methods, techniques, and resources they can utilize to enhance mental health support within their programs and improve the mental well-being of their students. Consequently, the data resulting from the study may help raise awareness and increase support for aviation students, the collegiate aviation community, and the industry as a whole, leading to solutions not previously considered. There are two primary gaps, temporal and empirical, which this study aims to fill. Temporally, there is a scarcity of studies examining the impact of educational advancements related to mental health tools and resources in aviation/aerospace, specifically in the context of mental health symposia. Empirically, there is a lack of studies assessing the effectiveness of MHS on the knowledge, understanding, and comfort of collegiate aviation students concerning mental health. This gap is particularly critical because it involves understanding whether these symposia enhance students' knowledge, awareness, and comfort regarding mental health, and if so, how they can be utilized by program leadership to improve safety and awareness.

Literature Review

U.S. Mental Health

Mental health has become a topic that is more readily embraced by Americans in the U.S. thanks to the pandemic (Johnson et al., 2024), awareness efforts through social media, and an increase in mental health-related research (Winter et al., 2017; Winter & Rice, 2015; Hoffman et al., 2024a; Hoffman et al., 2024b; Hoffman et al., 2019). Discussions surrounding current mental health initiatives are difficult to discuss without considering the context of the post-pandemic reality that has had marked effects on this topic. A recent study found that in populations of U.S. college students, mean depression and anxiety rates skyrocketed during the pandemic. Still, post-pandemic, depression rates returned to pre-pandemic levels, whereas anxiety rates continued to climb (Fruehwirth et al., 2025). Research by Turetsky and Sanderson (2017) focused on collegiate students, where the participants were given three different interventions of social norms, general mental health education, and stress management. The study found that in a collegiate setting, the lack of information surrounding mental health and its nuances has implications for attitudes surrounding the topic. Turetsky and Sanderson also found that presenting normative information does have measurable benefits to student mental health contexts (2017). What is interesting about these findings is that gender continues to be a significant covariate, with female students reporting higher rates of adverse mental health symptoms during and after the pandemic (Roche et al., 2022).

Despite the aviation/aerospace industry largely existing within a different set of standards and expectations surrounding mental health and wellbeing than other sectors of the workforce, that does not mean these professionals and aviation students are somehow exempt from the realities that exist. What is meant by this is best elucidated by Hubbard and Bor (2006), who proposed a similar argument, contending that aviation/aerospace professionals operate under a unique professional culture. This culture is one characterized by high performance standards, rigid safety protocols, and a perceived social status. Such a culture, collectively, does not eliminate nor truly mitigate the presence of stressors nor the susceptibility of these professionals to mental health challenges. Therefore, Hubbard and Bor (2006) help illustrate the notion that while aviation/aerospace professionals exist and operate in a specialized environment with different rules, expectations, and standards relative to mental health, the basic realities

of human vulnerability to stress, anxiety, burnout, and other common mental health challenges still apply to these professionals. The difference is not that aviation/aerospace professionals are immune to associated mental health challenges, but more so that the industry's standards, stigma, and historical context surrounding mental health have made non-disclosure the norm, and recognizing and addressing the realities are more complex. Thus, it is for these reasons and more that Maslow's Hierarchy of Needs is one of the first lessons Certificated Flight Instructors (CFIs) are taught in their training (FAA, 2020a).

Mental Health in Aviation/Aerospace

The stigma surrounding the perception of mental health within the aviation/aerospace industry is a resounding issue. Prior to delving into how stigma impacts those within aviation/aerospace, it is first necessary to define the term. Stigma is defined as "Prejudices held towards individuals that are either part of, or perceived to be part of, certain groups" (Johnson & Jones, 2025). Stigma is particularly prevalent within the context of social evaluations in the industry, as the importance of these perceptions is substantial (Sabik et al., 2019). Social evaluations and networking are widely regarded as critical aspects of success within the industry (Johnson, 2024). This is often encapsulated and emphasized by the adage, "It is not what you know, but who you know within the industry." Such a simple statement adds a significant amount of pressure on individuals to make the right first impressions and obtain positive social evaluations from everyone they encounter. Further, the correlation that exists between subjective and external perceptions has marked effects on potential health outcomes. The deeply ingrained stigma surrounding mental health in aviation/aerospace continues to be one of the most significant barriers preventing students from seeking help. This stigma manifests in multiple ways, including internalized shame, peer pressure, and concerns about being perceived as unfit for flight training (Jacobs et al., 2020).

Toughness and self-sufficiency have long been core values in the industry. Research by Hubbard (2016) provides a historical analysis of aviation training and professional culture, which shows a longstanding emphasis on mental fortitude within the culture of the industry and has created an environment where discussing mental health concerns is often equated with weakness. While an illogical maxim, it has become a widely propagated issue. This is demonstrated in the training phases of aviation/aerospace, and many, if not most, aviation students internalize these beliefs, leading them to suppress their struggles rather than seek assistance of any kind (Jacobs et al., 2020). Scholars contend that social isolation and loneliness exacerbate adverse mental health outcomes, especially for those who lack communities of support (Johnson, 2024; Johnson et al., 2024; Bruss et al., 2024). When considering aviation/aerospace professionals, who naturally have a propensity to refrain from discussing mental health issues due to the culture of fear within the industry (Hubbard, 2016; Johnson et al., 2024), merely discussing mental health and/or seeking help can be daunting tasks and inherently form a barrier to obtaining help. Furthermore, this leads to the high probability of mental health symptoms and diagnoses being largely underreported amongst the professionals, specifically pilots (Wu et al., 2016).

Arguably, stigma is one of the most severe barriers to seeking mental health treatment for those afflicted working in aviation/aerospace careers (Raus, 2024). A study conducted by Johnson et al. (2024) sampled a pool of Black aerospace professionals, in which he and his colleagues specifically highlighted that a "Culture of Fear" exists. Many participants discussed the overall anxiety surrounding the potential repercussions that exist from both aviation/aerospace employers and the FAA alike. Amongst collegiate aviation students, the majority believe FAA regulations themselves are too restrictive, and almost half report the regulations have negative effects on their desire to seek out resources or assistance for any mental health issues (Stein, 2023). More aerospace students were surveyed in a study by Waters et al. (2024), who found that nearly half of the respondents (47%) reported that seeking therapy would make them feel less satisfied with themselves. Additionally, 49% of participants expressed concerns that seeking professional help would damage their self-confidence and harm their professional image. These

findings highlight the important role that social perceptions and evaluations play in discouraging mental health discussions within the aviation community, especially at the collegiate level.

Mental Health in Collegiate Aviation/Aerospace Programs

Despite the larger social embrace of mental health in the U.S. recently, there are still subgroups of the population that experience difficulty grappling with mental health and associated challenges. Mental health challenges have become an increasingly pressing issue for collegiate students generally and more specifically for those enrolled in collegiate aviation programs. The number of college students struggling with serious mental health issues has been on a consistent rise in recent history, and barriers to seeking help and accessing resources are not a strife exclusive to aviation/aerospace students (Storrie, 2010). While the rise in mental health challenges is universal amongst college students, collegiate aviation students face unique sets of issues that set them apart from their counterparts. They must navigate the rigorous demands of traditional collegiate life in addition to managing stressors innate to being in an aviation program, such as FAA written and practical testing (Clarke et al., 2024; Robertson & Ruiz, 2010). For students on the professional pilot track, flight training bestows a more inordinate set of stressors, such as adhering to stringent medical certification requirements (Pitts, 2023), which can potentially exacerbate current mental conditions students possess. The stressors of being an aviation student and, in particular, those undergoing flight training, are often compounded by personal burdens or factors that adversely impact their mental health (e.g., the culture of fear innate to the aviation industry that prioritizes resilience and self-reliance) as posited by scholars (Johnson et al., 2024; Johnson, 2024; Boyd & Bliss, 2024). The aforementioned often constitute prominent barriers that cause students, specifically collegiate aviation students, to be less inclined to seek mental health support or help.

The higher education environment is undoubtedly stressful for students due to a myriad of reasons, the majority of which are linked to academic and/or social elements of pursuing higher education (Johnson, 2024). As such, accessing mental health support as a collegiate aviation student, particularly those engaged in flight training, possesses its own set of barriers, which tend to be viewed as burdens by the impacted students. These confounding factors, in conjunction with the already high-pressure and high-stakes environment of being a collegiate aviation student, presumably add to the mounting pressure and mental health challenges these students experience. Although mental health in aviation/aerospace has gained more positive attention and traction in recent years (Nealon, 2021; Panchal & Lo, 2024; PMHC, n.d.), many students remain hesitant to seek professional support or even admit that they may have a mental health challenge or disorder (Lipson et al., 2022). This reluctance to seek support or help and/or admit that they are afflicted by mental health stems from several reasons, most of which are underpinned by a fear of ramifications (Johnson et al., 2024) and stigma (Winter & Rice, 2015). Studies indicate that fear of professional consequences, including the potential loss of one's medical certification (Hubbard, 2016; Johnson et al., 2024) and potentially their future career, prevents these students from obtaining the care they need (Pitts & Faulconer, 2023; Johnson et al., 2024; Hoffman et al., 2024a). Furthermore, the stigma surrounding mental health discussions in the aviation community perpetuates a cycle of suppression, leading to unaddressed psychological distress and increased safety risks in training and flight operations (Hubbard, 2016; Winter & Rice, 2015; Wu et al., 2016).

FAA Policies and Mental Health Disclosure

An in-depth analysis of collegiate aviation students' perceptions of FAA mental health policies conducted by Stein (2023) found that many students frequently operate under false assumptions about the extent to which mental health diagnoses impact certification. The existing widespread misunderstanding of FAA policies and guidelines, in conjunction with the fact that many of these guidelines tend to be overly restrictive and punitive in nature, leads to unnecessary fear. Consequently, collegiate aviation students may be inclined to forgo treatment that might otherwise enhance their well-being and

performance. This highlights how the FAA's medical certification policies play a significant role in shaping how industry professionals and collegiate aviation students perceive and respond to mental health concerns. Research by Pitts and Faulconer (2023) highlights that nearly 50% of collegiate aviators actively avoid discussing mental health concerns due to fear that such disclosures may negatively impact their FAA certification status. This fear is further reinforced by the finding that nearly 90% of students would avoid seeking professional mental health treatment if they believed it would possibly threaten their ability to fly (Pitts & Faulconer, 2023). These alarming statistics reinforce the urgent need for policy reforms that allow for mental health transparency to occur without such severe professional repercussions, with the goal to mitigate healthcare avoidance behaviors (Hoffman et al., 2024) and create a more permissive environment (Johnson et al., 2024).

A growing body of research advocates for revisions to FAA policies that would create a more balanced approach to mental health evaluations. Boyd (2024) and Raus (2023) argue that more transparent and supportive policies could lead to improved mental health outcomes without compromising aviation safety. Proposed reforms include enhanced education about FAA regulations, increased mental health support resources, and mechanisms for pilots to seek treatment without fear of automatic consequences or disqualification. As of April 2025, instrumental legislation, namely the Mental Health in Aviation Act of 2025 and the Aviation Medication Transparency Act of 2025, has been introduced to update the FAA's existing mental health policies. Both pieces of legislation would help ensure aviation/aerospace professionals would be able to seek vital mental health care without the fear of facing professional repercussions (PMHC, 2025). The legislation is significant because it can diminish the fear culture that exists, encourage help-seeking behaviors, and provide a change in the mentalities of collegiate aviation students who may be following incorrect behaviors they see modeled within the industry.

Methodology

Data Collection and Analysis

This study employed a mixed-methods approach to capture both quantitative and qualitative insights from collegiate aviation students who attended the 2025 UNO Aviation Institute MHS. A pre- and post-symposium electronic survey was administered using QR codes placed on tables at the event. Participants were encouraged, though not required, to provide their names to allow comparison of pre- and post-responses to determine the impact of the symposium on collegiate aviation students' knowledge, understanding, and comfort with mental health. The surveys received Institutional Review Board approval from UNO's Office of Regulatory Affairs (IRB #0006-25-EX) (see Appendices C and D) and were placed on each table alongside the informed consent form (Appendix B) for participant review. Survey research was chosen to provide a quantitative description of the students' knowledge, understanding, and comfort regarding mental health, as well as their perceptions of a specified group (Creswell & Creswell, 2018). The pre- and post-surveys, which consisted of 40 questions, included 35 closed-ended (e.g., multiple choice and Likert scale) and five open-ended questions. The survey questions focused on personal information (e.g., demographics), mental health knowledge, understanding of mental health, and comfort with discussing or sharing challenges related to mental health (see Appendix A).

The inclusion of the open-ended questions provided respondents with an opportunity to furnish written responses to some of the more specific and/or sensitive mental health questions (Johnson et al., 2024). The usage of these questions helped elevate individual voices and specific concerns about mental health, which is paramount given the various stressors collegiate students experience. Additionally, the comments provided by respondents aided in contextualizing the data and identifying themes, effectively spotlighting information not obtained through the closed-ended survey questions. Therefore, using closed- and open-ended questions allowed a more complete understanding of collegiate aviation students'

knowledge, understanding, and comfortability relative to mental health, and what role or impact, if any, the MHS had on them.

As discussed earlier, the survey questions were developed using previous research studies that examined the mental health perceptions, attitudes, knowledge, and/or challenges individuals within the aviation/aerospace industry experienced. There has been extensive research conducted in recent years about collegiate aviation students' mental health, specifically examining their perception(s) on depression and anxiety and how this perception impacts flight students in particular. Research was also conducted by Albelo and McIntire (2023) who found that minoritized aviation students experienced unique challenges due to a myriad of factors (e.g., institutional inequities and cultural differences), all of which adversely impacted their mental health. While contemporary research exist that explores the mental health and challenges of collegiate aviation students, there is a paucity of research within the industry that assesses the impact MHS have on the mental health of students. There are a few studies that elucidate the positive impact these symposiums have had on participants' mental health, within the STEM field, but none that exclusively focus on aviation/aerospace let alone collegiate aviation programs. For the creation of this survey, the aforementioned studies were reviewed, and questions were derived using some of the survey protocols encompassed within the studies, allowing for the creation of pre- and post-symposium surveys inclusive of questions positioned to address the research questions.

Study Participants

The researchers targeted 150 completed surveys, which was deemed an appropriate sample size as it accurately represented the aviation flight program student body, allowed for over 50% of the students to be surveyed, and minimized sampling error (Boyd & Bliss, 2024; Johnson et al. 2024). To promote the event and encourage registration, the researchers sent an initial email to UNO faculty, staff, and students informing them that registration opened in October 2024. Follow-up emails were sent monthly thereafter until the event date. Registrant information (e.g., first/last name, year, major, etc.) was collected via Qualtrics. The registration link closed the day before the event in February 2025 after being open for responses for 120 days. In total, there were 244 registrants for the 2025 Aviation Institute Mental Health Symposium event. Of the 244 registrants, 225 attended (92.2%). With respect to response rates, 126 pre-symposium and 92 post-symposium surveys were completed, resulting in a maximum of 92 completed survey responses available for comparison analysis. Of the 92 completed responses, only 68 were eligible for analysis based on the inclusion criterion and successful completion of both the pre- and post-symposium surveys. The privacy of the participants was safeguarded by the researchers through de-identification methods, and the additional demographic data collected included race/ethnicity, age, sex/gender, year/status in school, and major.

Validation Process

To ensure reliability and clarity, the pre- and post-survey instruments were reviewed by the research team and pre-tested with six individuals who were known to the researchers in a professional capacity (Johnson et al. 2024; Lutte et al. 2024). These reviewers provided feedback on the readability, content relevance, and logical flow of the questions. Additionally, to enhance the drafting and clarity of the survey questions, each researcher independently reviewed the pre- and post-surveys and provided feedback via track changes. This process allowed any comments or revisions made during the independent review to be integrated into the final interview protocol (Appendix B). This multi-perspective review process added another layer of reliability and validity to the survey instrument. The final survey was designed to align closely with the study's research questions and to minimize ambiguity.

To assist in presenting the data and specifically elucidate the similarities and differences between the themes, points of convergence and divergence were utilized. Convergence occurs when the outcomes

of different approaches lead to the same conclusion, whereas divergence occurs when the results of different approaches show different outcomes, leading to divergent conclusions (Fouad, 2024). The combined use of these are essential in helping researchers understand the complexity and variation that are inherent to the data while also supporting the triangulation method (Fouad, 2024).

Statistical Analysis

Quantitative – Closed-Ended Questions. The collected data were analyzed using a range of widely accepted statistical methods to identify key trends and relevant patterns. This analytical process enabled the researchers to present a comprehensive findings section and to offer evidence-based conclusions grounded in the data. To begin, all Likert scale questions from both the pre-symposium and post-symposium surveys were analyzed using descriptive statistics. Specifically, the authors focused on the mean and standard deviation of each question to identify which questions received the highest and lowest average scores, as well as which questions exhibited the greatest and least variability in responses. This initial step helped understand overall response patterns and highlight areas of consistent or divergent perceptions among participants. Next, the authors calculated the difference in mean scores between the pre-symposium and post-symposium surveys for each question. This comparison allowed the authors to determine which questions showed the most notable increases or decreases in perceived importance, satisfaction, or awareness following the symposium. These differences provided insight into the impact of the symposium on participants' attitudes or knowledge. Finally, the authors conducted chi-square tests on all closed-ended survey questions to examine whether response patterns differed significantly across various demographic and experiential subgroups. These subgroups included race/ethnicity, gender, age, academic year or status, affiliation with a registered student organization, residential status (on-campus vs. off-campus), employment status, first-generation college student status, and whether the respondent had previously attended a mental health symposium. The chi-square analyses enabled the authors to assess the extent to which background characteristics influenced participants' responses and to identify statistically significant associations.

Qualitative – Open-Ended Questions. The qualitative data were analyzed through thematic analysis, a process typically consisting of six steps, yet only four were used based on the purpose of the study and the needs of the researchers. Prior to importing the data into NVivo, a qualitative data management software, the PI cleaned and deidentified the data to ensure only completed responses were included for comparative analysis. The data was analyzed through open coding the data line-by-line in Nvivo to identify the themes based on the respondents' comments.

Thematic analysis began with transcription and familiarization (Naeem et al., 2023), constituting the first step. This is where researchers thoroughly reviewed open-ended survey responses from both the pre- and post-symposium surveys. This process involved reading each of the five open-ended questions and their 68 corresponding responses to gain a comprehensive understanding, or "gestalt", of participant perspectives (Groenwald, 2004; Johnson et al., 2024). During this initial phase, salient phrases and incomplete or redundant entries were removed, and significant quotations were compiled into a "master bank" within NVivo to preserve participant voice and prepare for deeper analysis. Following familiarization, researchers identified keywords that captured recurring ideas and emotionally or conceptually significant terms related to mental health in aviation/aerospace, denoting the second step. These keywords served as the foundation for the coding process, where responses were broken into smaller units, each labeled with a code to represent its thematic meaning. Codes were then organized into broader categories to reveal patterns and relationships aligned with the research questions, signaling the third step. The keywords play a critical role in this step because they form the backbone of the thematic analysis, helping to convert raw data into insightful, informative, and manageable units (Naeem et al., 2023) that provide a holistic perspective of respondents' experiences and perceptions. This culminated in the development of core themes, constituting the fourth step, which synthesized participants' experiences

into an analytically rich and structured format, ultimately informing the findings presented in a tabular form within the *Findings* section. At the end of this step, there were eight themes formulated.

Findings

Participant Information

A total of 126 participants completed either the pre-symposium or post-symposium survey. However, only 68 participants completed both, and thus the quantitative analysis focuses exclusively on this group for pre- and post-comparisons. Table 1 presents the participants' background information. Among these 68 participants, the majority were White (59 participants, 86.8%), male (54 participants, 79.4%), aged 19 to 20 (49 participants, 72.0%), freshmen (37 participants, 54.4%), and employed (48 participants, 70.6%). Approximately half lived on campus, while the other half lived off campus. Fewer than half (25 participants, 36.8%) were affiliated with a Registered Student Organization (RSO). Additionally, only nine participants (13.2%) identified as first-generation college students, and 12 participants (17.6%) had previously attended a mental health event.

Table 2 presents the descriptive statistics of the survey questions. Before attending the symposium, students had limited knowledge about mental health in aviation and were unfamiliar with available resources, although they generally felt comfortable listening to others and learning about mental health topics.

Participants' comfort discussing mental health with friends or family, in group settings, and with someone they trust showed considerable variation. This suggests that while some individuals felt very comfortable, others were significantly less so. In contrast, participants expressed more consistent views on abstract concepts and overall satisfaction with available resources, highlighting a stark difference between shared understanding and personal comfort levels.

In the post-symposium survey, participants reported feeling satisfied with mental health resources and more knowledgeable about on-campus support services. However, their comfort in discussing mental health with others remained relatively low, suggesting that interpersonal comfort is more difficult to improve in a short period of time.

Similar to the pre-symposium survey, participants' comfort level varied persistently, reflecting differences in personal experiences, cultural attitudes, and readiness to be vulnerable—even after the symposium. In contrast, as with the pre-survey, responses to knowledge-related questions were more consistent across participants.

Respondents showed the greatest improvement in their knowledge of on-campus resources and support services (Q16, Q22, and Q25) after attending the symposium. However, their comfort with listening to others share mental health challenges (Q30) or discussing their own mental health with close friends or family (Q28) slightly declined, though the scores remained relatively high. These findings suggest that comfort-related attitudes may be more resistant to change and could require sustained, long-term interventions.

Table 1
Participant Information

	Count	Percentage
Race/Ethnicity		
White	59	86.8%
Asian	4	5.9%
Hispanic or Latino	2	2.9%
Two or More	2	2.9%
Black or African American	1	1.5%
Gender		
Male	54	79.4%
Female	13	19.1%
Non-binary	1	1.5%
Age		
19-20	49	72.0%
21-24	13	19.1%
25-29	4	5.9%
30-34	1	1.5%
35+	1	1.5%
Year/Status in school		
Freshmen	37	54.4%
Sophomore	14	20.6%
Junior	10	14.7%
Senior	7	10.3%
Affiliated with a Registered Student Organization (RSO) on campus		
Yes	25	36.8%
No	43	63.2%
Living on campus		
Yes	32	47.1%
No	36	52.9%
Currently employed		
Yes	48	70.6%
No	20	29.4%
First-generation student		
Yes	9	13.2%
No	59	86.8%
Attended a mental health event before		
Yes	12	17.6%
No	56	82.4%

Table 2
Descriptive Statistics

	N	Mean	SD	Min	Max
Q14. Do you know the definition of mental health and/or mental well-being?	68	0.853	0.357	0	1
Q14_Post. Did this event/program provide you with a clear definition of mental health and/or mental well-being?	68	0.882	0.325	0	1
Q15. What is your overall level of understanding of mental health as a concept or topical area?	68	3.412	0.674	1	5
Q15_Post. What is your overall level of understanding of mental health as a concept or topical area?	68	3.750	0.720	1	5
Q16. How would you rate your knowledge level about on-campus resources and support services focused on navigating mental health challenges?	68	2.897	0.831	1	5
Q16_Post. How would you rate your understanding of on-campus mental health resources and support services after the event?	68	3.809	0.738	1	5
Q17. How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the UNO AI?	68	2.588	0.918	1	5
Q17_Post. How has your knowledge of mental health initiatives, support, and resources within the UNO AI improved due to the program?	68	2.485	1.029	0	4
Q18. Do you feel that peer support systems are accessible and effective within your collegiate aviation program?	68	0.882	0.325	0	1
Q18_Post. Do you feel that peer support systems became more accessible and effective within your collegiate aviation program after attending the event?	68	0.809	0.396	0	1
Q19. How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the aviation/aerospace industry?	68	2.515	0.970	1	5
Q19_Post. How has your understanding of mental health initiatives and resources within the aviation/aerospace industry changed since the program?	68	2.574	0.834	1	4
Q20. How confident are you that future aviation/aerospace employers will support mental health initiatives?	68	3.044	0.836	1	5
Q20_Post. How confident are you now that future aviation/aerospace employers will support mental health initiatives?	68	3.206	0.939	1	5
Q21. What is your overall level of understanding of mental health as a concept or topical area?	68	3.235	0.775	1	5
Q21_Post. What is your current understanding of mental health as a concept or topical area now that the event has concluded?	68	3.750	0.720	1	5
Q22. What is your level of understanding of the resources or support services one can access on campus to assist with mental health challenges/issues?	68	2.868	0.809	1	5
Q22_Post. What is your current understanding of the resources or support services available on campus to assist with mental health challenges now that the event has concluded?	68	3.735	0.704	1	5
Q23. Do you know where you could go to receive psychological services on-campus and how to access these services?	68	0.632	0.486	0	1
Q23_Post. Do you now know where and how to access psychological services on-campus?	68	0.926	0.263	0	1
Q24. How satisfied are you with the mental health resources available on-campus?	68	3.397	0.672	1	5
Q24_Post. How satisfied are you with the mental health resources currently available on-campus, based on what you learned?	68	3.853	0.885	1	5

Q25. How familiar are you with the resources or support services one can access in the Greater Omaha community and/or on-campus to assist with mental health challenges/issues?	68	2.735	1.031	1	5
Q25_Post. How familiar are you with the resources or support services one can access in the Greater Omaha community and/or on-campus to assist with mental health challenges/issues?	68	3.441	0.983	1	5
Q26. What is your level of understanding of what factors or elements can contribute to, worsen, and/or improve one's mental health?	68	3.382	0.792	1	5
Q26_Post. How has your understanding of factors that contribute to, worsen, or improve mental health changed?	68	3.118	1.153	1	5
Q27. What is your level of understanding of the common signs of mental health struggles or challenges?	68	3.338	0.765	1	5
Q27_Post. How would you rate your understanding of the common signs of mental health struggles or challenges now that the event has concluded?	68	3.676	0.742	1	5
Q28. How comfortable are you talking about your mental health with close friends or family?	68	3.382	1.107	1	5
Q28_Post. How comfortable are you now discussing your mental health with close friends or family?	68	3.368	1.050	1	5
Q29. How comfortable are you talking to an education professional (i.e., teacher, professor, instructor, etc.) about your mental health?	68	2.897	1.024	1	5
Q29_Post. How comfortable are you now discussing mental health with an education professional (e.g., teacher)?	68	3.309	1.069	1	5
Q30. How comfortable are you listening to others share their mental health challenges or issues?	68	3.809	0.935	1	5
Q30_Post. How comfortable are you now listening to others share their mental health challenges?	68	3.735	0.857	1	5
Q31. How comfortable are you talking about mental health topics in a group setting?	68	3.000	1.093	1	5
Q31_Post. How comfortable are you now discussing mental health topics in a group setting?	68	3.235	1.024	1	5
Q32. How comfortable are you learning about mental health resources and coping strategies?	68	3.529	0.906	1	5
Q32_Post. How comfortable are you now learning about mental health resources and coping strategies?	68	3.632	0.862	1	5
Q33. How comfortable are you seeking help or assistance for mental health challenges or struggles?	68	3.191	0.950	1	5
Q33_Post. How comfortable are you now seeking help for mental health challenges or struggles?	68	3.529	0.819	1	5
Q34. How comfortable are you with participating in mental health awareness events or activities (e.g., Mental Health Symposiums)?	68	3.206	0.907	1	5
Q34_Post. How comfortable are you now participating in mental health awareness events or activities (e.g., Mental Health Symposiums)?	68	3.397	0.979	1	5
Q35. How comfortable would you be informing someone you trust if you were experiencing mental health challenges?	68	3.397	1.067	1	5
Q35_Post. How comfortable would you now feel informing someone you trust if you were experiencing mental health challenges?	68	3.603	0.831	1	5

To better understand whether participants with different backgrounds had significantly different responses, we conducted 549 chi-square tests, comparing participants' backgrounds with each binary or five-point Likert scale question. Table 3 presents the significant results of these chi-square tests.

The chi-square analyses reveal several important patterns regarding how different demographic groups responded to the pre-symposium and post-symposium surveys in terms of knowledge, comfort,

and perceptions of mental health resources. These results highlight both equity considerations and targeted opportunities for future interventions.

One of the most prominent findings is the difference in responses by race/ethnicity. Non-White participants consistently reported higher comfort levels in key areas such as discussing mental health with education professionals, participating in awareness events, and learning about mental health resources. These findings challenge generalized assumptions that students of color are less likely to engage in mental health conversations and instead suggest that when provided with safe and inclusive environments, these students may be especially receptive. This also underscores the importance of culturally responsive mental health programming, validating the experiences and perspectives of racially diverse populations.

Gender also emerged as a significant differentiator in how students responded to the symposium. Female students showed greater change—positive or negative—in both their understanding and comfort levels, suggesting a more dynamic response to the mental health content. This may reflect a greater willingness among female students to engage with emotionally or personally challenging material. These results imply that mental health programming should remain sensitive to gendered experiences, potentially offering more nuanced content or follow-up opportunities tailored to specific needs.

Differences by year in school and age further underscore the role of educational maturity and life experience in shaping mental health perceptions. Seniors and students aged 21 or older generally demonstrated higher levels of understanding and were more critical of the mental health infrastructure, particularly peer support systems. This group's more skeptical view may reflect both accumulated institutional knowledge and a higher standard of expectation. Conversely, younger students—especially freshmen—appear to benefit significantly from foundational knowledge-building efforts and may require more robust, entry-level mental health education and peer connection opportunities.

Additional group differences emerged by employment status and first-generation status. Employed students tended to report greater post-symposium gains in understanding and comfort, possibly reflecting greater real-world exposure or motivation to manage stress effectively. Meanwhile, first-generation students reported lower familiarity with mental health resources, indicating a possible gap in access to informal support networks or institutional knowledge. These findings suggest a need for targeted outreach to first-generation students to ensure they are aware of and feel empowered to access available services.

Interestingly, no significant differences were observed between students affiliated with RSOs and those who were not. This suggests that mere involvement in campus groups may not correlate with improved mental health awareness or comfort, and that deeper forms of engagement, such as participation in mental health-specific events, may be more impactful. Indeed, prior attendance at mental health events proved to be a strong predictor of greater confidence in employer support, increased understanding, and greater comfort seeking help, demonstrating the positive cumulative effect of repeated exposure to mental health content.

In summary, the chi-square results illustrate that the MHS was not experienced uniformly across the student body. While many groups benefited in measurable ways, the degree and nature of that benefit varied. These differences offer valuable insight into how future mental health initiatives can be more intentionally inclusive, data-informed, and responsive to the unique needs of diverse student populations.

Table 3
Results of the Chi-Square Test

Demographic Variables	Survey Questions	Pearson Chi-Square Values (Significance Level)
Race (White vs. Others)	Q29 Post – Comfort discussing mental health with an education professional	12.67 (**)
	Q32 – Comfort learning about mental health resources and coping strategies	12.22 (**)
	Q34 – Comfort participating in mental health awareness events	12.42 (**)
	Q35 Diff – Change in comfort informing someone trusted	12.10 (**)
Gender (Male vs. Female)	Q21 Diff – Change in understanding of mental health as a concept	12.71 (**)
	Q27 Diff – Change in understanding of signs of mental health challenges	9.62 (**)
	Q30 Diff – Change in comfort listening to others share struggles	14.99 (**)
	Q32 Diff – Change in comfort learning about resources	16.19 (**)
Year/Status (Class Standing)	Q15 – Pre: Understanding of mental health concepts	21.55 (***)
	Q18 – Perceived effectiveness of peer support systems	8.08 (**)
	Q21 – Understanding of mental health as a concept or topical area	25.99 (**)
	Q24 – Satisfaction with the mental health resources available on-campus	17.69 (**)
Age (19–20 vs. 21+)	Q29 – Comfort talking to an education professional	32.13 (***)
	Q33 Diff – Change in comfort seeking help or assistance	32.83 (***)
	Q18 – Effectiveness of peer support systems	5.38 (**)
	Q22 Post – Understanding of available support services post-event	7.76 (**)
RSO Involvement	Q27 – Understanding of common signs of mental health struggles	9.57 (**)
	Q35 – Comfort informing someone trusted	18.00 (***)
No significant difference.		
On- vs. Off-Campus	Q35 – Comfort informing someone you trust	9.99 (**)
Employment Status	Q26 Post – Change in understanding of contributing/worsening factors	10.02 (**)
	Q35 Post – Post comfort informing someone trusted	10.54 (**)
First-Gen Student	Q25 – Familiarity with resources	9.67 (**)
	Q30 Diff – Change in comfort listening to others share struggles	16.03 (**)
	Q35 Diff – Change in comfort informing someone trusted	11.85 (**)
Prior Event Attendance	Q20 Post – Confidence in employer support	9.74 (**)
	Q26 Post – Understanding of contributing/worsening factors	13.76 (***)
	Q32 Post – Comfort learning about mental health resources	11.48 (**)
	Q33 Post – Comfort seeking help	9.96 (**)
	Q33 Diff – Change in comfort seeking help	11.99 (**)

Note: 1. ** indicates p -values less than 0.05, and *** indicates p -values less than 0.01.
2. Due to space limitations, we report only the significant results.

Table 4
Pre-Symposium & Post-Symposium Themes

Associated Survey Question	General Theme	CQ/RQ Addressed
Q40	Education as Empowerment – Mental Health Understanding	CQ: What impact, if any, do Mental Health Symposiums, have on the knowledge and understanding of mental health of collegiate aviation students?
Q39	Pathways to Awareness – Mental Health Knowledge	RQ #1: What is the overall perception (positive, negative, or indifferent) collegiate students possess about symposiums relative to mental health?
Q38	Taboo Topics to Comfortable Conversations	RQ #2: Are collegiate aviation students more comfortable or inclined to discuss mental health related topics as a result of attending a mental health symposium?
Q37	Soaring Beyond Stigma to Sustaining Support	RQ #2: Are collegiate aviation students more comfortable or inclined to discuss mental health related topics as a result of attending a mental health symposium?
Q36	Access Granted – Barriers Bypassed	RQ #3: What barriers or impediments, if any, exist that may deter or prevents collegiate aviation students from seeking help, support, and/or resources to resolve their mental health challenges/issues?

Thematic Analysis Overview

Table 4 outlines the themes derived from the respondents' comments on the open-ended survey questions. In qualitative research, it is common for themes to be ranked or presented based on the frequency with which participants mention them or their prevalence in the study (Johnson, 2023; Johnson, 2024). For this study, the aforementioned ranking system was not utilized to preserve the richness of the themes derived from the thematic analysis process; such richness and detail could be lost if the themes were categorized hierarchically. Furthermore, since this was an exploratory study covering a relatively under-researched topical area, ranking the themes might have suggested a level of precision and finality that is inappropriate given its exploratory nature. It should be noted that due to the profound nature of the information garnered from this study and the seriousness of the subject matter itself, certain words or phrases were explicitly enumerated and stated, which is a tactic researchers have used in similar mental health studies to underscore the pervasiveness and gravity of the topic at hand (Johnson et al., 2024). The findings below provide in-depth detail about each of the emergent themes conveyed by the respondents and their connection to the stated research questions.

Education as Empowerment – Mental Health Understanding

The *Education as Empowerment – Mental Health Understanding* theme effectively addresses the CQ guiding this study as well as RQ #1 because it provided salient insight into the degree to which collegiate aviation students' understanding of mental health was impacted by attending an MHS, in addition to revealing what their overall perception of the MHS was at its conclusion. As a reminder, Q40 from the surveys inquired about what the participants found beneficial in improving their understanding of mental health before and after attending the MHS.

In the pre-symposium survey, participants shared statements centering a large reliance on themselves to treat and manage mental health challenges they experienced through coping strategies (e.g., counseling), self-guided research, self-care, and, in rare instances, support[ive] systems, whereas in the post-symposium survey, participants consistently cited various communities of support they intended to lean on or had used, reluctantly, in the past to overcome these challenges. This denotes a divergence in how support systems, such as communities of support, were perceived and understood before and after the MHS, with more students expressing they felt inclined to rely less on themselves and more on others to navigate their mental health. Such a transition in mentality was denoted by one participant who had a significant epiphany and said, "Realizing that I'm not the only one [experiencing mental health issues or challenges]" and another participant who, when detailing how they planned to give and receive support, stated, "Giving space to listen to others and trying to gain clarity on where they are coming from." The remarks about self-reliance were often conveyed in a negative or solemn context. While mental health is an intimate and sensitive topic, it is not something individuals have to deal with on their own, but this is something not everyone is cognizant of or knows how to do. Instead, some individuals opt to rely on themselves and their own devices to guide independent research as a means to intrinsically manage and understand their mental health.

The notion of self-guided research and utilizing information from the internet or textbooks presents another point of divergence. Prior to the MHS, participants' understanding of mental health was limited, as were their abilities to manage it. By the end of the MHS, participants were enamored by the symposium and proffered that by attending, they learned about a multitude of resources and tools they could utilize to manage their mental health, with the speakers themselves and their presentation serving as key resources. This indicates a clear and pivotal divergence in the parochial understanding and limited resources the participants entered the MHS with compared to the numerous individuals and resources on-campus they were aware of once they left the MHS. The sense of empowerment and confidence respondents conveyed between their pre- and post-symposium responses, as it relates to their understanding of mental health, was stark. This newfound confidence was especially prominent when respondents discussed resources and accessing them. For instance, one participant shared, "I feel like I now know where I can go to get help if I need it". Respondents also attributed the increase in their understanding to the presenters and speakers, praising them highly in their remarks because of the poise, information, and content delivery. This was captured by one participant who said, "I liked that each presentation and presenter hit a topic that made mental health even broader," and another who noted: "Hearing about the common issues students come to the student counseling resources with was insightful." The provision of even the most basic information, such as the definition and symptoms of mental illnesses/disorders was, for some in attendance, a difference maker in their understanding and an element they found beneficial in expanding their overall cognizance of mental health.

Pathways to Awareness – Mental Health Knowledge

The *Pathways to Awareness – Mental Health Knowledge* theme effectively addresses the CQ and RQ #1 while complementing the aforementioned theme: *Education as Empowerment – Mental Health Understanding*. As a reminder, Q39 from the surveys inquired about what the participants found beneficial in improving their knowledge of mental health before and after attending the MHS. This particular theme underscored the immense benefit participants received from attending the MHS as it relates to their knowledgeability of mental health, and because they benefitted from the symposium through edification, their overall perception of the symposium was more positive at the end than in the beginning. The benefit and educational importance of the MHS were elegantly stated by one respondent who cited, "The symposium was a general benefit to my knowledge of mental health, nothing specific; it was just good to have mental health talked about in such an open way." Part of this positive perception can also be attributed to the fact that participants were more confident in their ability to manage their mental health and that of others while also knowing how to navigate and access on- and off-campus

resources by the end of the MHS. Such confidence was communicated by several different participants as indicated by the following statements: “The AME speaker was a good resource, I learned how to access the medical certification requirement, and that mental health issues aren't a death sentence for your medical.” And “Bringing and showing the school's resources.”

In the pre-symposium survey, respondents shared a profound need for a safe space to exist for them to receive knowledge about mental health and embrace the information received. Without such a space, respondents reported feelings of reluctance and lacking the openness necessary to truly absorb any/all information related to increasing their mental health knowledge base. A similar sentiment was expressed in the post-symposium survey, as respondents cited the environment as an element that aided in improving their knowledge of mental health and a necessary precursor to engage in conversations surrounding the topic. For the context of this study, the safe space and environment the respondents appreciated were the MHS itself, as noted by one participant who said, “The openness and understanding [of the MHS].” This similarity between the pre- and post-symposium indicates a convergence in the paramount nature of the MHS, especially the conducive, open, and embrative environment or safe space that was cultivated by the presenters/speakers, attendees, faculty/staff, and volunteers. While the support of others, specifically students in attendance, aided in creating a conducive environment to have a serious conversation about mental health, it segues into another convergence point. This point of convergence was between the support of others and the presenter/speaker and topic diversity sub-themes. Across both surveys, respondents expressed a want or need to support others but did not necessarily know how to do so, or rather, the most appropriate way to approach such a sensitive topic. Due to the information shared by the diverse group of speakers/presenters, respondents obtained knowledge on how they could provide support to those in need. This signals a convergence in the role of supporting others and how the knowledge provided by the speakers/presenters equipped them with the necessary to feel comfortable doing so. The change in mentality, increase in knowledge, and underscoring of the importance of support is encapsulated briefly by one participant who stated, “Being able to put myself in others shoes and try to relate to them that way, instead of thinking about how it's a burden and annoying to me, because someone else might just be having a rough day” and another who said, “Every speaker improved my knowledge.”

Before attending the MHS, participants described two primary approaches they used to enhance their overall mental health knowledge and better understand how to manage their own mental well-being: coping strategies and social media, particularly TikTok. Frequently mentioned coping strategies included mindfulness, meditation, and various breathing techniques. According to one respondent, these strategies were beneficial to their mental health knowledge and management as evidenced by the following statement, “It gives me more mental clarity and allows me to focus on other parts of my life closer instead of living in my own head all the time.” Several respondents noted they learned some of these techniques through social media platforms, with TikTok being a prominent source. One participant noted the positive benefit of using these strategies, positing, “It has helped me to stay balanced as a person.” The mention of social media generally and one specific site conveys a limited knowledge base of mental health resources. When considering attendees largely leveraged social media for their mental health edification and knowledge pre-symposium, attendees were shocked to learn about the plethora of resources available to them, and they expressed intent to capitalize on them post-symposium. This underscores a key divergence in how parochial the mental health knowledge of respondents was pre- and post-symposium.

Taboo Topics to Comfortable Conversations

The *Taboo Topics to Comfortable Conversations* theme directly addresses RQ #2 because, as the thematic nomenclature suggests, MHS attendees explicitly expressed a more positive inclination to and a higher level of comfort with having discourse about mental health-related topics post-MHS as opposed to pre-MHS. As a reminder, Q38 from the surveys inquired about what made the participants feel uncomfortable when discussing mental health. This theme accentuates the positive impact participants

experienced from attending the MHS relative to the sense of discomfort they felt discussing mental health and highlights the dramatic shift in comfortability once the symposium concluded. Prior to the MHS, respondents expressed a strong reluctance to be vulnerable and open to discussing mental health for a variety of reasons. The most profound included a fear of judgement by/from others (e.g., friends/peers), a fear of repercussions (e.g., loss of medical certificate) if someone were to learn about their mental health challenges, and an immense worry about the lack of privacy if they were to talk to someone such as a mental health professional (MHP) about their challenges as well as a lack of understanding from others.

The fear of being judged by others, as conveyed by several participants, was a notable factor that inhibited their want/need to be open about any mental health challenges afflicting them, and the mere thought of it made them uncomfortable in mental health-related discussions. Such a fear was simply stated by one participant who said, "Feeling judged". Interestingly, some respondents expressed a desire to support others being impacted by mental health, but were uncomfortable doing so because they were unsure of the best way to do so without causing additional harm or injury unintentionally. This was encapsulated by one participant who shared, "When people talk about things I can't relate to or don't know how to answer." The fear of repercussions was another prominent factor that made participants feel uncomfortable discussing mental health and less inclined to share challenges with others. The root of this fear largely stemmed from the belief that doing so would negatively impact their aviation/aerospace career, especially those aspiring to be professional pilots. Such a belief was posited by one respondent who said, "The possible negative outcomes for my career."

This widely held belief amongst those in the industry connects to sentiments shared about the worry about a lack of privacy and understanding regarding mental health. Due to this belief and past experiences, specifically with those who claimed to be confidants, respondents shared a deep sense of concern about the lack of privacy surrounding mental health conversations. This concern was shared by two participants: one stated, "[The] lack of privacy and threats," and the other stated, "It [the mental health conversation] is not being private." The privacy concern, as conveyed by numerous respondents, was often accompanied by the angst of others not understanding their feelings or challenges, even if they were to share them. Such concern was proffered by two different participants, with one saying, "That they would not understand, I guess," and another postulating, "People that do not listen/care or understand."

Participants also cited, albeit to a lesser extent, mental health as a factor that made them more reluctant and uncomfortable with/in mental health-related conversations. The rationale underpinning this reluctance and discomfort was multi-faceted, but generally centered around the gravity and intimacy of the topic itself, in addition to not making it a common practice to discuss personal issues with others. With respect to the gravity and intimacy that are innate to mental health conversation, these feelings were described by various respondents, with one saying, "The weight of the issues," and another citing "Mentions of suicide" as reasons aiding in their discomfort. With respect to mental health not being a personal issue up for discussion, one respondent said, "Just not really a fan of talking about that stuff."

After the MHS, participants expressed a higher inclination to be vulnerable and experienced less discomfort when engaging in mental health-related conversations than they did pre-MHS. This underscores a key divergence in how and why attendees felt discomfort with mental health while also showcasing the beneficence of such an event in improving their openness to discuss an intimate topic. The positive impact on the discomfort and improved vulnerability or openness to mental health-centric conversations was evidenced as 28 respondents, or 41.2%, stated there was nothing that made them uncomfortable when discussing mental post-MHS, compared to the various remarks given pre-MHS. Participants attributed part of the diminishment in their discomfort to the MHS organizers, presenter/speakers, panelists, and faculty/staff who were present because of their genuine interest, concern, and support provided. This was adduced by one respondent who noted, "The program seemed like they had people who were passionate and cared." While this indicates positive progress, some

participants still conveyed sentiments that MHS content made them uncomfortable. The most common reason for the lingering discomfort was discussion about suicide and high suicide rates, particularly of teen- and college-aged individuals.

Across both pre- and post-MHS contexts, respondents' shared sentiments of fear and worry of the consequences that could result from being open about their mental health with anyone, including MHPs, even if they followed the proper protocol outlined by the FAA. This was stated by one participant who said, "The FAA can still strip my license even if I go through the proper steps." Specifically, respondents noted fearing having their medical certificate revoked and potentially jeopardizing their aviation career if information about their mental health status were to be shared outside of the circle of confidence. This indicates a convergence in the role of the taboo topic of mental health, which has been steeped in a culture of fear within the industry, regardless of the information shared at the MHS. Despite this convergence point, there were some attendees who experienced epiphanies during the MHS and latched onto pivotal information that showed them that all was not lost if they had a mental health challenge. This was eloquently encapsulated by one attendee who shared, "Understanding that the presence of a mental health issue does not automatically disqualify you from becoming an Aviation professional."

Soaring Beyond Stigma to Sustaining Support

The *Soaring Beyond Stigma to Sustaining Support* theme addresses RQ #2 and complements the previously discussed theme. This is because the shared consensus amongst the MHS attendees was that the event made them more comfortable and inclined to discuss their mental health (with others) and related topics due to several factors. As a reminder, Q37 from the surveys asked participants what made them feel comfortable when discussing mental health before and after the MHS. While the previous theme of *Taboo Topics to Comfortable Conversations* detailed the factors or elements that contributed to respondents' discomfort with mental health and negatively impacted their willingness to have conversations about mental health, this theme focuses on the opposite: outlining the factors that positively contributed to the MHS respondents' sense of comfort when discussing mental health, especially their own, with others such as peers/colleagues and MHPs.

Prior to the MHS, respondents posited needing two things to feel comfortable engaging in mental health discourse. The first is confidentiality from others, and the second is that the individual they would confide in needed to be relatable. Knowing that respondents could trust others they confided in with sensitive information and that it would remain private was a major factor in determining their level of comfort discussing mental health. This was accentuated by one different participant who noted, "Knowing it won't leave the room". Additionally, respondents expressed the need for relatability between them and the person they opened up to; this relatability was beneficial in creating a rapport to begin the difficult conversation(s). More importantly, the sense of familiarity helped the respondents feel more understood with their feelings and challenges shared, especially if the individual listening had experience with/in similar situations being described. This particular sentiment was proffered by several respondents as indicated by the following statements: "When someone else has been in that situation.", "Someone who understands what I'm going through.", and "Knowing who I'm talking to knows and understands what I've been through."

In the post-symposium survey, respondents shared a collective sense of relief that was nearly palpable due to critical information they learned from the MHS. This sense of relief stemmed from the demystification of mental health, which was facilitated by the speakers/presenters delineating fact from fiction with respect to mental health and its intersection with aviation. The edification and relief were captured by one participant who said, "Understanding that the presence of a mental health issue does not automatically disqualify you from becoming an Aviation professional." While respondents in the pre-symposium survey stressed the importance of having confidentiality and relatability as necessary

elements for them to be comfortable enough to discuss mental health, they also emphasized the importance of demystifying the mysteries of aviation mental health and how this delineation positively impacted their comfort levels. This highlights a key divergence in how comfort was determined and perceived. By understanding what was true versus not true regarding mental health treatment, reporting to the FAA, and insurance and diagnostic processes, participants expressed a higher inclination to not be impeded by stigma and seek support. At the conclusion of the MHS, respondents indicated a more sensible approach to and understanding of mental health, realizing that experiencing mental health challenges was not abnormal and that no one is immune to some of the innate struggles associated with it.

Before attending the MHS, attendees asserted that the environment played a salient factor in their comfort level to discuss mental health. Specifically, attendees described needing and wanting a calming, welcoming, loving, and understanding environment that contained familiar faces. These elements effectively cultivated a space conducive to a nuanced topic. Similar sentiments about the environment were shared post-MHS by the attendees, signaling a point of convergence in the role environment and in particular the MHS environment, had on the experiences, perceptions, and comfortability of the attendees regarding mental health discourse. A "safe space" was effectively created for the attendees by the organizing personnel, faculty/staff, speakers/presenters, and other attendees present. The aforementioned elements effectively created the environment that individuals expressed they needed and wanted.

Similar to the previous theme, participants shared some concern prior to the MHS about the subject matter of the event, specifically noting that mental health was just not a topic they were comfortable discussing. This was attributed to several reasons, and as one participant plainly stated, "Just how serious the topic is" as a prime reason why they were not willing to converse about it. Still, there were some participants who, despite not being as comfortable as they may have liked, saw the benefit in engaging in mental health discussions. Such an attitude was conveyed by one participant who said, "I love to learn how everyone thinks, and that involves talking about mental health". Both participants' comments demonstrate the importance of talking about mental health and being comfortable when doing so. Although participants shared reservations about their comfort levels relative to mental health discourse pre-MHS, participants expressed a higher level of comfortability and confidence post-MHS because of the information gleaned from the diversity of presenters/speakers and resources available to/for them. This stark difference signals a divergence in how mental health comfortability was perceived and altered (positively) by the participants. Specifically, participants described that they appreciated the knowledge level and expertise of the speakers/presenters as well as how genuine, sincere, and friendly they were when engaging in the topic. This sentiment was shared by two participants, one who noted, "Some of the speakers sound very friendly and open to hearing about people's mental health," and another who said, "How all the speakers seemed to be very understanding and open about their own experiences."

It should be noted that participants appreciated the representativeness of the speakers/presenters who comprised both panels for the events. The representation enhanced the relatability of the information shared and made it easier for attendees to engage in and understand the content being shared, especially from the student perspective. This sentiment was supported by many participants, with some making statements such as "I like to see people like me on stage speaking" and "Stories and students giving their opinions." Participants also expressed a sense of gratitude for being made cognizant of the resources available to them. Despite some being more seasoned students at the university and relatively comfortable with mental health discussions, they were unfamiliar with on-campus resources designed to aid with mental and emotional health challenges. This was adduced by one participant who noted, "Learning [about] CAPS was good," and another who said, "Information about the amount of resources the university has available [for students]."

Access Granted – Barriers Bypassed

The *Access Granted – Barriers Bypassed* theme explicitly addresses RQ #3 because it furnishes salient insight into the various barriers participants perceived as deterrents in seeking support and/or resources to navigate mental health challenges pre-MHS and how their perception was altered (or not) post-MHS. As a reminder, Q36 from the surveys inquired about what barriers existed that prevented them from seeking mental health support when experiencing a challenging time. This theme highlighted the multitude of barriers that negatively impacted participants' inclination and ability to obtain support and/or treatment for mental health challenges. Across both pre- and post-MHS contexts, participants shared that access to resources was a prominent barrier for them seeking support for their mental health challenges. This indicates a point of convergence in the salience of ensuring students have access to paramount services, specifically those for mental health, particularly after they are informed of and/or become knowledgeable about the resources they can and should use. The issue of inadequate access to resources went beyond knowing where to go or how to gain access to them, as participants shared that the unaffordability of mental health treatment posed a frequent barrier. This was communicated by one participant who stated, "The financial aspect once the University resources are no longer available as an enrolled student." It is clear that participants rely heavily on the free resources provided by the university because some lack the financial security to utilize them otherwise. This was adduced by one participant who posited, "For me personally, the lack of health insurance, but I am working on it...I know that there are free services on campus." Such a comment demonstrates just how much of an access barrier financial constraints pose to some MHS attendees.

In responses across both surveys, respondents described a sense of reluctance and fear for losing their medical certificate and thereby jeopardizing their job security as future aviation professionals. This fear was outlined as a prominent barrier to/their seeking mental health support services. The associated worry was summarized by one participant who said, "In aviation, the risk of losing your passion or dream", when explaining why it was a barrier. Other respondents shared similar sentiments about the potential loss of their medical certificates, as adduced by the following statements: "Risk of loss of flight medical." And "The fear of getting my medical taken."

Despite information being conveyed to participants about how they can seek mental health support and not be penalized for it, some still expressed trepidation about doing so because of the potential ramifications to their aviation career. Part of this trepidation stems from respondents not trusting the confidentiality that is assured when speaking to someone such as an MHP, as well as them not fully trusting the person they are confiding in. The concern about jeopardizing their job security, losing their medical certificate, and forfeiting an aviation career pre- and post-MHS denotes a convergence in the role a permissive environment has on mitigating perceived barriers, regardless of the education, awareness, and discussion of resources that can help. The lack of such an environment presents a barrier that was a common undertone amongst the responses and was encapsulated by one participant who noted, "Most employers and the FAA do not allow it." Additionally, it should be noted that respondents also highlighted how cumbersome the process was to seek mental health support as a barrier. One attendee briefly said, "Too much time", as a factor that made them less inclined to seek help.

The most profound and vividly described barrier shared across pre- and post-MHS contexts was stigma. This signals a convergence in the drastic impact and role stigma has on individuals' willingness to seek support for their mental health, regardless of the education or knowledge they receive about it, the resources available to treat it, and the support they may have to manage it. Attendees detailed the numerous ways the stigma surrounding mental health adversely impacted their willingness to seek mental health support and specifically cited themselves as a barrier for not being able to overcome the implications. Two participants explicitly stated this, with one saying, "Myself" and another saying "Me". Additionally, the stigma of being viewed or perceived as a burden or causing unnecessary trouble for

others by seeking mental health support was also explicated. Such a belief was expressed by one respondent who stated, "Not wanting to burden loved ones...have felt in the past, guilt over struggling with mental health, when I feel I shouldn't be." This feeling was supported by a different participant who said, "Embarrassed and causing others trouble." Despite the information and testimonies shared by the plethora of speakers/presenters, stigma still served as a barrier for some attendees. The stifling impact of stigma as a barrier post-MHS was cited by one participant who said, "I think just being scared to go and thinking my problems aren't enough". It is important to note that while some attendees still possessed barriers to mental health support post-MHS, as expressed by one participant who noted, "My perceived barriers to accessing mental health support have not changed; they were and still are personal barriers..." this was not the case for all. Based on respondent feedback post-MHS, at least 26 attendees, or 38.2%, expressed that they had no barriers to seeking mental health support as a result of attending.

Discussion

Central Research Question (CQ)

The CQ guiding this study sought to understand what impact, if any, MHS had on the knowledge and understanding of mental health of collegiate aviation students. Through an analysis of the survey data, which entailed examining the open-ended and Likert scale questions as well as a review of the emergent themes, it was determined that the theme *Education as Empowerment – Mental Health Understanding* was the most apt to address and expound upon the posited CQ. Further, it was revealed that the 2025 UNO Aviation MHS had two major positive impacts on the collegiate aviation students who attended. The first impact is that collegiate aviation students believed the information received from the MHS through the various speakers and presenters was empowering, and positively impacted their understanding of mental health overall (Table 1). The second impact is that collegiate aviation students believed their knowledge about mental health was positively impacted by the MHS because of the awareness and exposure to resources, strategies, and environment they were subjected to (Table 1). As a result, those students in attendance learned about the various pathways they could embark on toward mental health awareness, positively impacting their overall knowledge and understanding of the topic, thereby addressing the CQ.

The *Education as Empowerment – Mental Health Understanding* theme yielded insight into the perceptions UNO aviation students held with respect to their understanding of mental health pre- and post-MHS. This perception and their understanding were ascertained through open-ended Q40.² Within this theme, there were two points of divergence. The first point of divergence pertains to the difference in reliance of support (self v. community), participants expressed pre- and post-MHS. As noted earlier, pre-MHS, collegiate aviation students expressed a large reliance on themselves, as evidenced by engaging in self-guided research and self-care, and many shared reluctances in using their community of support or support systems to navigate their mental health challenges. This expression by the students supports research by Labouliere et al. (2015) a commonly-reported reason for youth/young adults not seeking help due to the perception that they should solve problems on their own, which is an illogical maxim.

The mention of self-reliance was often shared in a negative manner, and while some may deem this reliance as a positive attribute due to the sense of autonomy conveyed, it can quickly become problematic, especially for young adults similar to those sampled in this study. Specifically, over reliance on oneself can actually serve as a barrier to mental health support as cited by Ishikawa et al. (2023) who found that young adults who experience mental health challenges that do not seek support tend to develop growth in self-reliance, which results in a barrier to help-seeking. The navigation of mental health

²Q40 asked participants what they found beneficial to improving their understanding of mental health before and after the MHS.

challenges is something individuals should not have to handle on their own, even if they are extremely independent or exhibit a strong self-reliance, because of how pervasive and nuanced mental health is/can be. Self-reliance, relative to mental health, should be thought of as a spectrum where it can be extremely safe on one end and unsafe on the other. Research by Labouliere et al. (2015) shared instances of when self-reliance can be unsafe for individuals and found that reducing this extreme self-reliance, particularly for younger individuals, may increase their likelihood of seeking help. Several participants conveyed that they engaged in self-guided research as a way to improve their understanding of mental health, specifically their own and that of others. This behavior can and should be viewed on the “safer” side of self-reliance because it constitutes a data collection phase that individuals can use to make informed decisions on what first step(s) they should take to treat their mental health, such as leveraging support systems or speaking with an MHP.

The aforementioned provides a stark contrast to the sentiments expressed post-MHS, where collegiate aviation students shared a robust understanding of and inclination to utilize their support systems, signaling a divergence in how their communities of support were perceived and can be used to navigate mental health challenges. This constitutes the first point of divergence mentioned earlier. The divergence point supports research by Johnson et al. (2024) who found that having access to support programs and/or communities of support had a positive impact on mental health as well as the ability to navigate similar mental health challenges in the future. Such a finding confirms what is already known amongst those who are afflicted by mental health challenges, particularly in their ability to persist and overcome difficult situations that may exacerbate their mental health. The MHS aided the collegiate aviation students, especially those who were unaware or did not know, in understanding what a support system looked and felt like. This enabled the students to obtain a better idea of how to effectively leverage these systems to obtain the socioemotional support needed for their mental health challenges.

For some students, their community of support primarily consisted of colleagues and friends, constituting a more informal peer support network. Although informal in nature, the effectiveness of such a network still bears the same positive effect as a structured peer support program, like one would find in a professional organization. This positive effect stems from the fact that these support programs, comprised of peers, allow students to share their challenges in a judgment-free zone, as adduced by Miller (2024a). These zones, often filled with individuals who can relate to items shared more closely because of age and experience proximity compared to teachers or advisors who may be notably older, create a sense of comfortability and relatability for the students. In a similar vein, the inclusion of colleagues and friends in one’s support systems connects to and accentuates research by Johnson (2023) who found that Black Americans in aviation relied on socioemotional support from the “3Fs”, friends, family, and faculty, to overcome certain mental health challenges pertaining to a lack of belonging, inadequate representation, and other elements incumbent to the industry. Some of this is applicable to the collegiate aviation students included in this sample because they shared leveraging friends (one of the 3Fs mentioned). They did so to overcome mental health challenges they experienced that stemmed from traditional collegiate stressors (Clarke et al., 2024), a lack of belonging – their program or the industry (Johnson, 2023; Johnson et al., 2024), and program-specific stressors (Clarke et al., 2024; Robertson & Ruiz, 2010).

The second point of divergence pertains to the difference in participants’ understanding of mental health resources available and how to manage their mental health pre- and post-MHS. As noted earlier, prior to the MHS, the collegiate aviation students’ understanding of mental health was rather limited. This presents a contrast to their understanding post-MHS, which improved because they learned about a litany of resources they could utilize to manage their mental health from the MHS. The divergence point here elucidates the parochial understanding and limited resources that collegiate aviation students possessed pre-MHS. It is also worth noting that pre-MHS, the students were not as confident in their ability to use or access resources that would help their mental health, compared to post-MHS, where they had a newfound sense of confidence and expressed that they felt “empowered”. This difference in understanding and,

more importantly, the confidence levels pre-MHS v. post-MHS support and underscore research by Benwell et al. (2022), who found that confidence is linked to mental health and wellbeing. Individuals with high levels of anxiety and depression, which are common mental health challenges, particularly for collegiate students, tend to possess lower levels of confidence.

The lack of confidence students expressed pre-MHS makes sense and aligns with the consensus posited by Benwell et al. (2022) because they were likely anxious and unnerved at the thought of attending a MHS and not truly knowing what would be discussed, who would be speaking, and/or what their presence may result in. However, the positive improvement to their confidence post-MHS can likely be attributed to lessened anxiety and stress over the course of the event as students became acclimated and comfortable, in addition to the presenters/speakers making intentional efforts to create a welcoming environment. In other words, students felt more secure, prepared to succeed, and cultivated a growth mindset, all of which are characteristics confident individuals possess (Miller, 2024b). Consequently, collegiate aviation students began to enhance their understanding of mental health and how to apply what was being communicated to their own personal life. Additionally, the newfound sense of confidence impacted their innate ability to manage mental health because they were more comfortable using some of the techniques shared and less timid in their approach to seek mental health support, which also stems from a stronger understanding. This underlines the importance of the MHS because of their ability to enhance one's understanding of mental health as contended by Villarino & Villarino (2023). The two points of divergence outlined above significantly contribute to the body of research by showing MHS are an effective tool to improve the mental health understanding in STEM fields as posited by Till et al. (2024), and demonstrates this effectiveness for aviation/aerospace disciplines. This constitutes an under researched area for mental health and thereby adds a new, critical lens to the literature.

Research Question #1 (RQ #1)

The first research question centered on the overall perception collegiate aviation students possessed about MHS. There was one open-ended question, Q39³, leveraged to help address this RQ. Through an analysis of the open- and ended-questions in the survey, it was clear participants were positively impacted by the MHS as elucidated earlier in the CQ discussion, but also found the MHS to be extremely beneficial in improving their mental health knowledge (Tables 1 and 3). Several participants alluded to how educational the MHS was as shared by one participant who stated, "The symposium was a general benefit to my knowledge of mental health..." Other participants shared positive sentiments and remarks about the MHS, specifically praising the speakers and presenters for being excellent resources. This was captured by one participant who noted, "The AME speaker was a good resource, I learned how to access the medical certification requirement and that mental health issues aren't a death sentence for your medical." Both quotes connote a positive perception of the MHS, thereby addressing RQ #1. More importantly, this positive perception signals collegiate aviation students found the MHS to be a beneficial way to spend their time due to information gained regarding resource availability, meeting people they could speak to about mental health, and the reassurance that having mental health issues were not a "death sentence" for a career in aviation/aerospace contrary to popular belief (Hubbard 2016; Johnson et al. 2024).

Refuting such a stigmatized and widely propagated belief is where this theme, *Pathways to Awareness – Mental Health Knowledge*, truly shines because it supports research by several scholars (Hubbard, 2016; Johnson et al. 2024; Albelo and McIntire, 2022) regarding the negative notion about aviation mental health, and underscores research by Villarino and Villarino (2023) by demonstrating how MHS combat the pervasive stigma that exist within the industry. Further, the findings from this study

³Q39 sought to understand what elements from the MHS participants found beneficial in improving their mental health knowledge.

make a significant contribution to the aviation/aerospace literature by showcasing that MHS can be and are an effective tool to increase the mental health knowledge of aviation/aerospace students and is not just a tool exclusive to certain STEM disciplines where research has been conducted (Till et al. 2024).

It is important to note participants explained that their knowledgeability relative to mental health improved around knowing what type of environment they needed to be in to engage in candid mental health discussions, how to support and show up for others afflicted by mental health challenges, and expanded their foundational knowledge about mental with respect to resources utilization and availability. Simply, by attending the MHS, participants were made aware of the various pathways to/for mental health support, making the *Pathways to Awareness – Mental Health Knowledge* theme was most apt to address RQ#1. Within this theme there were two points of convergence and one point of divergence. The first point of convergence pertains to the immense need for an environment, or safe space, to engage in mental health-related conversations. Pre-MHS, attendees expressed they yearned for safe space that would allow them to be in an appropriate mental mindset to receive mental health knowledge being conveyed, embrace, and process it. Post-MHS, attendees cited the environment as an element that aided in the improvement of their mental health knowledge and a necessary pre-cursor to engage in discourse about the sensitive topic of mental health. The fact respondents shared similar sentiments pertaining to a safe space pre- and post-MHS indicates a convergence about the open and embrative environment was created during the MHS by the faculty/staff, speakers and presenters, student volunteers, and attendees.

For an effective discussion, it is important to first understand what “safe spaces” and “brave spaces” are, how they are defined, and what the difference(s) between them are. According to Trowell (2024) safe spaces are, “Environments that allow for students to express themselves in a manner that feel materially different – safer – than in the classroom or in the town square.” These spaces are created to allow students to be themselves without fear of attack or reprisal from others when having discourse about sensitive, difficult, and/or contentious topics. By definition a “brave space” is a learning space where risk-taking, discomfort, and fear are understood as fundamental elements (Lopez-Littleton et al. 2018). Simply, it is a space where students are open to serious, respectful, and empathetic discourse (Trowell, 2024), which is ideal to discuss mental health because students can be confident in their ability to engage in genuine discussions pertaining to controversial issues without feeling the need to conform to dominant behaviors (Lopez-Littleton, 2016). A brave space supersedes that of a safe space and the main difference between them is that brave spaces are created to encourage students to take risks to participate in sensitive conversations such as mental health, that will take them outside their comfort zone rather than allowing them to seek refuge in a “safe space” (Trowell, 2024). While the environment created during the MHS was a safe space because of the guidelines and tone established by institutional personnel– a pivotal requirement to develop trust and safety (Trowell, 2024) – one could argue that what was actually cultivated was a brave space with “brave instructors” who facilitated the event. These brave instructors, session moderators and faculty/staff, played a pivotal role in navigating difficult dialogue in the space and modeled non-defensive attitudes during tense times rather than deflecting or projecting, which are important elements for brave spaces to be successful (Trowell, 2024).

The effectiveness and embrace of the brave space was evident in the way the students interacted with one another at their tables, during the intermissions, and most prominently, during the question-and-answer sessions at the conclusion of the panels. It was during these sessions where students took the necessary risks to stand in front of their peers, be vulnerable, and ask questions others had on their minds, but may have been too apprehensive to pose. Such an action demonstrates the risk-taking behavior these spaces were created for as posited by scholars (Lopez-Littleton, 2016; Lopez-Littleton et al. 2018; Trowell, 2024). This is important to highlight because the use of safe and brave spaces are uncommon in STEM disciplines and are arguably a foreign concept within aviation/aerospace programs despite their profound impact as showcased with this study. These spaces are more commonly used within social science programs to assist with the incorporation of equity-related concepts in public administration

curricula (Lopez-Littleton et al. 2018), but clearly have a place within aviation/aerospace programs. While these are terms innate to public administration and social justice education, their application in the context of this manuscript underscores the intersectional, pervasive nature of mental health. Thus, this particular point of convergence and finding notably contributes to the aviation/aerospace literature by showcasing that MHS can serve as the safe and/or brave space necessary for students to engage in genuine conversations about mental health and are a paramount factor in initiating that discourse for those who may be reluctant to do so. This notion is further supported by Meherali et al. (2025) who found that safe spaces offered youth mental health support and guidance while highlighting the need to expand safe space initiatives within educational environments.

The second point of convergence pertains to the ability to provide social support to others experiencing mental health challenges. Prior to the MHS, participants shared a want/need to socially support others, but did not know how to do so nor were they aware of how to approach such a sensitive topic to start the conversation. This want/need of collegiate-aged individuals to support others is important to emphasize because of the critical role they play for those who need or want someone to talk about mental health, but are reluctant to do so because of stigma (Hubbard, 2016), fear of consequences (Johnson et al. 2024), are experiencing suicidal thoughts and depressive symptoms (Rickwood et al. 2007), and/or are overly self-reliant when handling their mental health problems (Labouliere et al. 2015). Due to the information shared by the presenters and speakers, attendees obtained salient knowledge they could use to support others experiencing mental distress post-MHS. This could be in the form of general support by taking a measured approach to start the conversation and ask how an individual would want to be supported. Such an approach taken by these collegiate-aged individuals is an important element of providing mental health support because younger people often seek help through talking to their family and friends first rather than an MHP (Rickwood et al. 2007). While the want/need to provide social support during times of mental health distress is admirable, there is often a cost associated students are unaware of. This cost is identified as emotional labor (Strazdins and Broom, 2007), and depending upon the type of social support given, namely companionship or help, those who assist others with mental health challenges should be cognizant of the impact (neutral, beneficial, or costly) to their own mental health. According to Strazdins and Broom (2007) companionship involves showing care to people, building feelings of happiness, pride, and belonging, whereas help involves assisting with feelings of distress, anger, and conflict. The latter is potentially much more stressful and as such, negatively impacts the mental health of the individual providing the help compared to the provision of companionship which has a much more neutral to positive impact on the support givers' mental health.

Although MHS participants noted wanting to give social support to those within their network, they did not differentiate how they wanted to support, rather if the support provided would be via companionship or help. Based on the generality and language of the comments surrounding social support, it is presumed the participants would like to provide social support via companionship (e.g., watching a movie or studying together), but instead use the term "help" loosely and interchangeably not realizing that helping could cause them to do things they really are not inclined to do (e.g., anticipating and preventing problems) (Strazdins and Broom, 2007). The contrast between the two is clear; one is more manageable for a collegiate student managing their own mental health and obligations, would be expected of a peer, and has fewer negative ramifications while the other is more emotionally laborious and would be expected of a family member due to the emotional investment required. Therefore, while commendable that many attendees expressed a need/want to socially support those within their network, students should be intentional in the type of support given to avoid overloading themselves. Thus, the difference between the two is important to delineate because of the potential impact on/to the giver. This particular finding contributes a new dimension to the aviation/aerospace literature because students are likely unaware of the difference between companionship and help, and they need to know the difference(s) so they can discern which to give to whom and when to prevent harming themselves.

The first and only point of divergence with this theme pertains to the level of knowledge relative to mental health and strategies participants possessed and used, respectively. Pre-MHS, there were only two primary approaches participants identified they used to enhance their mental health knowledge and/or manage their mental health. These included coping strategies and social media, most notably “X” (formerly Twitter). There was a stark difference post-MHS where participants expressed significant improvement in their mental health knowledge and felt they had a stronger foundation to work from. Specifically, participants exclaimed their attendance at the MHS made them aware of the pathways (at UNO and within the Omaha community) to support mental health, indicating a divergence from their once parochial knowledge and mentality pre-MHS. This divergence also supports research by Giroux and Geiss (2019) regarding the effectiveness of mental health interventions in improving attendees’ knowledge. Specifically, Giroux and Geiss (2019) found that a student-led mental health awareness campaign on campus (i.e., a mental health intervention) helped reduce stigma towards mental health and increased students’ attitudes towards help-seeking. This increase was attributed to the resources provided, educational sessions by the school counselor, and social support offered by the counselor to the students.

Ultimately, participants left the MHS with more knowledge than they entered with and knew how to effectively use that knowledge for their benefit and to benefit others. Therefore, based on the fact that they gained pivotal knowledge such as where to go for help, who they can or should contact for assistance, and how to navigate certain mental health challenges, participants possessed an overall positive perception of the MHS. It should be noted that while the vast majority of participants possessed an overall positive perception of the MHS, there were some who held a negative perception, which is to be expected. The common thread amongst those who attended and felt negatively about the event cited the mandatory nature of the MHS by program leadership and believed it was too long. Despite their negative perception, they still benefited because they likely learned something new about mental health they can use in the future, connected with peer(s), and/or discovered a resource they can access should the need arise. This finding supports and accentuates research by Giroux and Geiss (2019), Villarino and Villarino (2023), and Shim et al. (2022), who contend that mental health education is an effective tool for improving mental health awareness among collegiate students. This adds an important lens to the aviation/aerospace literature by showing proof of concept external to STEM-specific fields (Till et al., 2024).

Research Question #2 (RQ #2)

The second research question inquired about the level of comfort collegiate students possessed and how inclined they were to discuss mental health as a consequence of attending the MHS. There were two open-ended questions employed to aid in addressing this RQ: Q38.⁴ and Q37.⁵ Based on an analysis, students’ comfort with discussing mental health slightly declined post-MHS, although overall scores in this metric remained relatively high. Specifically, participants expressed less comfort with listening to others share mental health challenges or discussing their own mental health with those closest to them, such as family or friends (Table 2). This was evidenced by a diminished willingness to be more vulnerable with others when engaging in mental discourse over the duration of the MHS and was also shown by the lower completion rates of the voluntary post-MHS survey. The aforementioned also shows less of an inclination to have uncomfortable conversations and strained efforts to push past the stigma associated with mental health to seek support from others, thereby addressing RQ #2.

Despite the information provided and supportive environment cultivated during the MHS, the slight decline in mental health comfort is not surprising. This supports research by Raja et al. (2022), who found participants were less comfortable discussing sensitive topics such as trauma, an element of mental health, because of privacy concerns. This study’s findings suggest that comfort-related attitudes may be

⁴Q38 asked participants about what made them feel uncomfortable when discussing mental health.

⁵Q37 asked participants about what made them feel comfortable when discussing mental health.

more resistant to changes in the short term and require more long-term interventions to truly improve one's comfort. Such a notion parallels sentiments made by scholars who underscore the use of community education (Raja et al., 2022), such as an MHS and an anti-stigma campaign (Henderson et al., 2017), as tools to improve comfort discussing mental health, disclosing a mental health challenge, and engaging in help-seeking behaviors. Therefore, routine utilization of MHS within collegiate aviation programs appears to be a viable strategy to help participants overcome intra- or interpersonal barriers that negatively impact their comfort with mental health discourse by normalizing it and potentially improving mental health/well-being. As such, the most appropriate themes to address this RQ were *Taboo Topics to Comfortable Conversations* and *Soaring Beyond Stigma to Sustaining Support*.

Beginning with the *Taboo Topics to Comfortable Conversations* theme, there was one point of convergence. Participants expressed a strong reluctance to be vulnerable and were not comfortable with discussing mental health due to three main reasons: 1. A fear of judgment by friends/peers, 2. A fear of consequences or ramifications, and 3. Extreme discomfort talking about specific aspects of mental health (e.g., suicide and depression). The fear of being judged, especially by one's peers/colleagues, is a well-known impediment for those who would like to seek help or support for their mental health, but do not. Generally, this is referred to as Social Anxiety Disorder (National Institute of Mental Health, 2022), which is a persistent fear of being watched and/or judged by others. In the context of this study and discussion, there is more depth to this fear, and it is actually better characterized by a fear of poor social evaluations. According to Abdai and Miklósi (2016), social evaluation is a process during which an individual assigns different values (positive or negative) to particular behavioral patterns that are performed in a social interaction. This evaluation dictates how the individual is perceived and interacted with by others in society, meaning if others avoid or prefer them (i.e., their likability is impacted). That said, individuals tend to fear receiving adverse social evaluations from those close to them and/or in their network. The receipt of a poor social evaluation runs counter to the internal wiring of human beings, as they possess an innate want and borderline need to be liked by others (Sawhney, 2023).

Since conversing about mental health challenges carries a high likelihood of being viewed negatively by many in society, despite the recent societal shifts, it is not surprising that participants expressed a reluctance to be vulnerable, especially since collegiate-aged individuals can be harsher than necessary towards their peers. The harshness may manifest in the form of alienation of the individual who expressed their sentiments about mental health and consequently received a negative social evaluation, resulting in a type of social punishment, per se. This phenomenon of receiving a social punishment because of poor social evaluations supports research by Pederson (2023), who concluded that a fear of poor social evaluations is a stressor that impacts the psychological well-being of individuals. It also accentuates research by Sabik et al. (2019) and Johnson et al. (2024), who allude to the notion that poor social evaluations adversely impact one's comfort level and inclination to discuss mental health unless in a safe space. More importantly, these phenomena compound the already existing fear of judgment and provide a compelling lens to the notion of peer support that is widely propagated as a first line of defense for those afflicted. Peer support has been posited by scholars as a safe, effective, and efficient method to help aviation/aerospace professionals manage mental health challenges in a healthy way. Research by Winter and Rice (2015) stated that strong social support may help act as a buffer against stress in the workplace, which can also mean the collegiate environment. However, if collegiate aviation students are fearful of being judged by their peers for sharing their mental health and, as such, are not comfortable doing so, then where can or are they expected to seek help without judgment? Therefore, it can be surmised that students and especially collegiate aviation students, require a "safe space", "brave space", "brave instructors" or some combination within their program to be comfortable enough to discuss their mental health without the potential for social persecution from others, thereby reinforcing the importance of and need for a safe/brave space as noted earlier in the *RQ #1* discussion.

The fear of consequences or ramifications was the second reason participants cited for their reluctance and discomfort discussing mental health. Specifically, participants shared they were scared of losing their medical certificate and being “grounded” if the FAA were to learn of their mental health distress. This fear of the FAA and what action they may take against them is yet another widely known and shared fear amongst those in the industry, especially those working as or aspiring to be professional pilots. Given the pipeline that exists between collegiate aviation programs and the industry, it is not surprising that this same fear has permeated to the collegiate level. Due to the fear around reporting mental health-related challenges to others, especially Aviation Medical Examiners (AMEs), because of the impact it could have on one’s medical, a subculture of a lack of reporting has been created within the industry. This lack of reporting can be seen within the commercial airline sector as well as within collegiate aviation. The latter was showcased by Pitts and Faulconer (2023) who conducted an anonymous online survey of collegiate aviation students and found that 67.7% of the sample expressed concerns about seeking mental health treatment because of the potential impact on their medical certificate, and 29.3% admitted to withholding mental health issues from AMEs for the same reason.

The fact that such a fear is present amongst collegiate aviation students supports research by Johnson et al. (2024), who discussed and explained the “culture of fear” that is present within the industry. This culture of fear stems from the uncertainty of what action the FAA will take against an airmen’s medical certificate once they learn of an airmen’s mental health challenges. Any decision other than no action will likely result in the jeopardizing of their job security since they may not be permitted to fly until they have satisfied the numerous and often costly stipulations outlined by the FAA’s aeromedical division (Johnson et al., 2024). Consequently, rather than having their medical certificate and livelihood jeopardized (Hubbard, 2016), these professionals opt to engage in behaviors similar to what the students in this study expressed: be less vulnerable, less comfortable, and less inclined to share mental health distress. The aforementioned coalesce to constitute healthcare avoidance behaviors, which are prevalent amongst industry professionals (Hoffman et al., 2023; Hoffman et al., 2024a; Johnson & Jones, 2025) because of the steep consequences these professionals may receive, as well as the outdated approaches to aerospace medicine utilized by the FAA. While the reluctance to discuss mental health challenges, which may result in healthcare avoidance, is an undesirable outcome, it is the harsh reality many experience in the industry because they feel forced to choose between protecting their medical certificate and job or seeking help. This is an impossible decision many collegiate aviation students appear to be making in their young careers, and unfortunately, for some, they feel they cannot make the best decision and instead, opt to take their life.

The extreme discomfort when talking about specific aspects of mental health, namely suicide and depression, was the third reason participants detailed to explain their discomfort with mental health discussions. Given the sensitive and contentious nature of mental health within the U.S. and even more so in aviation/aerospace, the discomforting feelings some participants expressed relative to suicide and depressive symptoms are to be expected, as these conversations can be extremely awkward for anyone, including MHPs (Norman, 2021). Research by Helman et al. (2024) asserts that researching suicide is emotionally challenging work and could be considered a difficult research topic even for seasoned professionals in the field who deal with these issues frequently. Thus, if researching suicide and hearing stories of distress can prove to be too much for professionals in the space, then it is understandable why collegiate aviation students, who possess fewer life and emotional experiences, may have inordinate difficulty and a less comfortable level with the topic. Participants also conveyed their trepidation regarding discourse about suicide and depression stemmed from a fear that by discussing or merely uttering the word “suicide” to someone they suspected was in mental distress would place the idea in their head, thereby increasing their probability of conducting self-harm or suicide. Although an understandable concern, this belief is a myth that has, unfortunately, been enhanced by stigma. Research has shown that asking someone if they are having suicidal thoughts is more likely to save a life (Murphy, 2021) rather than take one. This myth was one dispelled during the MHS by one presenter from UNO’s School of

Social Work. While this was the least prevalent or commonly noted reason amongst the participants, it was still worth discussing because of implications on help-seeking behavior(s) and the divergence that occurred post-MHS.

The only point of convergence within this theme centered the fear and worry of consequences imparted by the FAA, which was thoroughly discussed earlier. Despite the wealth of information shared during the MHS about what mental health conditions, issues, and diagnoses are reportable and what counts as a diagnosis from AMEs and MHPs, participants still possessed trepidation and discomfort with sharing mental health information. This hesitation and discomfort stemmed from the participants not fully trusting the medical process, rather they believe that their privacy and confidence will be infringed upon. The lack of trust and confidence within the medical process, some medical professionals – including MHPs, and regulators conveyed by the participants supports research by Raus (2023). Additionally, the lacking confidence in the aforementioned is another well-known contributor to avoidance behaviors by industry professionals. While these professionals, specifically professional pilots must disclose medical visits, this disclosure is further confounded by the fact that there is ambiguity about which mental health services qualify as “treatment” and which do not. Unfortunately, the ambiguity exacerbates the problem and worsens the healthcare avoidance behavior and since these industry professionals tend to already possess a negative perception about mental health services that is underpinned by fear and anxiety, they typically opt to avoid them altogether to avoid reporting them as noted by Raus (2023). By avoiding the disclosure process and not reporting, these professionals do not have to put their faith or trust in the medical system or its operators, thereby mitigating their fears.

It is important to note that there were some attendees who experienced an enlightening regarding their career trajectory as it relates to the impact mental health could have. Specifically, some attendees realized that they could still have a viable and long career in aviation/aerospace if they experienced mental health distress or possessed a mental health disorder/condition (under certain circumstances). This realization runs counter to the widely propagated belief that having a mental health issue means you cannot be successful in aviation/aerospace particularly as a professional pilot and helps combat the horror stories about individuals' careers being cut short due to losing their medical certificate (Hubbard, 2016). This was provided in response to Q37, which asked, “What aspects of the program made you feel comfortable when discussing mental health?”. As noted earlier, one monumental myth that exist within aviation/aerospace is that if you experience a mental health challenge, then you will lose your medical certificate and be “grounded” until proven “fit for duty”. While just one example, it is a widely propagated and deep-rooted belief held by many within the industry that impacts the comfort of industry professionals, including collegiate aviation students. The refutation of such a belief and concerted efforts to replace fiction with fact from credible and experienced individuals exemplify why these MHS are a necessary tool within the industry, especially at the collegiate level.

The findings within this theme and theme itself, *Taboo Topics to Comfortable Conversations*, both contribute to the aviation/aerospace literature in a unique manner regarding the profound lack of trust many industry professionals have in the FAA medical certificate process, their perspective on mental health treatment, and the confidentiality and privacy promised by MHPs. Specifically this theme highlights professionals' low levels of comfort and inclination to use the commonly suggested support and treatment methods, thereby exposing a flaw in the current system that is known, but has experienced difficulty being addressed. This is because the requisite trust from industry professionals has not been established and cannot be cultivated due to breaches in their trust that has occurred over time, which further compounds the stigma around mental health (Winter and Rice, 2015; Johnson et al. 2024) culture of fear (Wu et al. 2016; Hubbard, 2016; Johnson et al. 2024), and potential consequences one may face. However, this flaw provides an opportunity to enhance mental health treatment options for these professionals, decrease healthcare avoidance behaviors, and improve both safety and the aerospace medical system, thereby constituting the literature contribution. Research by Hoffman (2021) and Daku (2021) found that 75% of pilots who reported at least one avoidance behavior stated they would utilize

sanctioned intervention if available and up to 60% reported they were open to using an anonymous hotline to obtain mental health assistance, respectively. The aforementioned demonstrates industry professionals want help, are open to treatment, and would like to manage their mental health if viable options were available to them. However, little to no options similar to the proposed alternatives exist or are FAA-approved, underscoring the need for their creation.

The aforementioned contribution connects to the *Soaring Beyond Stigma to Sustaining Support* theme, which also aids in addressing RQ #2, because of the divergence in comfort level attendees possessed pre- and post-MHS. This divergence stemmed from the demystification of the FAA medical process that was provided by the speakers and presenters during the MHS. The information shared helped attendees delineate what was fact from fiction relative to conditions and challenges that would result in a medical disqualification. They also debunked common myths and clarified rumors regarding the reporting process and several other items that cause aviation/aerospace professionals to exhibit healthcare avoidance behaviors. The genuine conversations and information shared empowered attendees and made them feel more comfortable talking about and seeking support for their mental health. This was because they received credible information from reputable sources to refute the myths, which helped destigmatize mental health for them to an acceptable level to where they could transcend the stigma and seek support.

Research Question #3 (RQ #3)

The third research question inquired about what barriers prevented collegiate aviation students from seeking support and/or services to manage their help when experiencing distress. There was open-ended question leveraged to aid in addressing this RQ, namely Q36⁶. There were several barriers attendees noted that prevented or made them less inclined to seek support for their mental health, thereby addressing RQ #3. Specifically, participants cited a lack of access to resources with an emphasis on financial inaccessibility and stigma as the most prominent barriers they faced, preventing them from engaging in help-seeking behaviors. As such the *Access Granted – Barriers Bypassed* theme was the most apt to address RQ #3. Within this theme there were three points of convergence.

The first point of convergence pertained to the lack of access to mental health resources participants detailed they had. Pre-MHS, participants shared they did not know where to go nor how to access the mental health resources located on their campus. This lack of knowledge about pivotal resources points to a critical issue underpinning the surface-level access problem initially stated, signaling that there is also a larger lack of awareness and/or exposure to any/all resources (not just those relative to mental health) that may exist on their campus. Therefore, the lack of access referenced by many attendees presents a more nuanced problem connected to the institution's and/or aviation program's inability to effectively communicate where resources are located and how they could be utilized. While not every participant shared or expressed this lack of access and knowledge issue, those that knew of the resources and how to access them were likely aware because they were: 1. An older, more experienced student who possessed institutional knowledge or 2. Learned about the resources through their communities of support on-campus. Both relate to a student's ability to circumnavigate the academic and social environments of their institution and for those participants who were aware of the mental health resources on-campus, it is likely they "Networked to Navigate". This is a term derived by Johnson (2024) that entails collegiate aviation students leveraging their various communities of support or "networks" to obtain pivotal information or resources. For those participants' who were not as fortunate to have a network to navigate to become cognizant of the resources, the MHS likely filled this paramount access gap.

⁶Q36 asked participants what barriers prevented them from seeking mental health services or support when they experienced a mental health challenge.

The lack of access to resources for student mental health is not a new phenomenon and could be considered the “norm”. According to Mowreader (2024), roughly 54% of students who attended four-year institutions (similar to that of the sample institution) reported their institution provided adequate mental health resources for students, whereas 56% of students at two-year colleges reported the same. This particular convergence point and finding support the research by Mowreader (2024) and provide a compelling contrast to Chessman and Taylor (2019), who reported that student mental health and well-being are campus-wide priorities at most institutions, with over 80% of presidents indicating student well-being is mentioned within their strategic plan. What is even more concerning is that only 40% of these strategic plans mention mental health specifically (Chessman & Taylor 2019). The problem with these figures is that a vast majority of institutional leadership proclaim student well-being are priorities for their institution, yet less than half of the strategic plans explicitly mention mental health and a little more than half of the students sampled believed their institution provided adequate mental health resources. Clearly, this is a disconnect between what leadership states is a priority and what actually gets created, funded, and/or implemented for students to use and access. There is gross misalignment between leadership and students, which adversely impacts the benefactors of the institution, the students, by limiting their access to and knowledge of the resources available to them, especially mental health resources.

The financial inaccessibility of mental health resources is another facet of the lackluster access to resources participants noted and may pose an even larger barrier for collegiate aviation students, especially those identifying as underrepresented, minoritized, low-income, and/or first-generation. It is well-known and documented that the cost of healthcare and specifically, mental health care, within the U.S. has increased significantly (Rowan et al. 2013). The cost of mental health treatment is a problem and often insurmountable barrier for many Americans as 42% of untreated U.S. citizens cited cost as barrier to them obtaining the necessary help needed. This is evident as the cost of psychotherapy within the U.S. is listed, on average, as \$100 to \$200 (with insurance or a co-pay) according to Laswell (2022), and is an expense many cannot afford. For collegiate students, IHEs are essentially a gateway to mental health services (Mossakowski, 2021), especially since most institutions provide students with up to 12 psychological sessions per year as long as they are enrolled. Anything beyond the allotted amount means they will be forced to seek external treatment and pay out-of-pocket for services. This expense is not something most college students can bear given the average four-year tuition rates of \$40,000-\$150,000 depending upon the type (Mossakowski, 2021) and the average income of \$3900-\$13,880 for student workers (Urban Institute, 2017). Simply, collegiate students tend to have lower income levels, which means less disposable income, rely on work study or part-time jobs, and nearly 1.6 million still lack medical coverage according to the House Committee on Education and the Workforce Democrats (2025). The situation and number only worsens when considering those who come from historically disadvantaged backgrounds (Vargas and Dancy, 2023) and/or identify as low-income or first-generation. Despite the impact of the MHS, access still served as a barrier for some, particularly the financial inaccessibility of certain resources. However, participants expressed that because of the MHS, they became cognizant of where to go on-campus to access mental health support such as Counseling and Psychological Services (CAPS) and off-campus such as the Charles Drew Health Center.

Although MHS participants were provided with pertinent information, the unaffordability of mental health support still serves as a prominent barrier for them; one that explicitly and consciously hinders their ability to seek help when they want/need it. As noted earlier, but cannot be overstated due to the tantamount and paramount nature, colleges and universities are a prime gateway for students to access and receive mental health services (Mossakowski, 2021), and there are some students that heavily rely on these institutions to obtain the support needed and worry about what future treatment will look like once they are no longer enrolled due to the immense financial burden. It is clear that students would use the services if they were financially accessible. This particular finding should serve as an alarm for institutional leadership to make their actions match their proclamations and expedite those actions to truly prioritize mental health with an emphasis on accessibility, which may save lives and aid in enrollment and

retention rates as well according to Carrasco (2024). If nothing else, it is the hope that the opportunity to increase the touted student metrics of enrollment and retention, rather than saving and impacting student lives, will finally be the catalyst leadership needs to remedy the inequities surrounding access to vital resources, such as mental health support, that exist across many U.S. IHEs.

The second point of convergence pertained to the immense fear participants had about losing their medical certificate and potentially jeopardizing their job security as a future aviation/aerospace professionals, especially those wanting to be professional pilots. This fear was thoroughly discussed in *RQ #2*, specifically within the *Taboo Topics to Comfortable Conversations* theme. Given the elaborate discussion in the aforementioned section, it will not be expounded upon further. Instead, the third point of convergence, which revolves around stigma, will be elucidated. Both pre- and post-MHS, participants explained that stigma was a notable barrier they experienced to seeking help or support for their mental health distress challenges. The fact stigma served as a barrier before and after the MHS despite the wealth of information conveyed in addition to the resources shared is shocking, but not surprising. Further, it denotes how paralyzing and much of a deterrent it is and can be for individuals, especially collegiate aviation students, who lack experience in navigating stigma and are soon-to-be professionals.

Given the prominence of stigma, it is necessary to define it. According to Winter and Rice (2015) stigma is defined as, “Prejudices held towards individuals that are either part of, or perceived to be part of, certain groups.” The main issue with stigma is that it can influence, typically in an adverse manner, a person’s perspective towards others or things, resulting in a diminishing effect. Within the context of this study, stigma can cause collegiate aviation students who may want or need help from seeking it due to fear of being viewed or labeled as “less than” or as “a burden” by those within their network. Collectively, this can be referred to as receiving poor social evaluations and participants alluded to this notion in their statements by mentioning they avoided seeking help because they wanted to prevent being perceived as a burden for others, thereby supporting research by Johnson et al. (2024). Unfortunately, this rationale participants shared is a commonly held belief within aviation/aerospace, underscoring the pervasiveness and gravity of the stigma. Many believe seeking help and/or merely having a mental health condition or distress is a sign of personal weakness according to the National Alliance on Mental Illness (2020), which is completely untrue, and work must continually be done to refute it within society.

Within the context of aviation/aerospace, this stigma is more pronounced due to the nature of the industry and tends to manifest itself in two types of behaviors: 1. Pilot reporting (or a lack thereof) and 2. Self-reliance. Due to the fear of being labeled as “less than” via poor social evaluations in conjunction with a perceived fear of consequences, aviation/aerospace professionals – specifically professional pilots – tend to not report certain mental health issues. This same reporting behavior is and can be seen amongst collegiate aviation students, highlighting that stigma exist at all levels of the industry as evidenced by the quotes within this manuscript. There is also the behavior of being overly self-reliant, which is a form of “self-stigma” according to Labouliere et al. (2015) and more commonly impacts youth such as those included within this sample. This type of stigma forces students to believe that they should handle all their problems on their own because they “own” the problem and may believe they are not worthy of help from others. Such a self-stigma may be more prevalent amongst collegiate aviation students given its likelihood to impact younger individuals.

The importance of this theme, particularly its discussion around stigma as a barrier, is the outlining of how stigmatization of mental health can be harmful for anyone, but especially detrimental for collegiate aviation students, who need or want to seek treatment. An element not largely considered that heightens the personal weakness facet of stigma is that aviation/aerospace professionals, specifically professional pilot and crew members, hold high responsibility positions (Winter & Rice, 2015; Winter et al. 2017). These positions intensify the duty to execute at a high level of safety, which usually results in the suppression of mental health ailments that would impact their ability to perform these duties. Consequently, succumbing to the notion of personal weakness is not something industry professionals

believe they can afford to do as there is little room for error within the industry. Subsequently, this is also a notion that has permeated to the collegiate level and is now negatively impacting students who are engaging in unhealthy behaviors modeled by professionals they look up to based upon the analyzed comments. Therefore, this theme supports research by scholars who detail the various barriers that deter individuals from seeking help for their mental health with the most prominent being a lack of access (Johnson et al. 2024), financial inaccessibility (Laswell, 2022; Carascco, 2024; Vargas and Dancy, 2023), and stigma (Johnson et al. 2024, Sabik et al. 2019; Raus, 2024; Waters et al. 2024). This theme also underlines the potential grave impact financial inaccessibility and stigma can have on collegiate aviation students, and adds a sense of urgency to redress the aforementioned barriers for the benefit of all students, especially those who desire to work in an industry that is highly stigmatized and where help-seeking behavior(s) are not the norm, but the exception.

Limitations and Assumptions

For this study, the following limitations and assumptions existed:

1. Due to the voluntary nature of survey research, this study was limited based upon the participation of the collegiate aviation students who attended the MHS and were asked to complete the pre- and post-surveys via Qualtrics.
2. The study was limited to only enrolled students at UNO, specifically those enrolled in the collegiate aviation program as a professional flight, administration/management, and/or unmanned aircraft systems major.

It is assumed the collegiate aviation students answered both surveys (pre- and post-) honestly, to the best of their knowledge and ability, and with the intent to contribute to the greater good of the aviation/aerospace industry, with special emphasis on collegiate aviation.

Recommendations for Policy and Practice

Based upon the findings and discussion, the following recommendations around policy and practice should be considered:

Policy

1. Call-to-Congress: Make the current Mental Health Aviation Rulemaking Committee a permanent body of the FAA. This was a recommendation made by Johnson et al. (2024) that should and needs to be re-iterated because of the quality and expeditious work they conducted to provide FAA with a set of actionable recommendations. Further, given the tantamount nature of mental health, its pervasiveness, and increasing prevalence amongst a vulnerable population, the permanent solidification of such a body is proving necessary if regulators and the industry want to become proactive in addressing mental health challenges.
2. Call-to-Congress: Enhance the financial accessibility of/to mental health treatment and associated resources to mitigate a prominent barrier that inhibits and deters collegiate aviation students from seeking mental health services they may need/want.

Practice

1. Collegiate aviation program leadership should host or organize an MHS for their students at least once per year. This would be done to educate, expose, and connect students to vital mental health resources that exist on- and off-campus, as well as to the individuals they may need to contact to obtain those resources. If collegiate aviation programs are unable to host or organize their own symposium, then program leadership should aim to attend the larger annual MHS that is coordinated by the consortium. This would be done to remain current on contemporary mental

health information and knowledge, be cognizant of changes to/in FAA aerospace medicine that may impact the students, and to relay pertinent information to the student body.

2. Collegiate aviation programs should conduct “safety stand-downs” that center on or emphasize mental health at least once per year, but ideally, once per semester. While these can be done under the umbrella of traditional safety stand-downs, the mental health-centric stand-downs may be more effective and impactful if they are held on their own, especially since they focus on more specific information. The implementation of these events add a source of support for collegiate aviation students, provide faculty/staff with an opportunity to demonstrate their prioritization of mental health as well as their commitment to enhancing safety, and helps destigmatize the topic.
3. Collegiate aviation programs should adopt mandatory mental health training for all aviation faculty/staff to demonstrate a strong commitment to mental health and to lead by example. The training could be included in the annual training requirements for faculty/staff and completed at the same time as other mandatory trainings.

Future Research

Given the exploratory nature of this study, the first recommendation centers extending the crux of the study itself. The purpose of this research was to understand how MHS affect the knowledge, understanding, and comfort level of collegiate aviation students regarding mental health. To understand this, collegiate aviation students were sampled, but only those enrolled at UNO. While this provided a strong reference point for future studies, it also furnishes an opportune platform for future research. Specifically, future research would benefit from studying the effectiveness of MHS on the collegiate aviation students at larger institutions such as UND. This would be done to determine how the symposia impacted the knowledge, understanding, and comfort level relative to mental health of the collegiate aviation students enrolled at those institutions. The provision of support and in particular, peer support, was a commonly cited factor that positively impacted the mental health of collegiate aviation students who were sampled. Some of this support was furnished through their aviation-centric or non-aviation-centric Registered Student Organization (RSO) as well as their social networks (e.g., study) had access to. Nonetheless, future research should examine how collegiate aviation students’ mental health challenges are managed when involved in peer support groups such as a RSO, TGBP, or an akin program.

Conclusion

The overarching goal of this exploratory study was to understand how MHS affect the knowledge, understanding, and comfort levels of collegiate aviation students regarding mental health. Existing research on the mental health of collegiate aviation students has been relatively sparse in conjunction with the fact that the impact of MHS constitutes a rather under-researched area. As such, this study aimed to fill two primary gaps, one temporal and one empirical, in the contemporary literature while building upon research already conducted on aviation/aerospace mental health, mental health in STEM, and that of minoritized students in collegiate aviation programs. The temporal gap was filled by conducting research on mental health resources within aviation/aerospace, specifically a MHS tailored for collegiate aviation students, that adds breadth/depth to the scarcity of studies examining such an issue/topic. The empirical gap was filled by conducting a robust, mixed-methods study that showcased the positive impact and effectiveness of an aviation-centric MHS on collegiate aviation students with respect to their knowledge, understanding, and comfort level regarding mental health.

The study demonstrated, qualitatively and quantitatively, that MHS are an effective tool, especially for improving the knowledge and awareness of mental health support and resources for collegiate aviation students. While comfort levels surrounding mental health discourse remained relatively unchanged, indicating that interpersonal comfort is more difficult to improve in a short period of time, the MHS provided a solid start to increase this comfort and suggests that sustained efforts are

likely needed to collectively improve one's comfort when engaging in such discourse. This may be accomplished by holding mental health safety stand-downs at the start of each semester and/or having MHPs visit aviation/aerospace classes, especially lower-level courses, to speak since first-generation students and minoritized students tended to be the most unfamiliar with mental health resources and the least comfortable, respectively. The study also informs collegiate aviation program leadership of techniques and/or resources they can leverage to increase mental health support for their students, which may also be beneficial for industry leadership due to the transferability of the findings.

There are several prominent takeaways centering the mental health of collegiate aviation students that warrant emphasis. The first is that there is a difference in comfort levels between White and non-White students (i.e., underrepresented students/students of color) relative to discussing mental health discourse and awareness with students of color having a lower reporting tendency. This points to the need for these students to have a safe and inclusive environment or space that will empower them to feel comfortable enough to engage in such discourse, underscoring the salience of culturally responsive and sensitive mental health programming. The second is the difference between male and female responses to mental health activities such as the MHS. Specifically, female students demonstrated a greater change in both their understanding and comfort with mental health discussions, highlighting the need for mental health programming and programmers to remain sensitive to gendered experiences. The third is that employed students benefitted more from the MHS, particularly their understanding of and comfort with mental health, than unemployed students, which may stem from their real-world exposure to various work environments and ability to manage stress more effectively. The fourth is that first-generation students typically possess lesser familiarity with mental health resources compared to non-first-generation students, indicating potential gaps in their access to pivotal resources and institutional knowledge.

At its core, this study clearly illustrates that MHS may serve as a transformative learning experience for collegiate aviation students and college students generally, and is an effective way to reframe stigmatized narratives surrounding mental health while promoting awareness and understanding of salient resources to support those afflicted by mental health challenges. Ultimately, MHS have shown to be a positive, effective, and efficient tool to counter institutional, regulatory, and societal barriers that adversely compound mental health and as such, are a tool that should be strongly considered for adoption and implementation within collegiate aviation programs, IHEs, the aviation/aerospace industry at-large, and any entity/organization that is predicated upon safety and has positions/roles with high levels of responsibility. Consequently, comfort levels may also be increased, which will help expedite the normalization of mental health discourse in various disciplines and sectors as a means to soar beyond the stigma that inclines individuals to bear a heavy load by themselves and suffer in silence.

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Appendix A – Pre- and Post-Survey Question Protocols

Please note that any information (e.g., name, age, gender, etc.) obtained through this survey will be kept confidential. We only ask your name to allow for question comparison between the pre- and post-surveys. Personal information we obtain will only be used for analysis purposes.

Pre-Survey

Nº	Question	Relational Area to Study
	What is your first and last name?	Personal Information
2.	What is your race/ethnicity?	Personal Information
3.	What is your sex/gender?	Personal Information
4.	What is your age?	Personal Information
5.	What is your year/status in school?	Personal Information
6.	What is your major?	Personal Information
7.	Are you affiliated with or involved in a Registered Student Organization (RSO) on-campus?	Personal Information
8.	If you are affiliated with a RSO, which one?	Personal Information
9.	Do you live on-campus or off-campus?	Personal Information
10.	Are you currently employed?	Personal Information
11.	If you are employed, how many hours per week do you typically work?	Personal Information
12.	Are you a first-generation student (i.e., are you the first person in your family to attend college)?	Personal Information
13.	Have you ever attended a mental health symposium, seminar, town hall, or similar event prior to this?	Personal Information - Baseline
14.	Do you know the definition of mental health and/or mental well-being?	Mental Health Knowledge
15.	How would you rate your current knowledge level of mental health (and closely-related topics such as mental fitness and emotional well-being)?	Mental Health Knowledge
16.	How would you rate your knowledge level about on-campus resources and support services focused on navigating mental health challenges?	Mental Health Knowledge
17.	How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the UNO AI?	Mental Health Knowledge

18.	Do you feel that peer support systems are accessible and effective within your collegiate aviation program?	Mental Health Knowledge
19.	How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the aviation/aerospace industry?	Mental Health Knowledge
20.	How confident are you that future aviation/aerospace employers will support mental health initiatives?	Mental Health Knowledge
21.	What is your overall level of understanding of mental health as a concept or topical area?	Mental Health Understanding
22.	What is your level of understanding of the resources or support services one can access on-campus assist with mental health challenges/issues?	Mental Health Understanding
23.	Do you know where you could go to receive psychological services on-campus and how to access these services?	Mental Health Understanding
24.	How satisfied are you with the mental health resources available on-campus?	Mental Health Understanding
25.	What is your level of understanding of the resources or support services one can access in the community and/or in general to assist with mental health challenges/issues?	Mental Health Understanding
26.	What is your level of understanding of what factors or elements can contribute to, worsen, and/or improve one's mental health?	Mental Health Understanding
27.	What is your level of understanding of the common signs of mental health struggles or challenges?	Mental Health Understanding
28.	How comfortable are you talking about your mental health with close friends or family?	Mental Health Comfortability
29.	How comfortable are you talking to an education professional (i.e., teacher, professor, instructor, etc.) about your mental health?	Mental Health Comfortability
30.	How comfortable are you listening to others share their mental health challenges or issues?	Mental Health Comfortability
31.	How comfortable are you talking about mental health topics in a group setting?	Mental Health Comfortability
32.	How comfortable are you learning about mental health resources and coping strategies?	Mental Health Comfortability
33.	How comfortable are you seeking help or assistance for mental health challenges or struggles?	Mental Health Comfortability
34.	How comfortable are you with participating in mental health awareness events or activities (e.g., Mental Health Symposiums)?	Mental Health Comfortability

35.	How comfortable would you be informing someone you trust if you were experiencing mental health challenges?	Mental Health Comfortability
36.	What barriers, if any, prevent you from seeking mental health services or support during/when you experience a mental health challenge?	Mental Health Support
37.	What makes you feel comfortable when discussing mental health?	Mental Health Comfortability
38.	What makes you feel uncomfortable when discussing mental health?	Mental Health Comfortability
39.	What have you found beneficial, if anything, in improving your knowledge of mental health?	Mental Health Knowledge
40.	What have you found beneficial, if anything, in improving your understanding of mental health?	Mental Health Understanding

Post-Survey

Nº	Question	Relational Area to Study
1.	What is your first and last name?	Personal Information
2.	What is your race/ethnicity?	Personal Information
3.	What is your sex/gender?	Personal Information
4.	What is your age?	Personal Information
5.	What is your year/status in school?	Personal Information
6.	What is your major?	Personal Information
7.	Are you affiliated with or involved in a Registered Student Organization (RSO) on-campus?	Personal Information
8.	If you are affiliated with a RSO, which one?	Personal Information
9.	Do you live on-campus or off-campus?	Personal Information
10.	Are you currently employed?	Personal Information
11.	If you are employed, how many hours per week do you typically work?	Personal Information
12.	Are you a first-generation student (i.e., are you the first person in your family to attend college)?	Personal Information
13.	Prior to this event/program, had you ever attended a mental health symposium, seminar, town hall, or similar event?	Personal Information - Baseline

14.	Did this event/program provide you with a clear definition of mental health and/or mental well-being?	Mental Health Knowledge
15.	How would you rate your current knowledge of mental health topics compared to before attending the program/event?	Mental Health Knowledge
16.	How would you rate your understanding of on-campus mental health resources and support services after the event?	Mental Health Knowledge
17.	How has your knowledge of mental health initiatives, support, and resources within the UNO AI improved due to the program?	Mental Health Knowledge
18.	Do you feel that peer support systems became more accessible and effective within your collegiate aviation program after attending the event?	Mental Health Knowledge
19.	How has your understanding of mental health initiatives and resources within the aviation/aerospace industry changed since the program?	Mental Health Knowledge
20.	How confident are you now that future aviation/aerospace employers will support mental health initiatives?	Mental Health Knowledge
21.	What is your current understanding of mental health as a concept or topical area now that the event has concluded?	Mental Health Understanding
22.	What is your current understanding of the resources or support services available on-campus to assist with mental health challenges now that the event has concluded?	Mental Health Understanding
23.	Do you now know where and how to access psychological services on-campus?	Mental Health Understanding
24.	How satisfied are you with the mental health resources currently available on-campus, based on what you learned?	Mental Health Understanding
25.	What is your current understanding of resources or support services available in the community for mental health challenges?	Mental Health Understanding
26.	How has your understanding of factors that contribute to, worsen, or improve mental health changed?	Mental Health Understanding
27.	How would you rate your understanding of the common signs of mental health struggles or challenges now that the event has concluded?	Mental Health Understanding
28.	How comfortable are you now discussing your mental health with close friends or family?	Mental Health Comfortability
29.	How comfortable are you now discussing mental health with an education professional (e.g., teacher)?	Mental Health Comfortability
30.	How comfortable are you now listening to others share their mental health challenges?	Mental Health Comfortability

31.	How comfortable are you now discussing mental health topics in a group setting?	Mental Health Comfortability
32.	How comfortable are you now learning about mental health resources and coping strategies?	Mental Health Comfortability
33.	How comfortable are you now seeking help for mental health challenges or struggles?	Mental Health Comfortability
34.	How comfortable are you now participating in mental health awareness events or activities (e.g., Mental Health Symposiums)?	Mental Health Comfortability
35.	How comfortable would you now feel informing someone you trust if you were experiencing mental health challenges?	Mental Health Comfortability
36.	What barriers, if any, do you still perceive when seeking mental health services or support?	Mental Health Support
37.	What aspects of the program made you feel comfortable when discussing mental health?	Mental Health Comfortability
38.	What aspects of the program made you feel uncomfortable when discussing mental health?	Mental Health Comfortability
39.	What elements of the program improved your knowledge of mental health, if any?	Mental Health Knowledge
40.	What elements of the program improved your understanding of mental health, if any?	Mental Health Understanding

Appendix B – Informed Consent Form

The Mental Health Symposium: An Effective Tool to Improve Collegiate Aviation Students' Knowledge, Understanding, and Comfortability with Mental Health

IRB # 0006-25-EX

You are invited to participate in a research study. This form has information to help you decide whether or not you wish to participate; please review it carefully as your participation is completely voluntary, meaning you can stop at any time. The purpose of this exploratory research is to understand the impact mental health symposiums have on the knowledge, understanding, and comfortability of collegiate aviation students regarding mental health (and related topics such as emotional well-being). Doing so may inform collegiate aviation program leadership of methods, techniques, and/or resources they can leverage to increase mental health support within their program.

You are eligible to participate in this study if you are currently enrolled as an aviation student at the University of Nebraska at Omaha (UNO) between the ages of 19 and 50 and are in attendance of the 2025 UNO Aviation Institute Mental Health Symposium held at the Milo Bail Student Center Ballroom on February 21st, 2025. If you agree to participate, you will be asked to:

- Complete the requested pre- and post-surveys, comprised of multiple choice, Likert-scale, and open-ended questions. There are two surveys to be completed - one pre-Symposium and one post-Symposium, each consisting of 40 questions, and each taking approximately 10-15 minutes to complete.
- Answer a series of questions, which will be directed at understanding what your knowledge, understanding, and comfortability with the mental health (and closely-related topics) are/is. The type of questions that will be asked will be in the form of, 'How would you describe...' or 'What has...' and relate to your mental health knowledge, understanding, and comfort level.

Risks involved in this study are minimal or unlikely to occur. You may experience discomforts from answering sensitive questions during the interview. Additional minimal risks include potential breaches of confidentiality or privacy, although every effort will be made to safeguard your data.

During the survey, you may skip any questions that you do not wish to answer. Your choice to participate or not will have no impact on you. Your participation in the study may be ended if it is learned that you do not meet the inclusion criteria mentioned earlier. Research records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available without your permission. However, it is possible that other people and offices responsible for making sure research is done safely and responsibly will see your information. This includes auditing departments of the University of Nebraska at Omaha and the University of Nebraska Medical Center's Office of Regulatory Affairs (ORA) (a committee that reviews and approves human subject research studies) - study records may be copied and/or inspected for quality assurance and data analysis. These records may contain private information. You are encouraged to ask questions at any time during this study.

For further information *about the study*, contact Dr. Theodore W. Johnson, Ph.D. at 734-330-3131 or theodorejohnson@unomaha.edu. If you have further questions or concerns regarding your rights as a research participant, then please contact the Office of Regulatory Affairs at (402) 658-6463 or IRBORA@unmc.edu.

Appendix C – Pre-Symposium QR Code

**Pre-Symposium Survey
SCAN ME!**



Principal Investigator (PI): Theodore W. Johnson, Ph.D.

Institution: University of Nebraska at Omaha (UNO)

Project Title: The Mental Health Symposium: An Effective Tool to Improve Collegiate Aviation Students' Knowledge, Understanding, and Comfortability with Mental Health

IRB Number: 0006-25-EX

Activity Statement: This voluntary survey is part of a research project being conducted by the PI that focuses on collegiate aviation students and their mental health.

Purpose Statement:

The purpose of this exploratory research is to understand the impact mental health symposiums have on the knowledge, understanding, and comfortability of collegiate aviation students regarding mental health (and related topics such as emotional well-being). Doing so may inform collegiate aviation program leadership of methods, techniques, and/or resources they can leverage to increase mental health support within their program.

Appendix D – Post-Symposium QR Code

**Post-Symposium Survey
SCAN ME!**



Principal Investigator (PI): Theodore W. Johnson, Ph.D.

Institution: University of Nebraska at Omaha (UNO)

Project Title: The Mental Health Symposium: An Effective Tool to Improve Collegiate Aviation Students' Knowledge, Understanding, and Comfortability with Mental Health

IRB Number: 0006-25-EX

Activity Statement: This voluntary survey is part of a research project being conducted by the PI that focuses on collegiate aviation students and their mental health.

Purpose Statement:

The purpose of this exploratory research is to understand the impact mental health symposiums have on the knowledge, understanding, and comfortability of collegiate aviation students regarding mental health (and related topics such as emotional well-being). Doing so may inform collegiate aviation program leadership of methods, techniques, and/or resources they can leverage to increase mental health support within their program.

Appendix E – Pre- and Post-Symposium Scores and Variation(s)

Table 5: Pre-symposium survey questions with the highest average scores:

Number	Category	Question	Average
Q30	Comfortability	How comfortable are you listening to others share their mental health challenges or issues?	3.8088
Q32	Comfortability	How comfortable are you learning about mental health resources and coping strategies?	3.5294
Q15	Knowledge/ Understanding	What is your overall level of understanding of mental health as a concept or topical area?	3.4118

Table 6: Pre-symposium survey questions with the lowest average scores:

Number	Category	Question	Average
Q19	Knowledge/ Understanding	How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the aviation/aerospace industry?	2.5147
Q17	Knowledge/ Understanding	How knowledgeable are you regarding mental health initiatives, support, and resources that are available within the UNO AI?	2.5882
Q25	Knowledge/ Understanding	How familiar are you with the resources or support services one can access in the Greater Omaha community and/or on-campus to assist with mental health challenges/issues?	2.7353

Table 7: Pre-symposium survey questions with the most variation:

Number	Category	Question	Std Dev
Q28	Comfortability	How comfortable are you talking about your mental health with close friends or family?	1.1067
Q31	Comfortability	How comfortable are you talking about mental health topics in a group setting?	1.0927
Q35	Comfortability	How comfortable would you be informing someone you trust if you were experiencing mental health challenges?	1.0670

Table 8: Pre-symposium survey questions with the least variation:

Number	Category	Question	Std Dev
Q24	Satisfaction	How satisfied are you with the mental health resources available on-campus?	0.6723
Q15	Knowledge/ Understanding	What is your overall level of understanding of mental health as a concept or topical area?	0.6744
Q27	Knowledge/ Understanding	What is your level of understanding of the common signs of mental health struggles or challenges?	0.7651

Table 9: Post-symposium survey questions with the highest average scores:

Number	Category	Question	Average
Q24_Post	Satisfaction	How satisfied are you with the mental health resources currently available on-campus, based on what you learned?	3.8529
Q16_Post	Knowledge/ Understanding	How would you rate your understanding of on-campus mental health resources and support services after the event?	3.8088
Q15_Post	Knowledge/ Understanding	What is your overall level of understanding of mental health as a concept or topical area?	3.7500

Q21_Post	Knowledge/ Understanding	What is your current understanding of mental health as a concept or topical area now that the event has concluded?	3.7500

Table 10: Post-symposium survey questions with the lowest average scores:

Number	Category	Question	Average
Q20_Post	Confidence	How confident are you now that future aviation/aerospace employers will support mental health initiatives?	3.2059
Q31_Post	Comfortability	How comfortable are you now discussing mental health topics in a group setting?	3.2353
Q29_Post	Comfortability	How comfortable are you now discussing mental health with an education professional (e.g., teacher)?	3.3088

Table 11: Post-symposium survey questions with the most variation:

Number	Category	Question	Std Dev
Q29_Post	Comfortability	How comfortable are you now discussing mental health with an education professional (e.g., teacher)?	1.0686
Q28_Post	Comfortability	How comfortable are you now discussing your mental health with close friends or family?	1.0496
Q31_Post	Comfortability	How comfortable are you now discussing mental health topics in a group setting?	1.0239

Table 12: Post-symposium survey questions with the least variation:

Number	Category	Question	Std Dev
Q22_Post	Knowledge/ Understanding	What is your current understanding of the resources or support services available on-campus to assist with mental health challenges now that the event has concluded?	0.7043
Q15_Post	Knowledge/ Understanding	What is your overall level of understanding of mental health as a concept or topical area?	0.7202
Q21_Post	Knowledge/ Understanding	What is your current understanding of mental health as a concept or topical area now that the event has concluded?	0.7202

Table 13: Pre-and-Post comparison: the questions whose score increased the most:

Number	Category	Question	Increase
Q16_Diff	Knowledge/ Understanding	How would you rate your knowledge level about on-campus resources and support services focused on navigating mental health challenges?	0.9118 (from 2.8971 to 3.8088)
Q22_Diff	Knowledge/ Understanding	What is your level of understanding of the resources or support services one can access on-campus assist with mental health challenges/issues?	0.8676 (from 2.8676 to 3.7353)
Q25_Diff	Knowledge/ Understanding	How familiar are you with the resources or support services one can access in the Greater Omaha community and/or on-campus to assist with mental health challenges/issues?	0.7059 (from 2.7353 to 3.4412)

Table 14: Pre-and-Post comparison: the questions whose score decrease the most/increase the least:

Number	Category	Question	Increase/ Decrease

Q30_Diff	Comfortability	How comfortable are you listening to others share their mental health challenges or issues?	-0.0735 (from 3.8088 to 3.7353)
Q28_Diff	Comfortability	How comfortable are you talking about your mental health with close friends or family?	-0.0147 (from 3.3824 to 3.3676)
Q32_Diff	Comfortability	How comfortable are you learning about mental health resources and coping strategies?	0.1029 (from 3.5294 to 3.6324)

10-16-2025

Fatigue Among Aviation Students and Time Management in Flight Training

Christie Roussou
University of Nicosia

This study investigated the prevalence, causes, and consequences of fatigue among aviation students in Europe. It examined their self-awareness of fatigue, lifestyle habits, time management practices, and the role of mindfulness in mitigating fatigue-related impairment. A total of 188 participants completed an online survey comprising the Collegiate Aviation Fatigue Inventory (CAFI-II), the Cognitive and Affective Mindfulness Scale-Revised (CAMS-R), and the Epworth Sleepiness Scale (ESS). Quantitative analyses included descriptive statistics, correlation analysis, and multiple regression. Participants reported moderate levels of fatigue and limited awareness of its impact on performance. Common causes included insufficient sleep, high workload, and psychological stress. Fewer than half of the students received formal fatigue training. A statistically significant negative relationship was found between mindfulness, particularly the acceptance subscale, and daytime sleepiness. Fatigue also showed a positive correlation with performance-related impairments and variability in alertness. The findings suggest that fatigue remains an underrecognized yet critical safety issue among aviation students. Training programs should incorporate fatigue management and mindfulness education to improve awareness, build resilience, and support safe flight performance.

Recommended Citation:

Roussou, C. (2025). Fatigue among aviation students and time management in flight training. *Collegiate Aviation Review International*, 43(2), 188–203. Retrieved from <https://ojs.library.okstate.edu/osu/index.php/CARI/article/view/10377/9175>

Introduction

Fatigue is a critical safety concern in aviation, impairing alertness, decision-making, and situational awareness. This study investigates the prevalence, causes, and consequences of fatigue among European aviation students, focusing on their sleep habits, time management, and the potential protective role of mindfulness. While fatigue has been extensively studied in commercial and military aviation, research on flight training students, particularly within the European Aviation Safety Agency (EASA) regulatory framework, is limited.

Fatigue arises from multiple factors, including poor sleep quality, psychological stress, academic workload, and irregular schedules. Student pilots, often young and less experienced, face unique challenges balancing academic responsibilities with demanding flight training. Despite the risks associated with fatigue, it is frequently underrecognized and inadequately managed in flight training environments (Stokes & Kite, 2017; ICAO, 2016).

This study also examines mindfulness as a potential buffer against fatigue-related impairment. Mindfulness traits such as attention control, present-moment awareness, and acceptance may enable students to detect early signs of fatigue and adopt healthier coping strategies. Specifically, mindfulness may support sleep-supportive behaviors, which can reduce daytime sleepiness and improve alertness.

Problem Statement

Flight training programs require intensive academic and practical instruction, often without regulated limits on daily workload for students. Unlike commercial pilots, student pilots are not covered by mandated rest periods under FAA or EASA regulations, necessitating self-management of fatigue. This absence of structured rest requirements, combined with long training hours and suboptimal sleep, creates conditions that jeopardize both safety and learning outcomes (Levin et al., 2019).

Fatigue impairs judgment, reduces attention, and slows reaction times, which are critical deficits during flight operations. In the flight training context, fatigue can compromise academic performance and increase risk in high-stakes scenarios. Therefore, it is vital to understand how students experience fatigue and identify effective strategies to mitigate its effects.

Statement of the Purpose

The purpose of this study was to evaluate aviation students' awareness of fatigue, its causes and symptoms, and the effectiveness of their coping strategies. It also assessed how lifestyle factors, including sleep hygiene, workload, and mindfulness, relate to fatigue and performance.

Specifically, the study aimed to:

1. Identify the most common causes and symptoms of fatigue experienced during flight training.
2. Explore the lifestyle changes students perceive as helpful in managing fatigue.

3. Determine the relationship between mindfulness and fatigue, with a focus on sleep-supportive behaviors.
4. Assess the association between fatigue and daytime sleepiness, measured by the Epworth Sleepiness Scale (ESS).

By addressing these questions, the study provides aviation training institutions with evidence-based insights to improve safety, educational practices, and student well-being.

Literature Review

Fatigue is a multifaceted condition that compromises performance and safety in aviation. Pilots and trainees must operate in environments that demand high levels of attention, precision, and decision-making under pressure. Marcus and Rosekind (2017) noted that fatigue reduces memory, communication efficiency, reaction time, and core competencies for safe flight operations.

Common contributors to fatigue in aviation include sleep deprivation, irregular schedules, academic pressure, and stress. Avers and Johnson (2011) distinguished between acute fatigue (short-term) and chronic fatigue (long-term), with the latter linked to reduced concentration, apathy, and irritability. Among students, poor time management and inexperience in balancing responsibilities often exacerbate these issues (Buboltz et al., 2010).

Research on student pilots confirms the pervasiveness of fatigue. Mendonça et al. (2019) found that over 50% of aviation students reported underperforming in training due to fatigue. Keller et al. (2019) observed that students most often attributed fatigue to poor sleep, extended duty hours, and high workload. While students were generally aware of fatigue management strategies such as napping or improving sleep hygiene, Romero et al. (2020) reported that these strategies were applied inconsistently.

Sleep plays a central role in fatigue mitigation. Inadequate rest disrupts cognitive functioning, impairs learning, and negatively impacts mood (Lund et al., 2010). Circadian misalignment, such as that caused by early morning or night flying, can further diminish alertness (ICAO, 2016). Additionally, sleep inertia, the grogginess experienced immediately after waking, may impair performance during early training flights (Vallat et al., 2019).

Mindfulness, defined as present-moment awareness coupled with non-judgmental acceptance, has been shown to enhance emotional regulation and cognitive control. In the aviation context, mindfulness may improve situational awareness and reduce stress (Shapiro & Weisbaum, 2020; FAA, 2020). Importantly, its underlying mechanisms, attention control (the ability to sustain focus on relevant stimuli) and acceptance (the capacity to acknowledge experiences without overreacting), can promote sleep-supportive behaviors, such as maintaining regular bedtimes and reducing pre-sleep rumination. These behaviors are associated with lower scores on the Epworth Sleepiness Scale (ESS), indicating reduced daytime sleepiness.

Although fatigue and mindfulness have been individually explored in aviation research, few studies have examined their interaction in the student pilot population, particularly in Europe.

This study addresses that gap by investigating how mindfulness may act as a protective factor against fatigue and sleepiness in flight training environments.

Research Questions

Descriptive Research Questions

1. What proportion of European aviation students report experiencing fatigue?
2. What do students identify as the primary causes of their fatigue?
3. What lifestyle adjustments do students believe would help them better manage fatigue?
4. What is the most common source of fatigue during flight training?

Inferential Research Questions & Hypotheses

5. Is there a statistically significant association between aviation students' levels of mindfulness and their reported daytime sleepiness (ESS scores)?

H1: Higher mindfulness scores, particularly in attention control and acceptance, will be associated with lower daytime sleepiness.

H0: There will be no statistically significant association between mindfulness scores and daytime sleepiness.

6. Is there a statistically significant correlation between fatigue levels (CAFI-II scores) and daytime sleepiness (ESS scores)?

H1: Higher fatigue scores will be positively correlated with higher daytime sleepiness scores.

H0: There will be no statistically significant correlation between fatigue scores and daytime sleepiness scores.

Methodology

This study used a cross-sectional, online survey design with a convenience sampling approach. Participants were aviation students enrolled in accredited European flight academies who were aged 18 years or older and currently engaged in flight training. Recruitment took place between March 3 and October 16, 2021, through direct email outreach to partner flight schools, which were asked to circulate the survey link among their students. The survey was conducted on Qualtrics and required approximately 15 minutes to complete. Participation was voluntary and anonymous; no personally identifying information was collected.

The study protocol received approval from the Social Sciences Ethics Review Board at the University of Nicosia (SSERB 00139). All participants were presented with an online informed consent statement detailing the study's purpose, estimated duration, confidentiality safeguards, and their right to withdraw at any time. Consent was implied by survey completion. A debriefing statement summarizing the research objectives and providing contact information for both the researcher and ethics board was displayed upon completion.

Measures

The survey contained three standardized psychometric tools and a demographic questionnaire.

1. Collegiate Aviation Fatigue Inventory – II (CAFI-II)

The CAFI-II measures fatigue awareness, causes, lifestyle factors, coping strategies, impact on flight activities, and alertness. Items are primarily rated on Likert scales, with several open-ended questions. Internal consistency in the present sample was strong: fatigue awareness $\alpha = .76$ (95% CI [.71, .81]), causes of fatigue $\alpha = .75$ (95% CI [.69, .80]), and lifestyle $\alpha = .77$ (95% CI [.72, .82]).

2. Cognitive and Affective Mindfulness Scale – Revised (CAMS-R)

The CAMS-R assesses mindfulness across four domains, attention control, present focus, awareness, and acceptance, via 12 items rated on a four-point scale (1 = “rarely/not at all” to 4 = “almost always”). Subscales in this sample demonstrated reliabilities ranging from $\alpha = .67$ to $\alpha = .79$ (95% CIs available upon request). Scores were calculated as the mean of all items; higher scores indicated greater trait mindfulness.

3. Epworth Sleepiness Scale (ESS)

The ESS evaluates general daytime sleepiness across eight everyday situations, with items rated from 0 (“no chance of dozing”) to 3 (“high chance of dozing”). Total scores range from 0–24, with ≥ 11 indicating excessive daytime sleepiness. Reliability in the present study was $\alpha = .74$ (95% CI [.68, .79]).

4. Demographics

Nine questions captured age, gender, flight certifications, total flight hours, and other training-related details.

Primary Outcome and Power

The primary outcome for inferential analysis was daytime sleepiness as measured by the ESS total score. A post-hoc power calculation indicated that with $N = 188$, $\alpha = .05$, and power = .80, the study could detect correlations of $r \geq .20$ or small-to-moderate effects in regression models ($f^2 \geq .04$).

Data Analysis

Survey responses were exported from Qualtrics and analyzed using IBM SPSS Statistics (Version 22.0). Analyses were designed to address the six research questions. Fatigue levels were assessed using total scores from the Epworth Sleepiness Scale (ESS), with scores ≥ 11 classified as indicative of excessive sleepiness. Descriptive statistics and frequency analyses were applied to the Causes and Consequences of Fatigue Inventory–II (CAFI-II) to identify common fatigue triggers. Participants’ rankings of coping strategies were analyzed by calculating mean ranks to determine the most preferred approaches.

Associations between mindfulness (as measured by the Cognitive and Affective Mindfulness Scale–Revised [CAMS-R]) and fatigue awareness were examined using multiple regression analyses. Pearson product–moment correlations were computed to assess the relationships between ESS scores, CAFI-II fatigue impact ratings, and alertness levels. All statistical assumptions, including normality, linearity, and homoscedasticity, were verified before conducting inferential tests. Cronbach’s alpha coefficients with 95% confidence intervals for all scales are reported in the Methodology section.

Results

Demographics

A total of 188 aviation students completed the survey (age range = 18–54 years; $M = 25.61$, $SD = 6.29$). Most identified as male (77.7%), followed by female (20.7%), and 1.6% who preferred not to disclose. Participants held a range of certifications: Private Pilot License (PPL), Instrument Rating (IR), Airline Transport Pilot License (ATPL), Certified Flight Instructor (CFI), and Commercial Pilot License (CPL).

Table 1

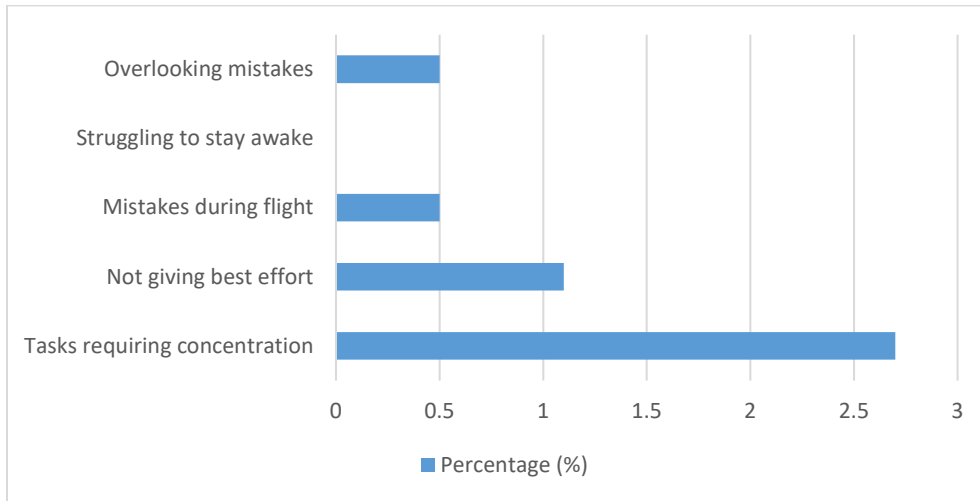
Aviation Students’ Rating (Training Program)

	N	%
PPL	56	29.8
IR	40	21.3
CPL	13	6.9
ATPL	39	20.7
CFI	26	13.8
Other	14	7.4
Total	188	100

Fatigue Awareness

Participants most strongly endorsed: “My ability to carry out tasks requiring concentration has been decreased due to fatigue”, “I have not given my best effort due to fatigue”, and “I have made mistakes during flight activities because I was fatigued”. Lower ratings were seen for struggling to stay awake or overlooking mistakes. Figure 1 presents item means and standard deviations.

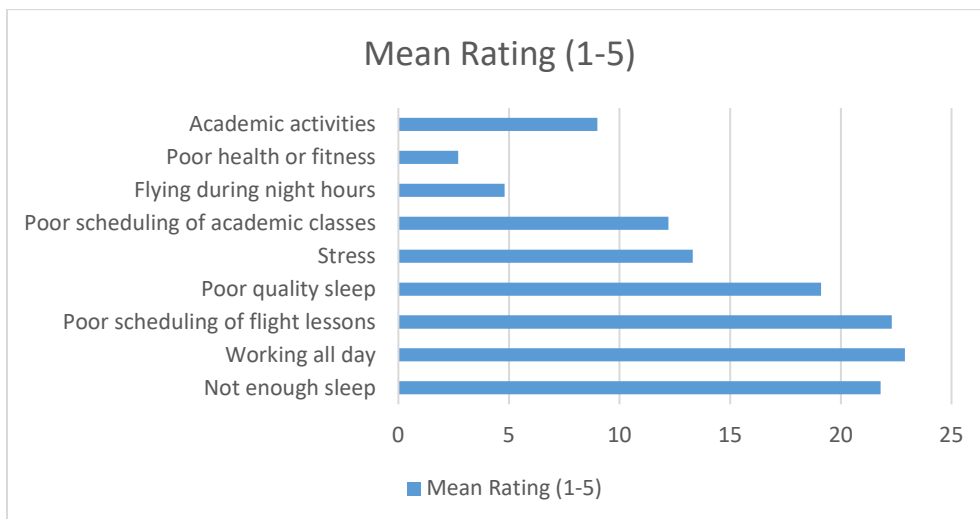
Figure 1
CAFI-II: Fatigue Awareness



Causes of Fatigue

Top contributors were insufficient sleep, full workdays, and poor scheduling of flight lessons. Stress, poor-quality sleep, and poor scheduling of academic classes were also notable. Figure 2 provides the full distribution.

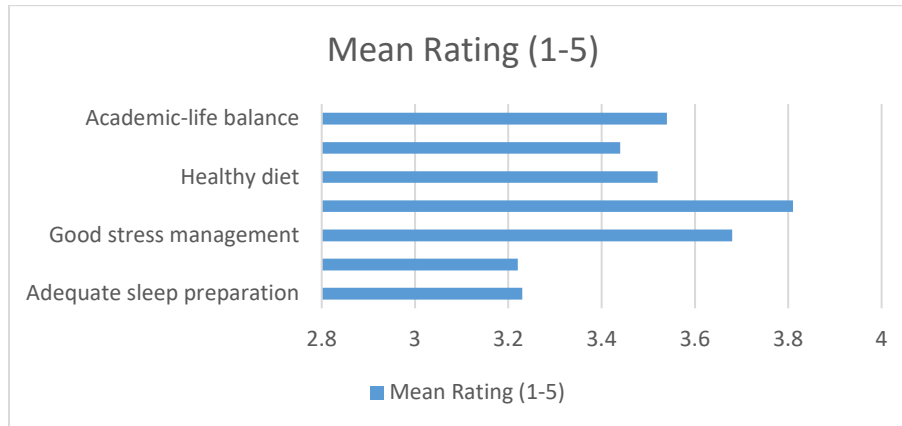
Figure 2
CAFI-II: Causes of Fatigue



Lifestyle

Participants reported moderate-to-good lifestyle habits, with the highest agreement for effective workload management ($M = 3.81$, $SD = 0.76$) and stress management ($M = 3.68$, $SD = 0.93$). See Figure 3 for full scores.

Figure 3
CAFI-II: Lifestyle



Personal Solutions

Most-endorsed coping strategies included improving schedule efficiency ($M = 4.31$, $SD = 1.05$), increasing sleep duration ($M = 4.12$, $SD = 1.08$), and taking scheduled breaks ($M = 4.92$, $SD = 1.11$). (Table 2)

Table 2.
CAFI-II: Personal Solutions They Use to Cope with Fatigue

	Minimum	Maximum	M	SD
More sleep	1	10	4.12	2.85
Efficiency in scheduling classes and flight activities	1	10	4.31	2.64
Scheduled breaks	1	10	4.92	2.42
Reduced workload	1	10	5.07	2.87
Self-awareness of fitness to fly	1	10	5.28	2.71
Guaranteed rest for a given amount of flying	1	10	5.35	2.65
Management of sleep preparation	1	10	5.44	2.61
Physical exercise	1	10	6.26	2.58
Healthy eating habits	1	10	6.90	2.70
Better management of non-work issues	1	10	7.35	2.94

Note: M= mean value, SD = standard deviation, 1=most important – 10= least important

Impact on flight activities & Time on activities

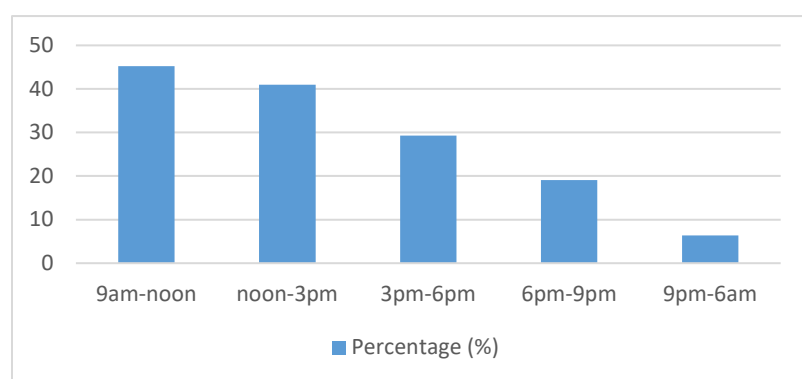
Average fatigue impact on flight activities was moderate ($M = 2.49$, $SD = 0.92$). Weekly work hours averaged 30.17 ($SD = 15.99$) during weekdays and 8.84 ($SD = 5.28$) on weekends.

Alertness

Morning (9:00 a.m.–12:00 p.m.) was the most alert period (45.2%), while night (9:00 p.m.–6:00 a.m.) was the least alert (6.4%). (Figure 4)

Figure 4.

CAFI-II: Alertness Level

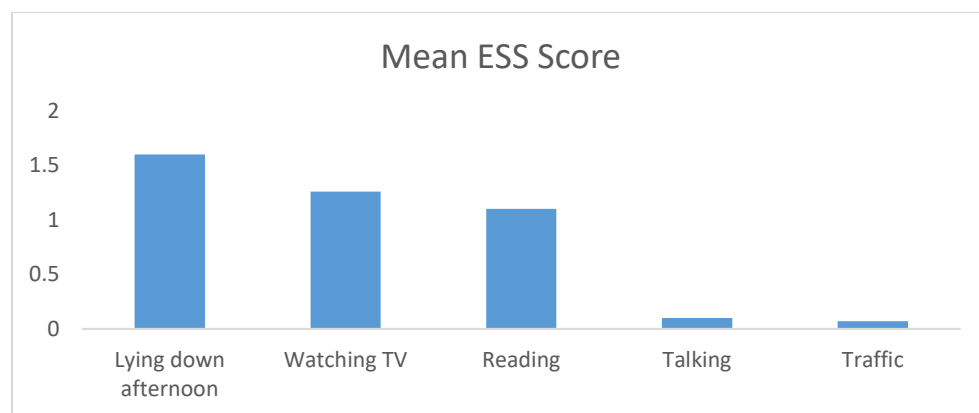


Epworth sleepiness scale (ESS)

Highest dozing likelihoods occurred while lying down in the afternoon ($M = 1.60$, $SD = 0.88$), watching TV ($M = 1.26$, $SD = 0.70$), and reading ($M = 1.10$, $SD = 0.78$). Mean total ESS score was 6.25 ($SD = 3.16$). (Figure 5)

Figure 5

Epworth Sleepiness (ESS)



Mindfulness (CAMS-R)

Corrected CAMS-R scoring produced: attention ($M = 9.31$, $SD = 1.97$), present focus ($M = 8.94$, $SD = 1.82$), awareness ($M = 8.18$, $SD = 1.94$), and acceptance ($M = 9.25$, $SD = 2.01$). The total mindfulness score was $M = 35.68$ ($SD = 5.22$), which is consistent with a 12-item, 4-point scale. Internal consistency was acceptable ($\alpha = .743-.719$). (Table 3)

Table 3
Mindfulness scale (CAMS-R)

	Minimum	Maximum	M	SD	Scale Range (M)	Cronbach's alpha*
Attention	4.0	12.0	9.31	1.97	3-12 (7.5)	.743
Present focus	3.0	12.0	8.94	1.82	3-12 (7.5)	.589
Awareness	3.0	12.0	8.18	1.94	3-12 (7.5)	.615
Acceptance	3.0	12.0	9.25	2.01	3-12 (7.5)	.719
Mindfulness (Total)	nan	nan	8.92	0.08		

Correlations

Table 4 shows Pearson correlations among key variables ($n = 188$ per cell). Each cell includes the 95% confidence interval and exact p-value. Higher mindfulness (total and subscales) was significantly associated with lower ESS scores (e.g., total mindfulness: $r = -.27$, 95% CI $[-.40, -.13]$, $p = .001$) and lower fatigue awareness.

Table 4
Correlations (Partial Example)

Variables	Mindfulness (Total)	Fatigue impacts flights	Alertness level
Mindfulness (Total)	1.0	-0.216	-0.459
Fatigue impacts flights	-0.216	1.0	0.414
Alertness level	-0.459	0.414	1.0
ESS	-0.271	0.284	0.295
Fatigue training	-0.082	-0.081	0.034
Fatigue awareness	-0.428	0.553	0.495
Acceptance	0.722	-0.193	-0.352
Awareness	0.777	-0.195	-0.35
Present focus	0.684	-0.182	-0.291
Attention	0.767	-0.069	-0.359

Multiple Regression Analysis

After removal of three influential cases (Cook's distance $> 4/n$), collinearity improved (all VIF ≤ 5.92). A hierarchical regression predicted ESS from:

- Step 1: demographics (gender, age), not significant.
- Step 2: training and workload variables — $\Delta R^2 = .06$, $p = .041$.
- Step 3: mindfulness variables — $\Delta R^2 = .10$, $p = .004$.

In the final model ($F(6,178) = 5.21, p < .001$, adjusted $R^2 = .12$), higher acceptance predicted lower ESS ($B = -0.38, SE = 0.11, \beta = -.25, p = .001$), whereas greater fatigue impact on flight predicted higher ESS ($B = 0.77, SE = 0.24, \beta = .23, p = .002$). Residual plots confirmed normality and homoscedasticity. (Table 5)

Table 5
Multiple Regression Analysis

Variable	B	Std. Error	Beta	t	p	Tolerance	VIF
Model 1							
(Constant)	5.693	3.047		1.868	0.063		
Attention	0.094	0.147	0.059	0.643	0.521	0.565	1.796
Present Focus	0.05	0.144	0.029	0.347	0.729	0.687	1.457
Awareness	-0.151	0.15	-0.093	-1.005	0.316	0.559	1.789
Acceptance	-0.279	0.13	-0.179	-2.141	0.034	0.687	1.455
Fatigue awareness	0.059	0.055	0.104	1.073	0.287	0.505	1.982
Lifestyle	-0.026	0.061	-0.036	-0.431	0.667	0.696	1.437
Alertness level	0.063	0.059	0.096	1.073	0.285	0.601	1.664
Work per week Mon-Fri	-0.015	0.016	-0.078	-0.982	0.328	0.755	1.325
Work per weekend Sat-Sun	0.032	0.047	0.053	0.667	0.506	0.754	1.326
Socializing time per week Mon-Fri	-0.041	0.039	-0.102	-1.063	0.289	0.518	1.929
Socializing time per weekend Sat-Sun	0.066	0.061	0.097	1.078	0.283	0.597	1.676
Fatigue training	0.46	0.459	0.074	1.004	0.317	0.894	1.118
Fatigue's impact on flight	0.458	0.296	0.135	1.546	0.124	0.634	1.578
Gender	-0.813	0.526	-0.115	-1.546	0.124	0.876	1.142
Age	0.034	0.039	0.068	0.87	0.385	0.777	1.287
Approx. total logged flight time	0.0	0.0	0.025	0.319	0.75	0.793	1.261
Model 2							
(Constant)	7.885	1.284		6.14	0.0		
Acceptance	-0.382	0.109	-0.245	-3.489	0.001	0.966	1.035
Fatigue's impact on flight	0.767	0.239	0.225	3.207	0.002	0.966	10.35

Discussion

This study investigated fatigue, mindfulness, and time management among European aviation students, offering a rare and focused insight into how lifestyle, awareness, and coping strategies affect performance in a collegiate aviation context. While fatigue in commercial and military aviation has been widely studied, student pilot populations, especially in Europe, have received comparatively little attention (Goode, 2003; Stokes & Kite, 2017). This research addressed that gap, examining four core areas: fatigue awareness, fatigue triggers, lifestyle habits, and mindfulness.

The reliability of the tools used was acceptable to strong. The Collegiate Aviation Fatigue Inventory (CAFI-II) demonstrated excellent internal consistency for the fatigue awareness ($\alpha = .896$) and causes of fatigue ($\alpha = .864$) subscales, and good consistency for the lifestyle subscale ($\alpha = .755$). The Cognitive and Affective Mindfulness Scale – Revised (CAMS-R) also showed acceptable reliability ($\alpha = .721$), with individual subscales ranging from $\alpha = .589$ to $\alpha = .743$.

The findings indicated that fatigue is a significant factor in the lives of aviation students. Many reported reduced ability to concentrate ($M = 2.31$), diminished effort ($M = 2.24$), and flight-related errors ($M = 2.21$) attributed to fatigue. These findings are consistent with previous studies by Romero et al. (2020) and Keller (2019), who linked fatigue to impaired attention, poor decision-making, and reduced situational awareness. Similar results were reported by Goode (2003), who showed that fatigue increases accident risk in aviation, and Caldwell (2012), who emphasized the detrimental effects of inadequate sleep on flight performance.

Importantly, 92% of participants reported never falling asleep during training flights, which aligns with general safety standards. However, 51% admitted to continuing flight training despite feeling extremely fatigued. Even more concerning, 78% reported making unnoticed errors during flight activities, raising the possibility that supervising instructors may also have been fatigued. These findings underscore the safety implications of unmanaged fatigue in training environments, echoing ICAO's (2016) call for embedding fatigue education and management strategies into training.

Fatigue Triggers and Training Demands

Sleep deprivation was identified as the most prominent trigger of fatigue. This aligns with prior research by Romero et al. (2020), who emphasized that aviation training environments, due to high mental and physical demands, often contribute to chronic fatigue. Participants highlighted insufficient sleep, poor sleep quality, workload intensity, and inconsistent scheduling as major contributors to their fatigue. Van Dongen et al. (2011) similarly found that irregular work-rest cycles lead to cumulative performance degradation, even when individuals believe they are coping.

Students also reported moderate impacts of fatigue on flight activities ($M = 2.49$). Although most indicated fatigue rarely or sometimes interfered with flight performance, the fact that some reported frequent or constant interference demonstrates the need for targeted interventions. Students also noted fatigue symptoms such as impaired decision-making ($M = 1.93$) and difficulty staying awake ($M = 1.38$) during training, signaling fatigue's direct impact on performance and safety.

Work-life imbalance was another central theme. Many students averaged over 30 hours of work during weekdays and additional hours during weekends, with limited time allocated to rest or social activities. This imbalance is especially concerning in high-stakes fields such as aviation, where cognitive readiness and alertness are essential. Keller (2019) recommended implementing prescriptive models to ensure that time for academics, flight training, rest, and personal well-being is effectively balanced.

Mindfulness and Fatigue

Mindfulness was examined as a potential buffer against fatigue. While overall mindfulness levels were moderate ($M = 8.92$), only the “acceptance” dimension showed a significant predictive relationship with lower daytime sleepiness. This finding suggests that students who can acknowledge and accept their internal experiences, without judgment, may be better equipped to manage fatigue. Furthermore, higher attention scores were negatively correlated with fatigue, indicating that enhanced focus and awareness may support resilience.

These results support earlier work by Meland et al. (2015) and Shapiro and Weisbaum (2020), who noted that mindfulness improves cognitive flexibility and situational awareness, both of which are critical for managing fatigue in complex environments like aviation training. Recent workplace studies (Hülshager et al., 2015) also show that mindfulness interventions reduce fatigue, improve concentration, and enhance safety-related performance, suggesting similar potential benefits for aviation students.

Limitations

While the study offers valuable insights, several limitations must be acknowledged:

1. **Incomplete Responses:** Not all participants answered every item. Although the sample size remained relatively robust ($N = 188$), some analyses may lack full statistical power.
2. **Instrument Validity:** Minor wording modifications in CAFI-II to fit a European audience could have influenced response interpretation or scale validity, though reliability remained acceptable.
3. **Self-Report Bias:** All data were collected via self-report, which may introduce social desirability bias or inaccurate recall. Participants may have underreported fatigue symptoms or overestimated coping abilities.
4. **Sample Scope:** While the sample size is sufficient for initial insights, broader generalizability is limited. Future studies should aim for a larger and diverse pool of student pilots across more countries and training environments.

Despite these limitations, the study presents one of the few in-depth examinations of fatigue and mindfulness among European aviation students. It offers a critical foundation for both academic research and practical policy development in aviation training.

Conclusions

This study found that many aviation students experience symptoms of fatigue that can impact flight performance, academic achievement, and mental well-being. Despite moderate levels of mindfulness and relatively low reported levels of excessive daytime sleepiness (ESS $M = 6.25$), the findings highlight systemic concerns, such as poor scheduling, insufficient rest, and inconsistent fatigue awareness.

Notably, nearly half of the participants (47.9%) reported receiving no formal fatigue training, and many exhibited limited awareness of fatigue's impact on performance. Students

cited poor flight scheduling, lack of sleep, academic pressure, and psychological stress as key fatigue triggers. These conditions can erode both flight safety and learning outcomes.

The study also established statistically significant correlations between fatigue and variables such as mindfulness, lifestyle, and sleepiness. Specifically, higher acceptance and attention levels were associated with lower sleepiness, while fatigue-related impairments were more common among students with poor alertness and high self-reported stress.

Recommendations

To promote safety and well-being, the following recommendations are proposed:

For Flight Schools and Institutions:

- **Implement Fatigue Education:** Integrate mandatory fatigue awareness modules into flight training programs. These should cover sleep hygiene, circadian rhythms, and risk factors (ICAO, 2016).
- **Enhance Scheduling Practices:** Establish policies that ensure students are not overloaded with academic and flight duties in a compressed timeframe.
- **Adopt Fatigue Risk Management Systems (FRMS):** Use predictive and reactive models to identify fatigue risks, collect self-reports, and adjust training as needed.
- **Promote Mindfulness Training:** Incorporate brief mindfulness programs to help students manage stress, improve focus, and enhance self-regulation (Hülshager et al., 2015).

For Students:

- **Prioritize Sleep and Recovery:** Develop consistent sleep routines and limit caffeine, screens, and other disruptions before bed.
- **Balance Responsibilities:** Use time management tools to distribute workloads evenly and allocate time for recovery and personal well-being.
- **Engage in Regular Physical Activity:** Maintain a healthy lifestyle to build physical and mental resilience.
- **Conduct Self-Evaluations:** Use tools like the IMSAFE checklist (Illness, Medication, Stress, Alcohol, Fatigue, Eating) before flights to assess readiness.

Suggestions for Future Research

To build upon these findings, future research should:

1. Use mixed methods (qualitative and quantitative) to explore how fatigue affects decision-making and mental health.
2. Expand sample sizes and geographic diversity to compare fatigue experiences across regions and training systems.
3. Investigate how technological solutions, such as fatigue-monitoring wearables, can aid in real-time awareness and prevention.

4. Assess the long-term benefits of mindfulness and stress-management training in improving flight safety and student retention.

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Analyzing Trends in UAS Altitude Deviations in the United States: Exploring Human Factors Issues

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The usage of unmanned aircraft systems (UAS) for recreational and commercial purposes has been rapidly growing in the United States (U.S.). As of December 2023, over 1.54 million new recreational drones have been registered in the Federal Aviation Administration's (FAA) database. With the increase in the usage of UAS, violations related to flying UAS into unauthorized airspace are also accumulating. According to the Code of Federal Regulations, 14 CFR§107.51, "the altitude of a small, unmanned aircraft system cannot be higher than 400 feet above ground level." Human factors, such as difficulty in visual scanning, lack of multiple sensory cues, loss of communication, and spatial disorientation, play a significant role in altitude compliance problems with respect to UAS operations. Historically, various studies have examined the trends of UAS operations in unauthorized airspace. However, there is a dearth of research focused on examining the trends in altitude compliance issues related to UAS operations and their association with human factors constructs. Therefore, the purpose of the current study was to investigate the trends in UAS sightings over 400 feet in the U.S. and the associated human factors issues. All UAS sightings reported between January 2021 and December 2024 were obtained from the FAA's UAS sightings database. All the data were explored through Tableau and JMP. Results of the analysis, and the role of human factors issues, such as visual workload, multimodal cues, and situational awareness in UAS operations, are discussed.

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Introduction

Unmanned Aircraft Systems (UAS), including small UAS (sUAS), are defined by the Federal Aviation Administration (FAA) as aerial vehicles operated remotely without an onboard pilot (Huang et al., 2021, p. 1). Over the last decade, the use of UAS or drones in the United States (U.S.) has gained tremendous popularity across various commercial operations, such as package delivery, construction, firefighting, and inspection. Along with commercial operations, there has also been consistent growth in recreational UAS operations in the U.S. According to the FAA's Aerospace Forecast (n.d.), by 2028, the UAS fleet for recreational operations is projected to reach approximately 1.92 million units, and the commercial operations fleet is projected to reach approximately 1.12 million units. Their rapid integration into the national airspace reflects significant advances in affordability and accessibility. However, this growth has led to complex regulatory and safety challenges for the industry. Most operations involve a small sUAS and are restricted to 400-foot(ft) above ground level (AGL; FAA, 2024). The UAS operator is responsible for maintaining an altitude below 400 ft AGL throughout the mission. Despite these efforts, concerns remain regarding the ability of recreational and commercial users to consistently comply. As Okoli et al. (2024) noted, the influx of UAS operations introduces a novel set of risks to the National Airspace System, emphasizing the critical need for a literature-based understanding of altitude compliance.

FAA sighting reports from 2020 to 2021 revealed that a significant portion of UAS activity exceeded the legal altitude thresholds. Specifically, 93% of drones were observed flying above the 400 ft AGL limit, and 32% exceeded 4,000 ft, raising serious concerns regarding airspace violations (Howard, 2023). These unauthorized flights occurred most often during daylight hours and in proximity to airports (Howard, 2023), meaning that they also represent an increased safety risk to manned flights. Furthermore, demographic studies have shown a correlation between education level and compliance, with operators with higher education and income levels being more likely to follow altitude rules (Huang et al., 2021), underscoring the influence of sociocultural factors on regulatory behavior.

Previous studies have focused on trends in UAS sightings (Abraham, 2022; Howard, 2023; Huang et al., 2021), geographical factors causing UAS noncompliance, and the consequences of noncompliance within controlled airspace and in the vicinity of airports. These studies have highlighted the operational and safety issues posed by UAS activities in restricted areas, emphasizing the importance of regulatory enforcement and technological solutions for mitigating potential threats. Another prominent challenge in achieving full compliance with these regulations is the human element, where operator error and insufficient situational awareness significantly impact adherence to altitude constraints. Compounding these concerns is the need for ongoing investigations and enforcement measures to accommodate future technological developments and operational scenarios. As the FAA continues to refine its guidelines, a critical focus on addressing human factors is essential to enhance compliance and uphold airspace safety. Therefore, this study aims to extend beyond operational and future trends by establishing a foundation for understanding the human factors contributing to UAS noncompliance.

Purpose Statement

The purpose of the current study is multi-fold: (a) to investigate the trends and regional patterns in UAS altitude deviations in the U.S., (b) to predict future trends in UAS altitude deviations based on historical data in the U.S., and (c) to explore human factors issues related to UAS altitude deviations in the U.S.

Research Questions

Research Question 1: What are the trends in UAS altitude deviations in the U.S. between 2021 and 2024?

Research Question 2: What future trends in UAS altitude deviations can be predicted in the U.S. based on historical data between 2021 and 2024?

The third objective, related to human factors issues in UAS altitude deviations, was investigated from an exploratory perspective by grounding the findings into the Human Factors Analysis and Classification System (HFACS) framework (Wiegmann & Shappell, 2001). Therefore, the third research question is not presented here.

Literature Review

Various studies have been explored as a part of the current literature review and have been summarized into the following sections: safety risks and impact on controlled airspace, operator demographics and regulatory compliance, predictive models and future trends, and human factors in UAS operations.

Safety Risks and Impact on Controlled Airspace

Altitude violations by UAS pose tangible risks to controlled airspace, particularly near busy airport corridors. Howard (2023) identified 241 close encounters between UAS and manned aircraft, with six classified as near mid-air collisions. These incidents often necessitate evasive maneuvers, jeopardizing the safety of both the aircraft and passengers. Okoli et al. (2024) highlighted the systemic nature of this risk, pointing to the lack of detection and response capabilities that could otherwise mitigate these threats. As drone operations continue to expand, their unchecked presence in regulated airspace could result in significant disruptions or disasters without improved risk management strategies being implemented.

Operator Demographics and Regulatory Compliance

The vast majority of UAS operations are conducted by recreational users, who comprise approximately 80% of the user base (Huang et al., 2021). This group is significantly less likely to adhere to altitude restrictions, in part due to limited formal training or a lack of regulatory awareness. In contrast, commercial operators are required to obtain FAA certification and demonstrate their aeronautical knowledge. These credentialed users are statistically more compliant (Huang et al., 2021). Although the FAA has issued more than one million airspace authorizations, Howard (2023) noted that these are often highly location-specific and temporary,

raising concerns about the apparent mismatch between issued waivers and the number of high-altitude UAS operations reported.

Predictive Models and Future Trends

Recent advances in predictive analytics have offered promising tools for managing UAS safety. Abraham (2022) trained a machine learning model using Bidirectional Encoder Representation from Transformers (BERT) to classify drone incident data with 96% accuracy, demonstrating that textual FAA reports can be processed to identify hazardous behavior patterns. Howard (2023) cautioned that unverified sightings, inconsistent levels of detail, and a lack of standardized reporting limit the reliability of FAA UAS data for researchers and predictive modeling. While emerging technologies such as Remote ID and low-level airspace traffic management show promise, their effectiveness will hinge on operator participation and robust enforcement mechanisms.

Human Factors Issues in UAS Operations

Understanding human factor issues associated with UAS operations is critical for the safe integration of UAS into the National Airspace System (NAS). According to Reason's Swiss Cheese Model (Reason, 1990), an accident is a breakdown or is caused by the absence of a safety barrier across four levels within a sociotechnical system, including Unsafe Acts, Preconditions for Unsafe Acts, Supervisory Factors, and Organizational Failures. Based on the Swiss Cheese Model, the HFACS framework was developed to identify human error at each of the four levels (Wiegmann & Shappell, 2001). The current study employs the HFACS framework, which classifies unsafe acts as operator errors or violations. Operator errors are further classified into skill-based, rule-based, and decision-making errors. Skill-based errors are associated with slips and lapses due to attention failure during routine tasks. For instance, a recreational UAS operator may lose control due to high-speed winds or get distracted. Perceptual errors occur when an operator's sensory inputs are distorted owing to environmental conditions (Endsley, 1995). For example, a UAS operator misjudged the altitude owing to low visibility. However, in contrast, decision errors are associated with an operator's flawed judgment after the operator knowingly accepts the risk (Reason, 1990). For instance, a commercial or recreational operator exceeding the 400 ft altitude to capture an image or complete an operational task.

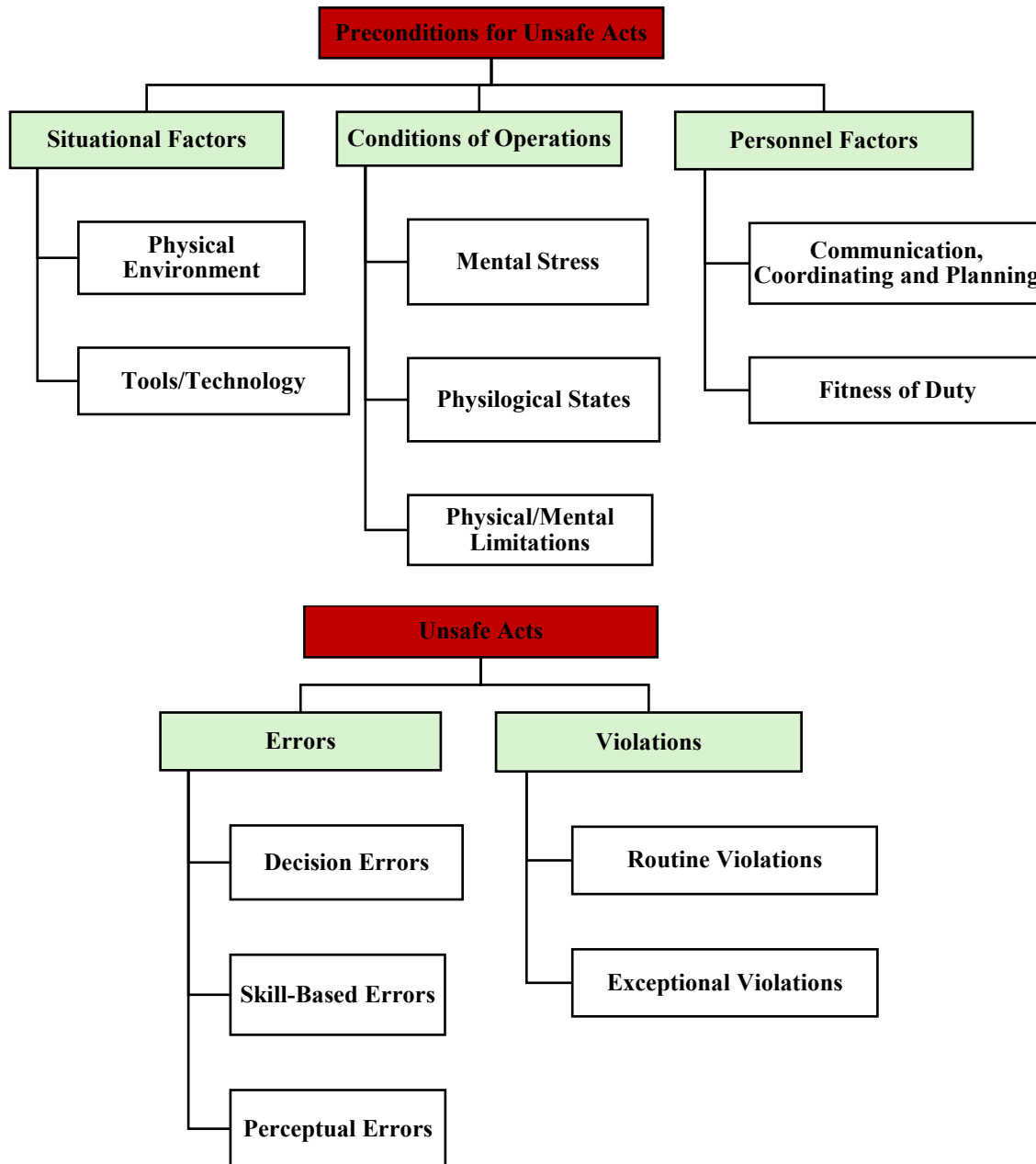
According to Wiegmann and Shappell (2001), preconditions such as environmental factors, conditions of operations, and personnel factors make the outcome of an unsafe act more likely. Factors such as limited situational awareness due to poor display design, insufficient training, fatigue, high workload situations, and environmental stressors create conditions where errors are more likely to occur (Carmody et al., 2023; Hobbs & Lyall, 2016). For example, an inexperienced recreational operator may lack perceptual accuracy while scanning the sky for altitude in an urban environment. A commercial UAS operator may struggle with limited situational awareness by focusing their entire attention on the live video feed and failing to recognize controlled airspace boundaries.

UAS operations have several challenges related to human factors, such as Excessive Alertness, Excessive Mental Fatigue, Monitoring, Excessive Concentration, Discernibility, Distraction, and Workload (Namukasa et al., 2023), which play a significant role in non-

compliance in UAS operations, especially regarding inadequate sensory clues that may impact situational awareness. The UAS display design and command interface play a significant role in the presentation and availability of data to operators (Howe, 2017). A new UAS operator would have limited aeronautical knowledge, training, and/or ability to effectively control and understand operational complexities.

Figure 1

HFACS Framework Emphasizing Pre-conditions from Unsafe Acts and Unsafe Acts



Note. HFACS Framework Adopted from Wiegmann and Shappell (2001).

The lack of command, control, and communication (C3) are critical human factor issues in UAS operations that can significantly affect operators' performance and decision-making (Balog et al., 2017). Neff and Garman (2016) identified skill-based errors and decision errors as the top two human factors contributing to UAS mishaps, emphasizing the need for prioritized training strategies to mitigate these recurring issues. Williams (2005) found that many UAS accidents could have been prevented with better interface design and procedural safeguards, noting that human error contributed to 21% to 68% of mishaps across different systems. Interface design has also proven problematic: 24% of UAS mishaps have been linked to poorly designed ground control stations (Waraich et al., 2013, p. 26). These human-machine interface failures point to the need for better ergonomic standards and training protocols tailored to UAS operation.

Environmental and operational demands further complicate the altitude deviation. Howard (2023) reported that drone operations at high altitudes face significant environmental challenges, including increased wind speeds and freezing temperatures, which impair control and elevate the risk of flight instability (p. 10). (Carmody et al., 2023; Hobbs & Lyall 2016). interfering with emergency response activities is explicitly prohibited without special FAA permission and emphasized that compliance is influenced by the type of use, user knowledge, and operational location (p. 4). Limitations, such as battery duration and range of communication systems, also push operators to take risks, underscoring the importance of designing technology and rules that reflect real-world challenges.

Research Gap

Historically, very few studies have explored trends in UAS operations (Abraham, 2022; Howard, 2023; Huang et al., 2021). However, there are limited studies that have analyzed the altitude deviations of UAS operations in the U.S. Several studies have investigated human factor issues associated with UAS operations from both commercial and recreational perspectives (Carmody et al., n.d.; Hobbs & Lyall, 2016; Hobbs & Shively, 2012; Namukasa et al., 2023). According to Hobbs and Shively (2022), operators' workload management, interface design, and reduced sensory control are major concerns associated with UAS operations. Carmody et al. (2023) stated that training considerations for UAS operators will play a huge role in safe integration of UAS into the NAS. However, there is a dearth of research on the human factor issues associated with altitude deviations during UAS operations. Moreover, despite the growth in regulatory and technical literature, research on operator behavior and long-term trends remains limited. Therefore, the current study will fill the gap by examining the trends in altitude deviation from 2021 to 2024 and grounding them in the HFACS framework (Wiegmann & Shappell, 2001).

Methods

Population and Sample

The current research focuses on all UAS operations in the U.S. Therefore, the target population constituted all FAA Part 107 and recreational operations in the U.S. The accessible population consisted of all the operations that were reported in the FAA's UAS sightings database between 2021 January and 2024 December that are over 400 feet (Federal Aviation Administration, 2025). The sample for the current study was similar to the accessible population.

Research Methodology

A predictive correlational research methodology was used for the current study, as one of the objectives was to examine the historical trends in UAS sightings and predict future UAS altitude compliance sightings. In addition, an exploratory research design was used to summarize UAS sightings based on different operational characteristics.

Data Collection

All data for the current study were collected from the FAA's drone sightings near airports database (Federal Aviation Administration, n.d.). All data in the current study were archival and collected from a federal database accessible to the public. Although we did not have any direct control over data collection, we assume the data to be valid and reliable as it is coming from a federal database accessible to the public.

Table 1
UAS Report Counts by Year and Month

Month	Year			
	2021	2022	2023	2024
January	120	90	75	70
February	132	159	114	128
March	199	162	108	116
April	214	166	162	138
May	321	221	225	194
June	385	200	189	222
July	203	157	161	147
August	219	168	118	126
September	224	131	142	118
October	190	126	126	130
November	138	85	113	97
December	113	48	81	128

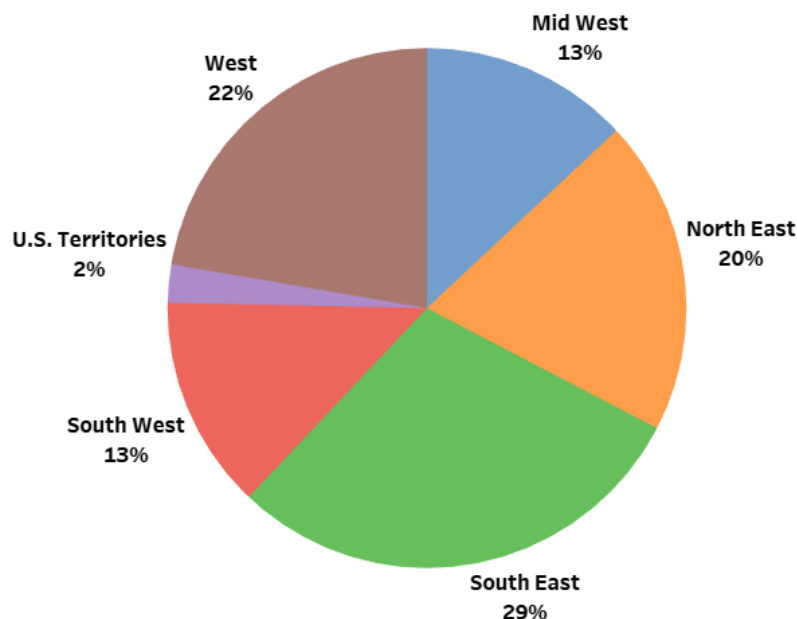
Note. $N = 7,392$. Data from FAA (n.d.).

Table 2
UAS Altitude Compliance Issues by Region

Region	N	%
West Region	1,674	22.64
Southwest Region	981	13.27
Mid-West Region	963	13.03
South-East Region	2,196	29.71
North-East Region	1,406	19.03
U.S. Territories	175	2.37

Note. $N = 7,392$. Data from FAA (n.d.).

Figure 2
Proportion of UAS Reports by Region



Note. The percentages are based on $N = 7,392$. Data from FAA (n.d.).

Results

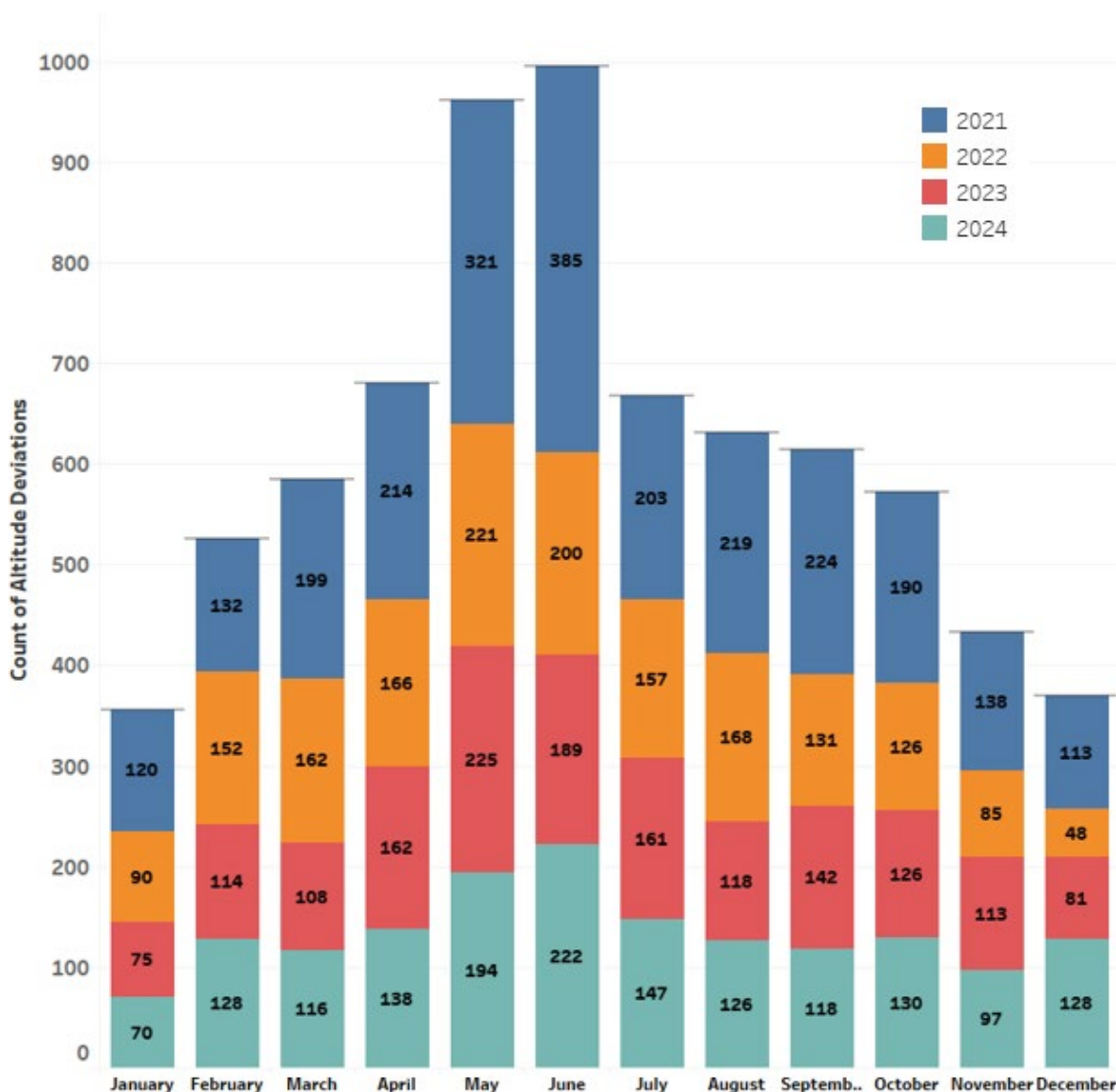
The current study involved two primary research aims: (a) What are the trends in UAS altitude deviations in the U.S. between 2021 and 2024? and (b) What future trends in UAS altitude deviations can be predicted in the U.S. based on the historical data between 2021 and 2024?

Figure 3 shows the monthly breakdown of reported UAS sightings over 400 feet altitude between 2021 and 2024. May, with average sightings of $M = 240$, and June, with average sightings of $M = 246$, were the months with the most UAS sightings over 400 feet in a calendar year. In most regions of the U.S., these months mark the beginning of summer. During these months, the weather is more favorable, with longer daylight hours, providing ideal recreational and commercial UAS operations. A geographical breakdown of UAS sightings by state is provided in Figure between 2021 and 2024, with California ($N = 966$), Florida ($N = 941$), Texas

($N = 580$), New York ($N = 521$), and Illinois ($N = 335$) reporting more than 300 sightings. The higher number of altitude deviations in the above-mentioned states could be the result of some cities within states that are densely populated and have complex airspace structures.

Figure 3

Monthly Breakdown of UAS Altitude Deviations Between 2021 and 2024



As reported in Figure 5, cities with airports serving as major hubs for airlines reported more sightings than cities with non-hub airports. Cities such as New York, Chicago, Seattle, Los Angeles, and Miami, which serve as hubs for some major airlines, such as American, Delta, JetBlue, and United Airlines, reported more than 100 sightings between 2021 and 2024.

Figure 4

Geographical Breakdown of UAS Altitude Deviations Between 2021 and 2024

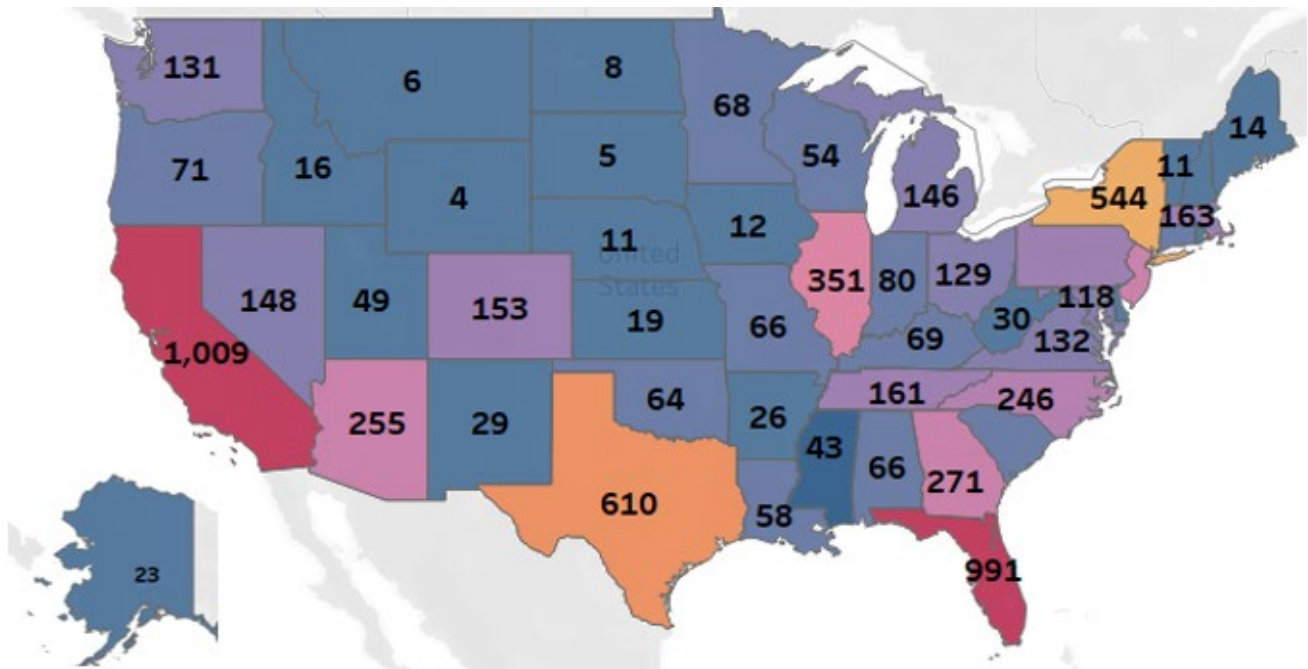
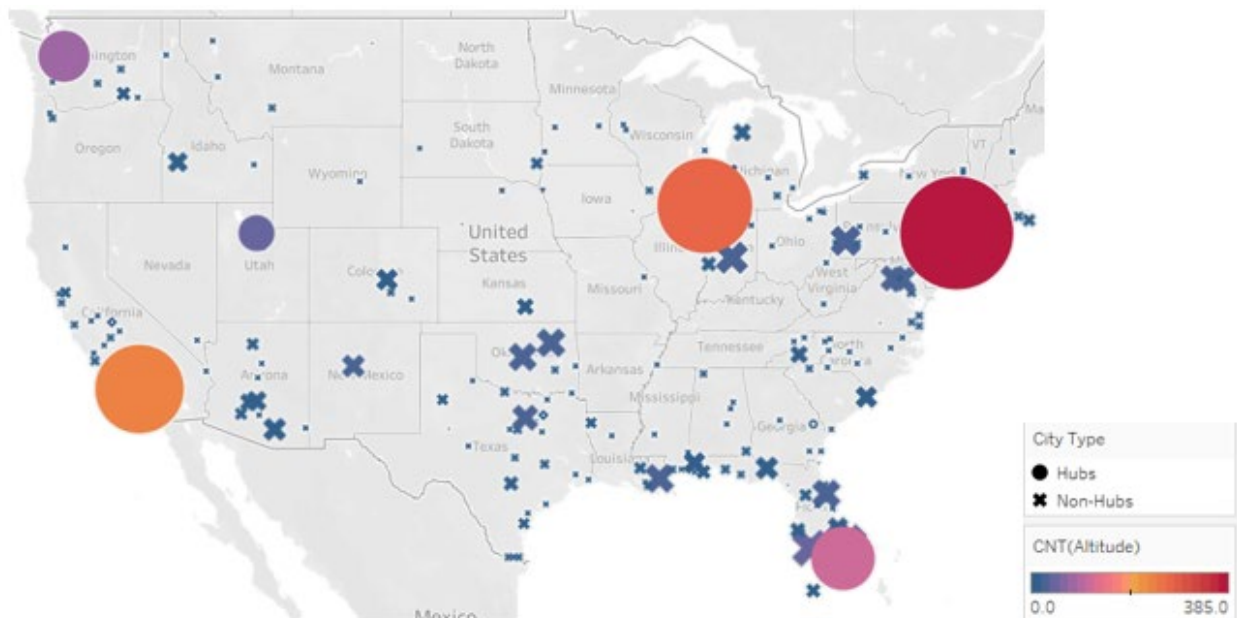


Figure 5

UAS Altitude Violations Between 2021 and 2024 Based on Hub and Non-Hub Airports



A bivariate linear regression analysis was conducted to predict future UAS sightings at over 400 ft in the U.S. Before conducting the primary analysis, all four assumptions for bivariate regression—linearity, homoscedasticity of residuals, independence of residuals, and normality of residuals—were tested. To confirm linearity, a bivariate scatterplot was created with residuals of Y = altitude violations on the x -axis and Y = altitude violations on the y -axis, as shown in Figure 6 (Gallo et al., 2023). A similar plot was also used to determine homoscedasticity, as shown in Figure 6. In addition to linearity, no other discernible pattern was observed. To test for independence a scatterplot was conducted with case numbers on x -axis and residuals of violations on y -axis (Gallo et al., 2023). As shown in Figure 7, there appears to be no detectable pattern, indicating that the residuals are independent of each other. Shapiro-Wilk Goodness of Fit test was conducted to test normality which yielded a p value of .018, indicating a non-normal distribution. However, as the sample size was $N = 48 > 30$, the central limit theorem (CLT) was applied, which indicates that “even if the parent population is not normal in form, the sampling distribution of sample means will approximate a normal distribution if the samples are sufficiently large ($n > 30$)” (Gallo et al., 2023, p. 78).

Figure 6

Assumption of Linearity & Homoscedasticity

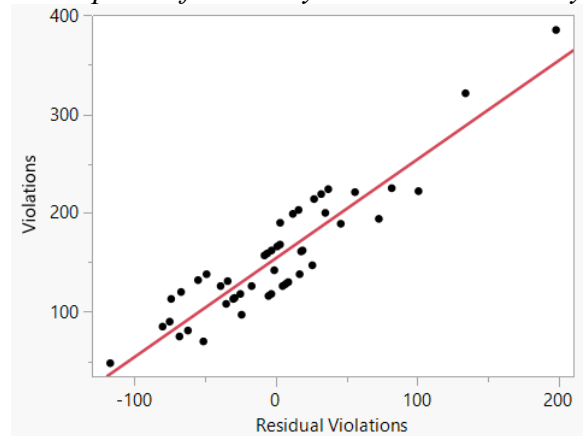
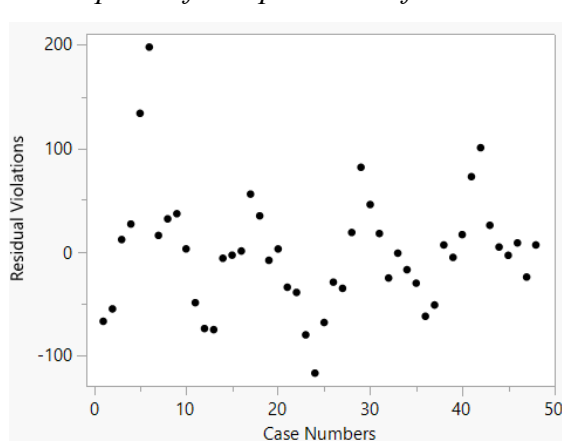


Figure 7

Assumption of Independence of Residuals



As reported in Figure 8, the annual altitude deviations declined between 2021 and 2024. As reported in Table 3, the prediction model was found to be $\hat{Y} = -21.93 (\text{Year}) + 44,497.45$. The R^2 was .16, and the model was significant at $F(1, 46) = 8.80, p = .005$, indicating that approximately 16% of the variance in altitude violations was explained by year. A Post-hoc effect size was conducted to determine the true magnitude of the effect, based on Cohen’s (1998) formula $f^2 = \frac{R^2}{1-R^2} = \frac{.16}{(1-.16)} = .19$, which is considered as medium effect. A post-hoc power analysis was also conducted to help interpret the reliability and robustness of the results of the current study and was found to be .86, indicating that 86% of the effect found in the sample existed in the population (Gallo et al., 2023; Kelly et al., 2024; Osman et al., 2022). A forecast model was also built using the 95% confident interval derived from the regression model (see Figure 9) based on the data available between 2021 and 2024, which predicted 1,303 UAS sightings in 2027, which is approximately 300 fewer sightings than in 2024.

Table 3

Regression Summary of UAS Altitude Deviations

Statistics	Estimates	R^2	F	p
		.161	8.801	.0048
B_0	44497.45**			
B	-21.93**			

Note. $N = 45$, * $p < .05$, ** $p < .01$, *** $p < .001$

Figure 8

Prediction Model of UAS Sightings by Year

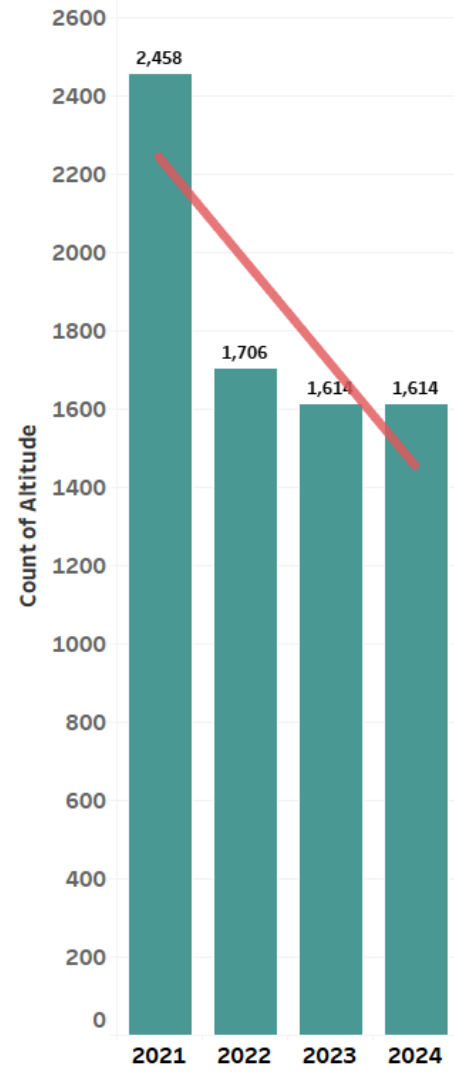
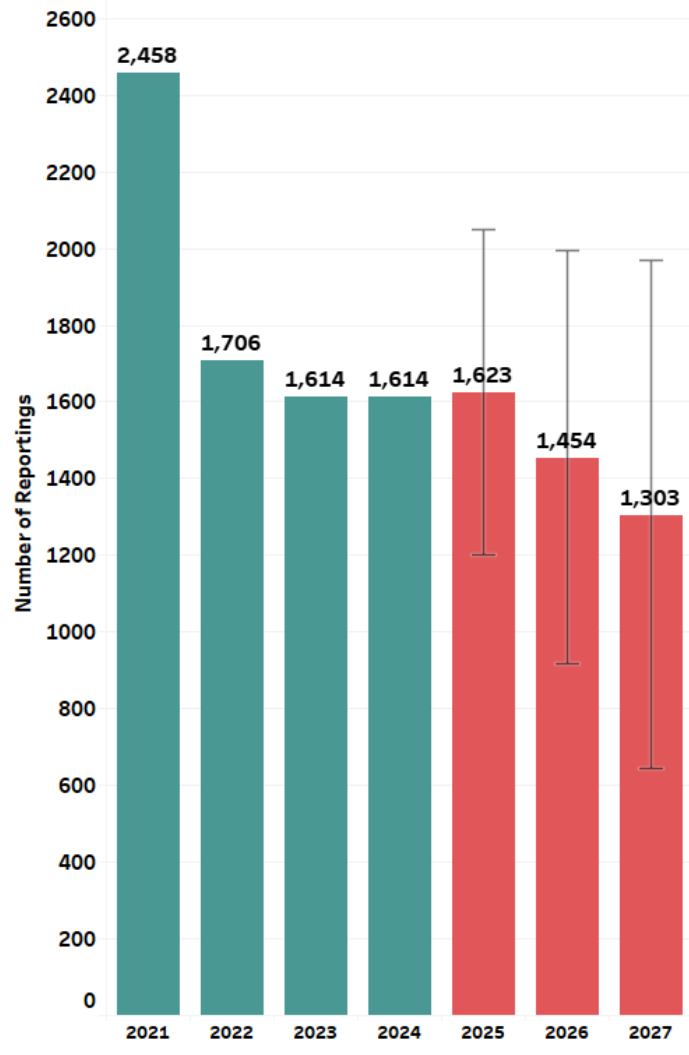


Figure 9

Forecast of UAS Sightings by Year



Discussion

The current study's findings highlight the positive trends in UAS altitude deviations in the proximity of airports serving as hubs, which are part of urban cities such as New York, Miami, Chicago, and San Francisco. The findings can be attributed to multiple factors, such as

the lack of awareness of recreational fliers in highly restricted airspace near the hubs; urban cities tend to have a higher demand for commercial operations, including last mile delivery, photography, and inspection; and the lack of awareness or limited pilot training of recreational fliers with respect to the FAA's regulation on UAS altitude requirements. The current study's findings suggest that there is a downward trend in altitude deviations between 2021 and 2024; projected trends over the next three years also indicate a similar downward trend. A plausible explanation for the declining reports could be the FAA's efforts to improve the awareness of UAS regulations with respect to recreational fliers through programs such as the recreational UAS Safety Test (TRUST), Low Altitude Authorization Clearance (LAANC), and the increased emphasis on UAS registration. However, the findings also revealed that the problem of UAS altitude deviations is not fully resolved, especially near airports.

The findings of the current study can also be interpreted from the perspective of the HFACS framework. For instance, as shown in Figure 5, a larger number of altitude deviations in cities with large hub airports, such as Miami, New York, and Chicago, demonstrate the decision errors of UAS operators' when operating in a complex airspace with high workloads. Altitude deviations in non-hub cities can be attributed to skill-based errors such as attention lapse due to reduced situational awareness. The seasonal trends shown in Figure 3, with more deviations during the summer months, can be attributed to unsafe acts by either recreational or commercial operations that plan to finish the mission during favorable weather conditions. The low count of altitude deviations during the winter months can be attributed to perceptual errors due to reduced daylight or visibility.

Based on the study's findings, we have recommendations from three perspectives: regulatory, original equipment manufacturers (OEMs), and designers. From a regulatory perspective, increasing awareness of UAS altitude regulations by the FAA will likely enhance recreational fliers' airspace and operational knowledge. From the designer's perspective, promoting geofencing and real time altitude warning features in drones that give real time safety alerts to the drone operators will likely reduce the altitude deviation issues. From the OEMs' perspective, training programs, such as TRUST and LAANC, should be integrated as part of training modules to enhance awareness relayed to UAS regulations among recreational flyers. The literature reviewed here confirms that UAS altitude compliance is a multifaceted challenge involving technical systems, human behavior, environmental dynamics, and policy gaps. Unsafe operations are driven by a mix of limited training, flawed interface design, and mission-driven risk tolerance. Future strategies must integrate human factors into policy design, training, and system architecture to ensure that drones can safely coexist with manned aircraft in shared airspaces.

Limitations, Delimitations, and Future Research

The findings of the current study have to be interpreted with the following limitations: (a) all the data for the current study were obtained from FAA's UAS sightings database, including all reported UAS sightings, which may have incomplete information, (b) the correlational research design, prevents causal inferences between year and altitude deviation frequency, and (c) some of the states had sparse data, limiting the generalizability across all U.S. regions. Some of the delimitations of the current study were (a) time period, data between only 2021 and 2024 were

collected, (b) all the data with missing altitude were removed from the database before analyzing the trends, (c) A simple bi-variate regression model was selected over some advance time-series models such as Autoregressive Integrated Moving Average (ARIMA), due to low sample size, and (d) The reader is also cautioned that the forecast model presented in Figure 9 was based on limited data between 2021 and 2024, and therefore the readers need to treat them as an illustrative trend rather than precise limitations. Future research should combine sighting data with other sources of UAS incident reports, such as the Aviation Safety Reporting System (ASRS) database and LAANC authorizations. Moreover, critical datasets, such as National Aeronautics and Space Administration's (NASA's) ASRS (ASRS, n.d.), have not yet been fully leveraged to understand non-compliance. Filling these gaps is vital for developing evidence-based strategies that blend human factor insights with technological solutions. Another recommendation for future research is to examine the qualitative data in the reports, using machine learning – natural language processing (NLP) techniques to analyze the human factor issues related to altitude deviations.

Conclusion

The findings of the current study were able to demonstrate meaningful patterns in altitude deviations with respect to UAS operations in the U.S. between 2021 and 2024. The sightings demonstrated a steady decline in altitude deviations between 2021 and 2024. The results from the prediction model also project a declining trend in altitude deviations. The study also highlights human factor issues, such as workload, situational awareness, communication, design, and training, as critical factors associated with altitude deviations.

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Evaluating the Impact of Virtual Reality-Integrated Flight Training Compared to Traditional Methods on Student Pilot Performance

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This study evaluated the efficiency and effectiveness of traditional flight training methods compared to virtual reality (VR)-integrated instruction at a large FAA Part 141 university flight program. Through the integration of the Pre-Flight Immersion Laboratory for Operations Training (PILOT) Program, which used VR technologies to simulate real-world flight conditions, this research examined whether VR-integrated flight training resulted in differences in total flight hours required to complete a flight rating and checkride pass rate outcomes. Using a quasi-experimental design, internal flight program student learning achievement/progression data were analyzed to compare checkride pass outcomes between students trained via traditional methods and those utilizing the VR-integrated curriculum. Results suggest that VR-integrated flight training contributed to reduced total flight hours required to complete a flight rating while maintaining comparable checkride pass rates. VR-integrated flight instruction may help provide a more efficient approach to training new pilots. These findings have practical implications for curriculum design and training efficiency in collegiate flight training programs.

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Introduction

The first step in pursuing an aviation career is obtaining a Private Pilot rating, with students typically choosing between Federal Aviation Administration (FAA) certified Part 61 or Part 141 flight schools (Federal Aviation Administration [FAA], 2024). Part 61 programs are generally more flexible and suited for independent learners, such as those training part-time or outside formal academic settings (Rotaru, 2024). In contrast, Part 141 programs follow a highly standardized and structured curriculum that is FAA-approved, with detailed lesson plans, stage checks, and minimum flight hour requirements that are lower than those of Part 61 (Rotaru, 2024). These Part 141 programs are commonly housed within universities as collegiate aviation programs, where students simultaneously pursue academic degrees in aviation-related fields in addition to obtaining the certifications required to become a professional pilot (Hampton et al., 2017). A bachelor's degree in aviation has also been linked to higher rates of airline hiring and long-term career advancement, highlighting the relevance of collegiate aviation programs (Smith et al., 2010).

Many collegiate aviation programs integrate airline-style flight training concepts early in Private Pilot instruction, beginning with flight simulator sessions and ground-based theoretical coursework before transitioning to hands-on in-airplane flight experience (Hampton et al., 2017). To further enhance student preparedness and address common training challenges, certain Part 141 institutions have implemented virtual reality (VR)-based immersive flight training programs that simulate preflight and in-flight scenarios as part of their flight course curricula. These VR-based simulation training programs often include components such as air traffic control (ATC) communication practice, preflight procedural labs, and advanced flight control simulation, providing students with immersive, risk-free environments to develop essential piloting skills. By bridging the gap between theory and practice, these VR-based initiatives may help build students' confidence and competence.

Traditional flight training methods are often resource-intensive, requiring significant time and financial investment (Dahlström, 2008). With advancements in immersive technology, VR has emerged as a promising tool for enhancing aviation training by potentially reducing required training hours while maintaining or improving pilot competency (Thomas et al., 2023). This study examined the impact of VR-integrated training on student pilot flight training outcomes, focusing on total flight hours and checkride success rates needed to obtain a Private Pilot rating. The objective was to evaluate whether a VR-enhanced training model could match or exceed the effectiveness of a traditional Private Pilot training curriculum. Specifically, the research explored whether incorporating VR could improve training efficiency and shorten the time to proficiency without compromising critical skill development.

Operational Definitions of Constructs Used in this Study

- **Oral Instruction Time:** The total number of hours students spend receiving instructor-led knowledge in designated oral instruction and examination rooms, as part of the approved training syllabus.

- **Simulator Time:** The total duration students engage in training using certified flight simulation devices, in accordance with the structured curriculum requirements of a university-based flight training program.
- **VR-Integrated Training:** VR-based training sessions that were included in the FAA-approved institutional curriculum but not counted towards the minimum flight hour requirements for course completion. These VR-based training sessions included three components: ATC communication practice, a preflight preparation lab, and flight simulation exercises.
- **Total Flight Time:** The combined number of hours a student accumulates in flight training, including both instructor-led and solo flights.
- **Checkride:** A comprehensive practical exam necessary for pilot certification, consisting of both an oral knowledge evaluation and an in-flight performance assessment.
- **Checkride Pass Rate:** The proportion of students who successfully complete both portions, oral and flight, of the checkride examination on their first attempt.

Definition of VR Environments in this Study

In this study, VR is defined as a fully immersive, computer-generated environment in which users interact with simulated aircraft systems, controls, and procedures through head-mounted displays and motion controllers (Guthridge & Clinton-Lisell, 2023). Augmented reality (AR) refers to the overlay of digital elements or instructional cues onto a real-world environment (Al-Ansi et al., 2023), whereas mixed reality (MR) combines both physical and virtual elements, allowing users to interact simultaneously with real and simulated components (Crogman et al., 2025). The Pre-Flight Immersion Laboratory referenced in this study incorporated elements of both VR and AR. While most procedural training occurred within a fully virtual cockpit and environment, the preflight inspection component utilized AR-based overlays that enable students to examine physical training aircraft while receiving digital annotations and system feedback. For the purposes of this research, both modalities were collectively described as VR-integrated training to reflect their shared immersive and interactive instructional design.

VR-Integrated Pre-Flight Immersion Laboratory for Operations Training (PILOT) Program Background

The VR-integrated Private Pilot training curriculum (Pre-Flight Immersion Laboratory for Operations Training [PILOT] Program) evaluated in this study consisted of three structured phases. The first phase comprised a four-week VR-based training module designed to introduce foundational flight knowledge and skills prior to aircraft operation. Students participated in weekly four-hour sessions, which included one hour of flight simulation, 30 minutes of ATC communication practice, 30 minutes in a preflight laboratory simulation, one hour of oral instruction with a certified flight instructor (CFI), and an additional hour of FAA Part 141-compliant simulator training. The second phase transitioned to in-aircraft flight instruction, delivered on a daily basis and supplemented by oral lessons conducted with an instructor and a student peer. This stage continued until students completed their first solo flight. The third and final phase focused on cross-country flight operations and end-of-course checkride preparation. Flight activities during this phase occurred daily or at a minimum frequency of three sessions per week, depending on student progress and aircraft availability.

VR Flight Simulation Curriculum and System

Three VR instructional domains, ATC communication, preflight inspection, and advanced flight control, were strategically selected to align with key skill categories outlined in the FAA Private Pilot Airman Certification Standards (ACS; FAA 2023). Specifically, ATC communication and preflight procedures correspond directly to discrete ACS task areas under Sections I and II, while advanced flight control encompasses multiple performance elements related to takeoff, landing, and stall recovery (FAA, 2023). These domains were chosen because they represent foundational procedural and decision-making components of early flight training that require strong spatial awareness, situational judgment, and repetitive practice to master. The VR-integrated training sessions were organized into daily modules aligned with the FAA's Private Pilot ACS (FAA, 2023). Students were expected to complete each assigned module on schedule, with any missed sessions required to be made up within the same week. Modules could also be repeated as needed to reinforce learning and ensure proficiency before advancing to subsequent phases of instruction.

Training was delivered through the university's VR-integrated flight simulator system, which combined desktop-based and headset-based simulation using commercially available VR software built on the X-Plane platform and custom-developed three-dimensional inspection modules. The hardware configuration included PC-based workstations equipped with head-mounted displays, motion-tracked controllers, and integrated ATC voice simulation, providing both interactive and procedural fidelity while maintaining scalability for group instruction (Refer to Figures 1, 2, 3). To ensure consistency, all specifications, task selections, and training conditions were standardized across participants. The VR training was offered at no additional per-hour cost beyond standard tuition fees, and instructional support was provided by trained staff within the simulation laboratory. Attendance was emphasized as a key component of program success, and continued access to supplemental training opportunities was contingent upon consistent participation and engagement.

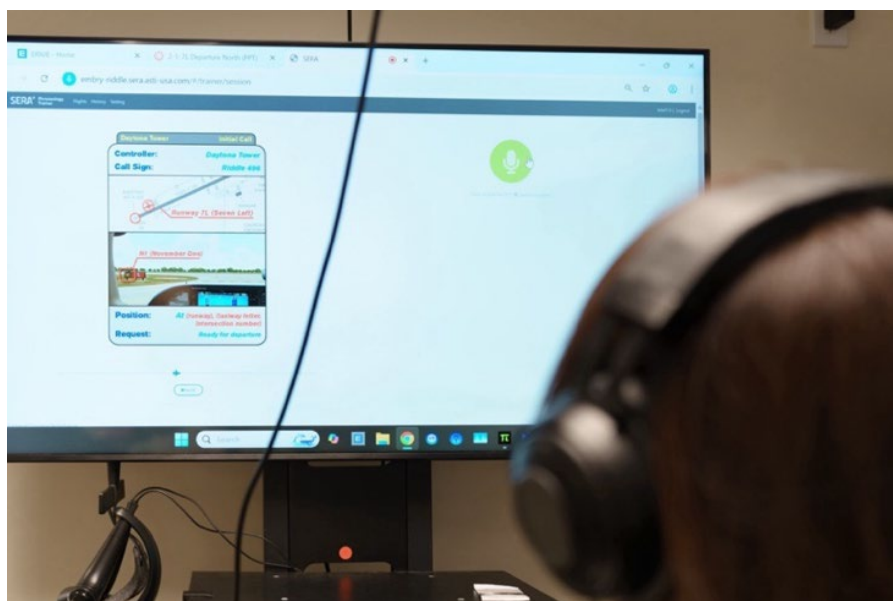
The VR flight simulation system was calibrated to replicate the specific aircraft model used later in the flight training program. This configuration featured realistic operational scenarios incorporating dynamic weather conditions and airport environments to enhance environmental realism and situational awareness. The system accommodated users with or without corrective eyewear and featured aircraft-representative controls, including throttle, mixture, and flap settings, with optional interaction through a mouse-based interface.

Figure 1
Pre-Flight Immersion Laboratory Simulator Setup



VR-Based ATC Communications Training. The ATC communication component of the VR-based training was scenario-based and designed in collaboration with aviation English experts. The full communication sequence from taxi clearance through departure from controlled airspace was simulated in each training module. A noise-canceling headset and integrated microphone captured student responses, which were automatically evaluated for alignment with standard ATC phraseology (Refer to Figure 2). This repeated exposure to realistic communication tasks aimed to improve student confidence and proficiency prior to initial flight operations.

Figure 2
ATC Communications Scenario within VR-Based Training Module



VR-Based Preflight Inspection Training. The preflight laboratory module utilized VR headsets and handheld controllers to simulate the preflight inspection process. One controller displayed and navigated the procedural checklist, while the other enabled physical interaction with aircraft components in the virtual environment (Refer to Figure 3). Procedures were modeled after industry-standard preflight protocols, and contextual hints were available to support independent student learning. This module enabled students to develop familiarity with inspection procedures in a controlled, risk-free environment that supported experiential learning and procedural accuracy.

Figure 3

Preflight Inspection Scenario within VR-Based Training Module



Review of Relevant Literature

The rapid advancement of VR technology has enabled new possibilities across industries, particularly in education and training. By enabling immersive, interactive experiences in controlled environments, VR technology is a powerful tool for enhancing learning, simulating complex scenarios, and delivering more personalized hands-on practice (Crogman et al., 2025; Dodevska et al., 2025). This literature review examines the practical applications and educational benefits of VR technology, with a focus on its growing role in the industry and flight training programs.

Applications of VR Technology

Research consistently highlights VR's positive effects on learning retention, student engagement, and accessibility, particularly in complex fields such as medical training, technical education, and psychological therapy (Elendu et al., 2024; Ifanova et al., 2023). For example, VR has been used to simulate real-world scenarios for medical procedures, military exercises, and complex assembly tasks, allowing learners to gain hands-on experience without the risks or costs of physical equipment (Ifanova et al., 2023). These simulations help bridge the gap between theoretical knowledge and practical application. VR also plays a critical role in expanding access to high-cost tools and technologies by providing realistic virtual alternatives, making advanced training more widely available (Elendu et al., 2024).

VR's ability to simulate complex, hard-to-access environments offers significant advantages for students by enabling practical, risk-free learning experiences and helping to overcome logistical barriers to traditional instruction (Virtual Reality Society, n.d.; Shin, 2002; Suria et al., 2023). For instance, desktop-based VR platforms have been used effectively in web-based science education, allowing students to explore geophysical and astronomical concepts through interactive, self-paced modules (Shin, 2002). Beyond education, VR has also shown promise in therapeutic settings, such as exposure therapy for anxiety and phobias, demonstrating its versatility as both a learning tool and a means of supporting mental well-being (Suria et al., 2023).

These applications highlight VR's potential to enhance conceptual understanding and student engagement through exploratory, hands-on learning. Collectively, these studies highlight VR as a tool for bridging cognitive, affective, and psychomotor learning domains. Across disciplines, VR-based learning may better promote engagement and retention by enabling learners to interact with content dynamically, which supports deeper conceptual understanding. These outcomes suggest that the instructional design of VR experiences, rather than the technology alone, may be the primary determinant of learning effectiveness (Makransky et al., 2019; Radianti et al., 2020). However, despite these benefits, widespread adoption still faces challenges, including high hardware costs, the need for faculty training, and difficulties integrating VR into existing curricula (Ifanova et al., 2023). As technology becomes more accessible and affordable, broader adoption in educational settings is likely to increase.

Educational Benefits and Theory of VR-Based Immersion Training

The educational benefits of VR-based training stem from its ability to replicate scenarios that are otherwise inaccessible due to logistical, safety, or financial constraints. VR technology enables opportunities to interact with simulated environments, such as distant geographies, historical events, or scientific phenomena, in ways that enrich traditional educational methods (Marougkas et al., 2023). Students can engage directly with content in a hands-on manner, which is particularly beneficial for visual and kinesthetic learners (Luberger, 2025). Additionally, VR's capability to transform abstract data into interactive, three-dimensional formats enhances student comprehension of complex systems, such as planetary motion or molecular structures (Virtual Reality Society, n.d.).

The theoretical foundation supporting VR-based training can be drawn from *Experiential Learning Theory* (Kolb, 1984) and *Constructivist Learning Theory* (Piaget, 1980). Both frameworks emphasize the role of active participation and reflection in constructing knowledge. Virtual reality environments embody these principles by immersing learners in interactive contexts where they can observe, perform, and refine tasks in real time (Lehrman, 2025). Through feedback loops and repetitive exposure, VR enables deeper cognitive processing and promotes skill mastery, making it particularly suited for the complex, procedural nature of flight training (Thomas et al., 2023).

Another emerging area of interest involves VR's influence on long-term knowledge retention, particularly within accelerated training environments. Makransky et al. (2019) found that immersive simulations enhanced memory retention by promoting cognitive engagement and contextual encoding. Similarly, Dela Peña (2025) observed that VR-based repetition in aviation maintenance training led to stronger recall and skill transfer after delays compared to traditional methods. In time-compressed flight programs, this suggests that VR may help mitigate knowledge decay by reinforcing procedural memory through interactive, scenario-based repetition.

VR Applications in Flight Training

In the aviation field, the potential of VR to supplement and enhance flight training has gained significant attention. Given the complexity, cost, and safety considerations of flight instruction, VR and extended reality offer an efficient alternative or supplement to traditional training environments (Marron et al., 2024; Somerville et al., 2025). By simulating realistic flight conditions, flight deck layouts, and emergency procedures, VR allows student pilots to develop technical and decision-making skills in a controlled, low-risk setting (Guthridge & Clinton-Lisell, 2023).

Applications in Primary (Ab-Initio) Flight Training

While much of the current literature focuses on commercial and airline training environments, comparatively few studies examine VR use in ab-initio or private pilot instruction. Lawrynczyk (2018) demonstrated that VR-based procedural training reduced time-to-proficiency during pre-solo phases, while Lewis and Livingston (2018) reported improvements in students'

confidence and systems knowledge but minimal change in overall flight hours. These findings suggest that the advantages of VR-based learning may be most evident in cognitive and procedural learning rather than direct reductions in training time. More targeted research is needed to determine how VR integration at the primary level influences measurable outcomes such as solo readiness and checkride pass rates.

Integration in Commercial and Airline Training

Recent airline industry adoption of VR-integrated training supports this shift. Alaska Airlines, for instance, implemented VR-based training modules in initial Boeing 737 ground training, replacing static diagrams with interactive, immersive instruction (Goodwillie, 2022). Such initiatives enhance pilot confidence and familiarity with aircraft systems before entering the cockpit (Thomas et al., 2023). VR's effectiveness extends beyond airline training to maintenance education, aircraft design, and procedural standardization across aviation roles (Fussell & Truong, 2020; Jensen & Konradsen, 2018).

Comparing Low-Fidelity VR and Certified Simulators

Studies comparing low-fidelity, non-certified VR systems with certified flight training devices (FTDs) provide valuable insight into the appropriate application of each technology. Jensen and Konradsen (2018) noted that while non-certified VR tools enhance procedural familiarity and situational awareness, they lack the motion and instrument realism critical for high-fidelity simulation. Fussell and Truong (2020) emphasized that VR functions best as a complementary tool, allowing students to rehearse tasks before engaging in FTD sessions. These findings underscore that VR should augment rather than replace certified simulators, reinforcing skill transfer through repeated exposure and contextual practice.

Advantages of VR-Based Immersive Learning in Flight Training

VR-based training offers key advantages in aviation education by providing instant feedback and personalized learning paths, allowing students to quickly correct errors and better understand aircraft systems and cockpit operations (Fussell & Truong, 2020). This real-time feedback loop is essential for mastering the complexities of flight, as it enables learners to refine skills through repetition and gain insight into the consequences of their actions. Multiple studies support the effectiveness of VR in teaching complex aviation tasks. Fussell and Truong (2020) emphasized how VR improves comprehension of aircraft systems and cockpit procedures. Jensen and Konradsen (2018) found that immersive VR environments enhance learning by fostering spatial awareness and procedural memory, both critical for pilot performance. Similarly, Marron et al. (2024) found that VR-based flight training strengthens cognitive and psychomotor skills, leading to improved situational awareness and responsiveness under pressure. These studies suggest that VR-based immersive learning can bridge theoretical knowledge and practical application, creating a more holistic and effective training environment that better mirrors real-world flight dynamics.

Summary

VR technology presents a transformative opportunity for both education and aviation training by offering immersive, adaptable, and scalable environments for skill development. In educational contexts, VR enhances access to complex systems, accommodates diverse learning styles, and fosters engagement with abstract concepts. In aviation, VR serves as a valuable supplement to traditional pilot training, allowing students to safely practice high-risk scenarios, reduce training costs, and build proficiency through repeated exposure and immediate feedback.

Growing interest and early success stories suggest a shifting trend toward greater adoption of VR technology. Continued research and testing are essential for evaluating the long-term impacts of VR-integrated flight training and supporting its broader integration into existing regulatory frameworks, such as FAA-approved curricula for primary flight instruction. As educational institutions and aviation programs seek innovative, cost-effective strategies to improve training outcomes, VR emerges as a potential solution. Realizing its full potential, however, will require sustained research, infrastructure investment, and institutional willingness to adapt. With appropriate implementation, the literature suggests that VR can significantly enhance the quality and efficiency of pilot training, ultimately contributing to safer and more effective aviation practice.

Despite the demonstrated benefits of VR in education and professional training, its integration into civilian flight training programs remains limited. Studies by Lawrynczyk (2018) and Lewis and Livingston (2018) reveal a persistent gap between VR's potential and its practical implementation within the aviation training sector. Key obstacles include organizational resistance to pedagogical change, substantial initial investment costs, and the absence of standardized VR instructional frameworks aligned with regulatory requirements (Akinradewo et al., 2025). While previous research consistently supports VR's effectiveness in enhancing engagement, procedural understanding, and cognitive skill development, empirical evidence on its long-term impact within structured flight training environments remains insufficient. Specifically, few studies have examined quantifiable outcomes such as training efficiency, student performance, and certification success rates. Synthesizing findings across disciplines and training application indicate consensus on VR's capacity to enrich learning experiences, yet uncertainty persists regarding its measurable effects on pilot proficiency and regulatory compliance. This inconsistency may stem from methodological variability, differences in simulator fidelity, learner populations, and assessment criteria, which underscores the need for systematic, data-driven research comparing VR-enhanced and conventional pilot training within standardized curriculums.

This study aimed to address this research gap by testing the following hypotheses:

H₀₁: There is no significant difference in oral hours between pilots trained with traditional training methods and those trained with VR training method.

H₀₂: There is no significant difference in simulation hours between pilots trained with traditional training methods and those trained with VR training method.

H₀₃: There is no significant difference in flight hours between pilots trained with traditional training methods and those trained with VR training method.

H₀4: There is no significant association between the type of training and the oral check-ride pass rates.

H₀5: There is no significant association between the type of training and the flight check-ride pass rates.

H₀6: There is no significant association between the type of training and the total check-ride pass rates.

Methodology

This study utilized a quasi-experimental design to compare pilot training outcomes between two independent groups: one group trained using a VR-enhanced curriculum and the other using traditional training methods. Existing data from an internal learning management system that tracked detailed metrics on oral instruction, simulator usage, flight hours, and check-ride performance were analyzed. Independent-samples *t*-tests were conducted to compare average training hours between the two groups, while chi-square tests were used to assess the relationship between training type and check-ride pass rates. All statistical analyses were performed using IBM Statistical Package for Social Sciences (SPSS) software to evaluate the impact of VR integration on training efficiency and student pilot performance.

Participants

The study population consisted of students enrolled in a large, university-based, FAA Part 141 flight training program who completed the Private Pilot course and obtained the rating. The sample included 159 students who received training through traditional flight instruction methods between late 2020 and mid-2021, and 421 students who participated in the VR-integrated flight training program implemented through the PILOT initiative from mid-2021 to mid-2024, as previously described in the introduction.

For the traditional training cohort (trained between late 2020 and mid 2021), data were collected from students who completed the private pilot course under a previous iteration of the flight school's FAA-approved Training Course Outline (TCO) that did not include VR-integrated components. The VR-integrated training cohort (trained between mid-2021 and mid-2024) comprised students who completed the course under the FAA-approved VR-integrated TCO implemented in mid-2021 up to when this research was conducted in mid-2024. The only modification between the two TCO curricula involved a reordering of modules to incorporate VR-integrated training activities. All other elements, including total course hours, instructional content, aircraft types, instructor assignments, admission standards, and assessment procedures, remained consistent across both cohorts.

Data Collection

Data for this study were obtained from an internal flight department student learning and training management system, which provided comprehensive and reliable records on key metrics such as total flight hours and checkride outcomes for students enrolled in the Private Pilot course. The collected dataset was anonymized to ensure participant confidentiality and was accessed with departmental approval, ensuring its ethical use and relevance to the study. To

ensure consistency, only students who completed the full course under a single training method were included in the analysis.

Instrument Reliability/Validity

Both instrument reliability and validity were ensured throughout the study through the use of the internal flight department student learning and training management system that systematically tracked key flight training metrics. Reliability was maintained through precise recording of Hobbs time, automatically calculated when simulation or aircraft devices are activated, and manually verified by dispatch staff during aircraft or simulator ramp-in and ramp-out procedures. Oral instruction time was logged based on mutual agreement between the instructor and student, with any discrepancies requiring documentation and approval from dispatch personnel or supervisory staff. Validity was supported by the system's detailed capture of training activities, including simulator and aircraft use as well as instructor-led instruction time, ensuring that the data accurately reflects intended constructs. Verification protocols, such as confirmation of oral contact time and reconciliation of Hobbs time discrepancies, further ensured data accuracy and integrity.

Treatment of the Data

Check-ride pass rates were coded for statistical purposes, with a pass coded as one and a failure as 0. Descriptive statistics were used to summarize the data, focusing on central tendency (mean, median, mode), variability (standard deviation, variance), and distribution (range, interquartile range, frequency distributions, and histograms). For hypothesis testing, the null hypothesis stated that no significant difference existed in training outcomes between the VR-integrated PILOT program and traditional flight training methods. Independent-samples *t*-tests were conducted to compare mean training hours between groups, while chi-square tests were used to examine the association between training type and checkride pass rates. Statistical significance was assessed at an alpha level of 0.05.

Results

This section presents the analysis comparing training outcomes between students trained using a traditional flight training program (Traditional Training Group) and those who trained through a VR-integrated flight training program (VR Training Group) to obtain a Private Pilot rating. The metrics compared were oral instruction time, simulator time, and total flight time, with independent *t*-tests used to assess differences between the groups. Chi-square tests were also conducted to examine the association between training methods and checkride pass rates. Box plots and histograms were used to visualize these findings for visual data interpretation.

Descriptive Statistics

To provide a comprehensive overview of the sample groups before hypothesis testing, the descriptive statistics for both the traditional training group and the VR training group were first analyzed. This section focused on key measures such as mean, standard deviation, and range for oral instruction time, simulator time, total flight time, and checkride pass rates.

In terms of oral instruction time, the traditional training group took an average of 47.42 hours with a standard deviation of 15.05, ranging from 30 to 70 hours to complete the Private Pilot course. In contrast, the VR training group demonstrated a higher mean of 74.48 hours and a larger standard deviation of 16.47, with values spanning from 55 to 100 hours to complete the Private Pilot course, indicating greater variability. For simulator time, the traditional group took an average of 16.83 hours and a standard deviation of 5.11, with a range between 10 and 25 hours. The results of the VR training group had a similar mean of 16.66 hours but with a smaller standard deviation of 3.34, reflecting a range from 12 to 22 hours and less variability compared to the traditional training group.

Total flight training time to complete the Private Pilot course exhibited notable differences between the two groups. The traditional training group had a mean of 115.98 hours with a higher standard deviation of 32.19, demonstrating significant variation among students, with flight hours ranging from 85 to 150. Meanwhile, the VR training group showed a lower mean of 99.60 hours and a standard deviation of 25.78, indicating a range of 75 to 130 hours and a relatively more consistent distribution.

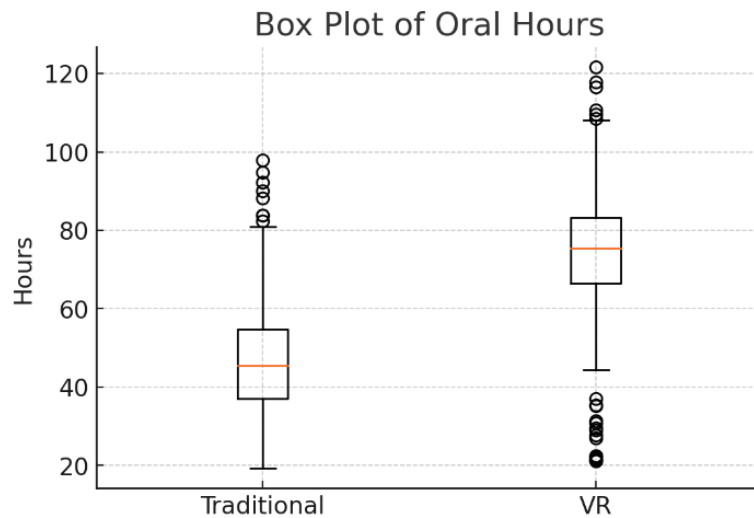
When examining checkride pass rates, the traditional training group had an oral pass rate of 80.51%, a flight pass rate of 65.41%, and a total pass rate of 53.46%. The VR training group presented a slight improvement in oral pass rates at 84.56%, while the flight pass rate was similar at 65.08%, and the total pass rate showed a marginal increase to 55.34%. These descriptive statistics highlight the initial differences and distributions in training and performance metrics between the two training methods.

Hypothesis Testing

Oral Instruction Time Comparison

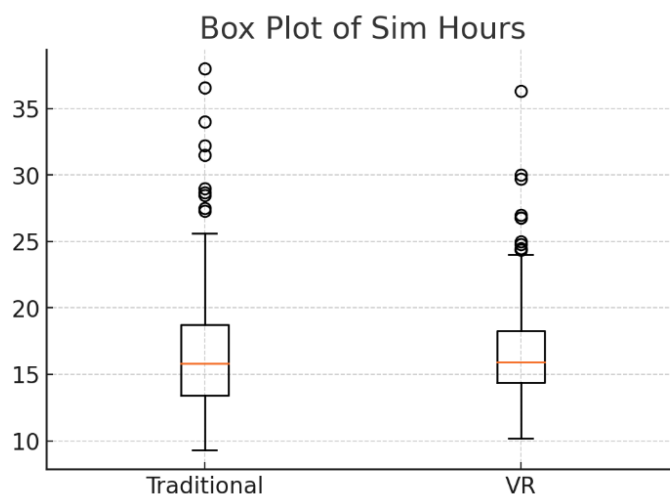
An analysis was conducted to compare the oral instruction time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test indicated unequal variances; therefore, an independent t-test was conducted without assuming equal variances. The VR training group required a significantly higher mean oral instruction time (Hours; $M = 74.48$, $SD = 16.47$) compared to the traditional training group (Hours; $M = 47.42$, $SD = 15.05$), with a t -statistic of -18.06 and a p -value of less than .0001. The null hypothesis was rejected, confirming a significant difference in oral instruction time between the two groups. A box plot (Figure 1) illustrated that the VR group consistently required higher and more variable oral hours.

Figure 1
Box Plot of Oral Instruction Time (Hours)

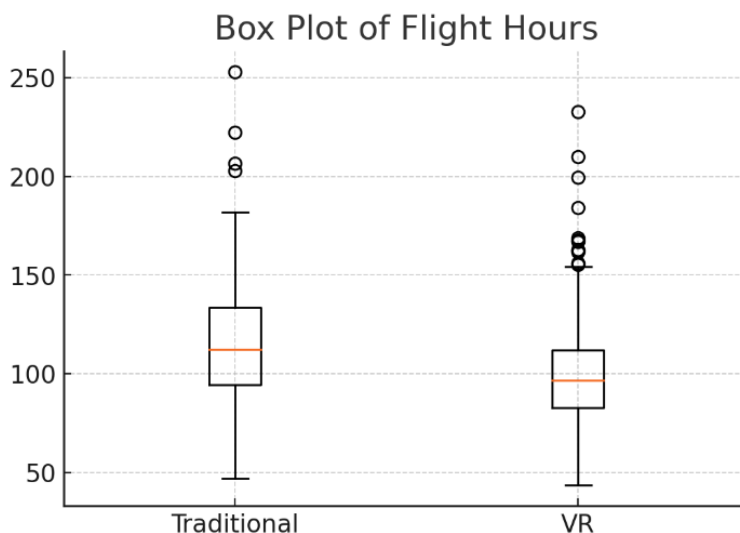


Simulator Time Comparison

An analysis was conducted to compare the simulator time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test confirmed equal variances; therefore, an independent t -test was performed assuming equal variances. The mean simulation hours for the traditional group (Hours; $M = 16.83$, $SD = 5.11$) and the VR Group (Hours; $M = 16.66$, $SD = 3.34$) were similar, with a t -statistic of 0.46 and a p -value of 0.64. Since the p -value was greater than 0.05, the null hypothesis was retained, indicating no significant difference in simulation hours between the two groups. A box plot (Figure 2) confirmed these similar distributions.

Figure 2*Box Plot of Simulator Time (Hours)***Total Flight Training Time Comparison**

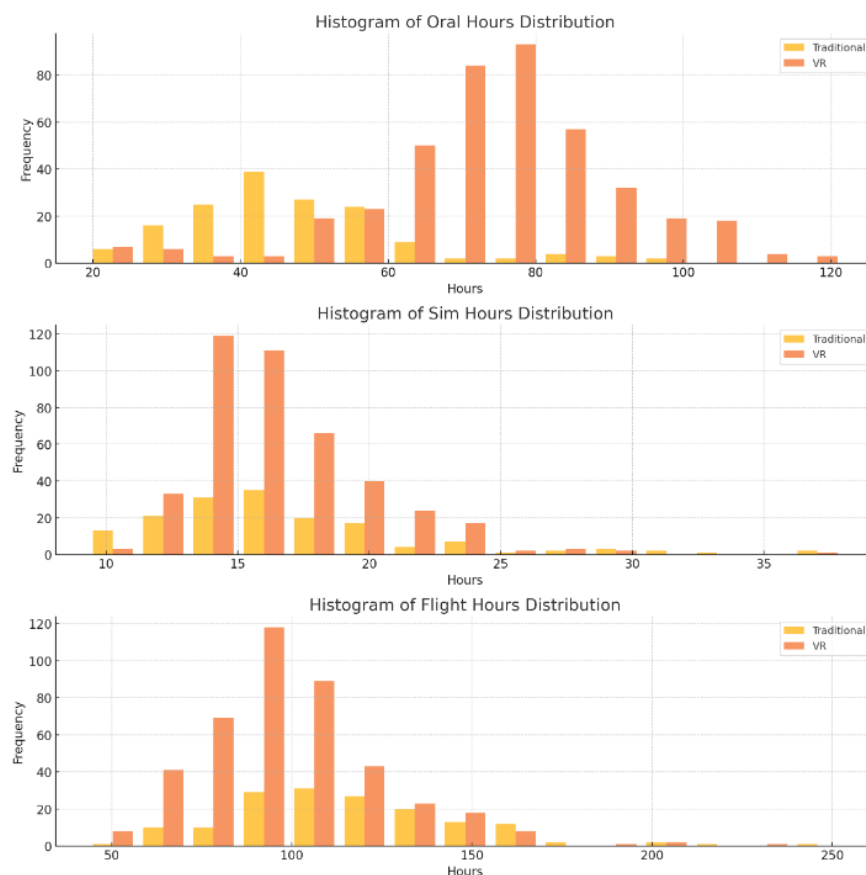
An analysis was conducted to compare the total flight time required to complete the Private Pilot course between the traditional training group and the VR training group. Levene's test indicated unequal variances; therefore, an independent *t*-test was performed without assuming equal variances. The traditional training group had significantly higher mean total flight hours (Hours; $M = 115.98$, $SD = 32.19$) compared to the VR training group (Hours; $M = 99.60$, $SD = 25.78$), with a *t*-statistic of 6.35 and a *p*-value of 4.24e-10. The null hypothesis was rejected, indicating a significant difference in flight hours between the two groups. A box plot (Figure 3) further illustrates that the traditional training group consistently required higher total flight hours to complete the Private Pilot course.

Figure 3*Box Plot of Total Flight Time (Hours)*

Overall Training Comparison

Figure 4 presents histograms illustrating the frequency distributions of oral instruction time, simulator time, and total flight time required to complete the Private Pilot course for both the traditional and VR training groups. These visualizations clearly highlight key differences between the groups. The VR training Group required significantly higher oral instruction time, a comparable simulator, and notably lower total flight time to complete the course than the traditional training group. This comparison highlights the shift in training emphasis and performance introduced by the VR-integrated curriculum.

Figure 4
Histogram of Oral Instruction/Simulator/Total Flight Time (Hours) Distribution



Relationships Between the Type of Training and Checkride Pass Rates

The relationship between checkride pass rates and the type of training (traditional training group compared to VR training group) was analyzed using the Chi-square test for independence.

Relationship Between the Type of Training and Checkride Oral Pass Rates

A chi-square test was conducted to assess the relationship between training type (Traditional vs. VR) and oral pass rates. The pass rate for the traditional training group was 80.51%, and for the VR training group, it was 84.56%. The chi-square value was 1.391, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated that there was no significant association between training type and oral pass rates, suggesting that the type of training did not significantly affect students' checkride oral pass rates.

Relationship Between the Type of Training and Checkride Flight Pass Rates

A chi-square test was conducted to assess the association between training type (Traditional vs. VR) and flight pass rates. The pass rate for the traditional training group was 65.41%, and for the VR training group, it was 65.08%. The chi-square value was 0.003, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated no significant association between training type and flight pass rates, suggesting that the type of training did not significantly affect students' checkride flight pass rates.

Relationship Between the Type of Training and the Overall Checkride Pass Rates

A chi-square test was conducted to assess the association between training type (Traditional vs. VR) and overall checkride pass rates. The checkride pass rate for the traditional training group was 53.46%, and for the VR group, it was 55.34%. The chi-square value was 0.168, with a p -value greater than 0.05, meaning the null hypothesis was retained. This result indicated no significant association between training type and overall flight pass rates, suggesting that the type of training did not significantly impact students' overall checkride pass rates.

Summary

Overall, measurable differences were identified between the VR-integrated and traditional training groups across multiple performance indicators. Students trained using the VR-integrated curriculum required fewer average flight and simulator hours to complete their course requirements compared to those in the traditional group. Differences in oral instruction hours were less pronounced, indicating that theoretical and ground instruction time remained relatively consistent across cohorts. In terms of performance outcomes, the VR group demonstrated slightly higher oral and flight checkride pass rates, suggesting potential benefits in knowledge retention and procedural proficiency. While these results indicate that VR integration may enhance training efficiency and performance, further analysis in the discussion section explores possible confounding variables and contextual factors influencing these differences.

Discussion

The findings of this study highlight both the practical benefits and implementation challenges associated with VR in flight training. The results suggest positive and promising student flight training outcomes in utilizing VR-integrated curriculums, particularly in reducing

the number of required total flight time while maintaining checkride pass rates comparable to those of traditional training methods. These findings align with previous research indicating that VR can effectively supplement traditional educational methods by reinforcing practice of procedural knowledge and enhancing situational awareness (Tene et al., 2024; Zhan et al., 2024).

However, an increase in oral instruction time was observed in the VR training group, likely stemming from the PILOT program curriculum structure, which front-loads theoretical content. In contrast, traditional flight training programs often distribute oral instruction more evenly throughout the course. To mitigate this content delivery imbalance of the VR-integrated flight training course, CFIs could assign supplemental materials during canceled or rescheduled flight activities and integrate review exercises into pre-flight preparation briefings to support ongoing student knowledge reinforcement and reduce content redundancy.

The intensive structure of the VR training model features compressed ground school phases and extended simulation blocks. While such condensed formats may lead to short-term gains in skill acquisition and reduced flight course completion times, they may potentially hinder long-term student skill/knowledge retention. This concern aligns with prior research indicating that densely packed instructional timelines in aviation training may hinder knowledge retention and contradict established best practices in educational design. (Ambrose et al., 2010; Dinçer, 2023; Pashler et al., 2007). A more effective approach may involve gradually introducing complex elements such as ATC communication and preflight procedures throughout the flight training course instead of front-loading it through VR-integrated training. Integrating and combining additional essential flight procedures into VR practice modules could also help reduce the total simulator hours required by minimizing content repetition.

Limitations of the Study

While the findings indicate meaningful advantages of VR-integrated flight training, some limitations should be considered when interpreting the results. Because this study used archival data from the university's flight department management system, control over contextual variables such as instructor differences, aircraft availability, and weather-related delays was limited. Instructor experience, teaching style, or scheduling flexibility may have influenced the pace and quality of instruction. Likewise, fluctuations in aircraft maintenance or scheduling could have affected student progression, introducing variability beyond the instructional method itself.

As a quasi-experimental design, group assignment was not randomized, which increases the potential for confounding factors. Although both cohorts followed the same FAA Part 141 curriculum, differences in cohort size, instructional context, and institutional procedures may have influenced outcomes. The VR-integrated group, trained between mid-2021 and mid-2024, may have also benefited from newer instructional resources with regard to VR training.

Directions for Future Study

Although the reduced total flight hours required to complete the flight course for the VR training group suggest improved training efficiency, substantial opportunities remain to optimize

the VR-integrated flight curriculum in future studies. For example, targeted feedback from students and CFIs could be collected to identify current inefficiencies in curriculum design and content delivery. This iterative approach to curriculum improvement, based on user experience, can enhance learner engagement and improve training outcomes. Qualitative studies incorporating student and CFI perspectives could provide a deeper understanding of the perceived value, technology acceptance, limitations, and usability of VR-integrated training, guiding future curriculum design and further integration of technology into aviation education.

Future research should explore the long-term impacts of VR-integrated flight training on student/pilot performance, operational decision-making, and career progression. A longitudinal study comparing graduates of traditional and VR-integrated flight training programs could provide valuable insights into the real-world preparedness and safety performance of pilots from each training method. Additionally, replicating this study across a broader range of flight schools (i.e., comparing multiple Part-141 collegiate flight training programs) and training environments (i.e., Part 141 vs. Part 61 flight training institutions) would improve the generalizability of the findings.

Conclusion

This study demonstrated the potential of VR to enhance the efficiency and effectiveness of flight training by reducing the total flight time required to complete a flight rating/course while maintaining essential pilot competencies. The immersive, hands-on nature of VR simulation offers a complement to traditional training approaches, particularly when thoughtfully integrated into the curriculum. While VR-integrated training can introduce new challenges, such as increased oral instruction time, these can be addressed through strategic curriculum design and ongoing instructional refinement. As flight training continues to evolve, it is crucial to adapt innovative teaching methods that leverage the strengths of emerging technologies while maintaining a focus on both theoretical understanding and practical skill development. Although this study was conducted within a single institutional context, the findings highlight the broader value of continuous assessment and curriculum innovation. Future research should explore the long-term performance of VR-trained pilots and examine the effectiveness of such programs across different training environments beyond aviation.

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Development and Validation of a Vertiport Usability Scale

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Introduction: Urban Air Mobility (UAM), a distinct subset of Advanced Air Mobility (AAM) research, has begun reaching a critical phase in its establishment, particularly with the development and implementation of vertiports. Few studies have assessed consumer perception of vertiports. One particular study focuses on the ideal usage and applicability of vertiports for medical emergencies; however, this current study aims to broaden that perspective by producing a valid scale that other researchers can use. **Method:** The Vertiport Usability Scale was developed using a multi-stage approach with 1,243 participants. A consensus methodology was employed, whereby participants generated relevant descriptive items, determined which items were most relevant, and provided construct validity to the final scale. **Results:** The final scale resulted in a single-factor model comprising seven items (convenient, efficient, functional, good location, high quality, usable, and useful). Factor analysis was used to ensure validity, while Cronbach's Alpha and Guttman's split-half tests provided evidence of high consistency and reliability. **Conclusion:** This scale offers a common language for consumers, designers, engineers, and human factors experts to design future vertiports in line with consumer opinions and needs.

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Introduction

The National Aeronautics and Space Administration (NASA) conceptualizes Urban Air Mobility (UAM) as a safe and efficient method of air operations for both crewed and uncrewed aircraft systems, often in metropolitan areas (Thippavong et al., 2018). There is currently no valid method for quantitatively assessing vertiport usability. The purpose of this study was to develop a valid and reliable scale for assessing the usability of both current and proposed vertiports. Developing a usability scale with consumer needs in mind is crucial for implementing future vertiports and ensuring seamless integration of general aviation, ultimately improving the user experience for the general consumer. To provide a systematic and uniform implementation of vertiports globally, aviation governing bodies across different countries need to attain harmony while implementing rules and regulations for the establishment of these vertiports. The purpose of this study was to develop a valid and reliable scale for assessing the usability of proposed experimental vertiports.

Literature Review

As metropolitan cities such as New York, Los Angeles, and Miami become more densely populated, innovative solutions to alleviate traffic congestion and improve mobility efficiency have catalyzed UAM development efforts. Active efforts are constantly being made to bring the UAM industry to fruition, with a heavy focus on the domestic and international governing bodies, like the Federal Aviation Administration (FAA), European Union Aviation Safety Agency (EASA), and the Directorate General of Civil Aviation (DGCA), and their policies and regulations. UAM now expands beyond its conceptual phases as a subset of aviation, where it was assumed that AAM is a subset of UAM, which is, in fact, the other way around. UAM is widely recognized as a subset of AAM, and its development follows similar foundational principles. The International Air Transport Association (IATA) mentioned in its January 2020 report that it expects a 4.1% growth in revenue passenger kilometers (RPKs) and a 2.0% increase in the freight ton-kilometers (FTKs). However, after the global COVID-19 outbreak, IATA made several revisions to the original report, indicating a steep decline in the aviation industry growth projections (IATA, 2020). Covering a span of five years, IATA noted in its January 2025 report that the RPK rose by 10.0% year-on-year (YoY), which is significantly higher than in previous months (IATA, 2025).

Considering the already successful and promising tests various UAM-oriented companies have conducted, the possibility of UAM establishment seems to be moving from concept to deployment. Companies like Archer Aviation have already established collaborations in Abu Dhabi to launch their first commercial electric air taxi flights (Archer Aviation, 2024). At the same time, Eve Air Mobility, a subsidiary of Embraer, has also revealed its full-scale plan for an eVTOL prototype to improve commuting times for the general public while also reducing the average amount of carbon emissions while operating a motor vehicle (Eve Air Mobility, 2024). Companies like commercial aircraft manufacturer Airbus have also been researching UAM prospects, where Airbus recently announced its *CityAirbus* prototype that aims to reduce the traffic and carbon emissions issues in major metropolitan cities (Airbus CityAirbus, 2024). With advanced technological capabilities and competition pressure, it seems it is only a matter of time before these services become standard. Beyond the United States of America, companies are also

heavily focusing on establishing UAM technologies worldwide while also attempting to standardize their methodology and operations.

Numerous research efforts have explored consumer perceptions of UAM and consumer perceptions of highly automated aircraft (Hughes et al., 2009; Marte et al., 2018; Ragbir et al., 2020; Rice et al., 2014; Rice et al., 2016; Rice et al., 2019; Shaheen et al., 2018). According to researchers, after analyzing the user and non-user perspectives on UAM, it has been widely understood that the biggest concerns for consumers would be safety, passenger screening, the preference for a piloted aircraft, as well as cybersecurity (Al Haddad et al., 2020). Another objective for exploring the vertiport usability scale is the acceptance of driverless vehicles among consumers. Anania et al. (2018) examine the variability of automation acceptance between people based on gender and nationality. The concept similarly expands to the development and usage of vertiports to supplement automation within the aviation industry, particularly in UAM. Asgari and Jin (2019) utilize trend analysis and mathematical models that have been constructed from previous real-world introductions and integrations of technologies into human lives around the world. However, to understand the progression of UAM, it is imperative to understand how consumers perceive usability after the successful implementation of UAM in subsequent years.

Another study by Ragbir et al. (2018) aimed to find how different variables like nationality, weather conditions, and distance affect the level of consumer willingness to fly in autonomous aircraft. The findings suggest that different consumer groups may need to be targeted differently when being introduced to different automation technologies. Based on these relevant findings, a usability scale is being developed to assess vertiport usability as a supplementary step in the implementation of the overall UAM ecosystem. Findings indicate that there is often apprehension toward boarding autonomous flights in inclement weather, with Americans exhibiting highly negative attitudes towards these technologies unless weather conditions are perfect (Ragbir et al., 2018). In addition to cultural differences, gender differences are also present when accepting UAM. Women are less willing to fly in autonomously piloted aircraft, with fear being the most significant mediator (Rice & Winter, 2019).

A more recent study concluded that implementing consumer-friendly designs and features in a vertiport is essential, as it directly impacts the willingness to pay (WTP) for services among consumers (Ison, 2025). The study also emphasizes the need for integrating UAM technologies with public transportation systems and advanced security technologies and strategies to keep the UAM system sustainable while maintaining profitability. This establishes a strong premise to conduct our study to assess usability as well. A study by Zhao et al. (2025) found participants strongly preferred small and nearby vertiports. Value was also added if multi-model options were available with connections to public transport.

Justification for a Vertiport Usability Scale

AAM and UAM are realistic for widespread use because of their vertical takeoff and landing (VTOL) capabilities, which allow these aircraft to operate without a runway. In the context of emergencies where ground access is not feasible, VTOL capabilities would prove beneficial in reaching persons who would otherwise be inaccessible with conventional aircraft.

For this reason, vertiports are one of many necessary considerations in the design and implementation of UAM. The FAA has previously established vertiport location and design criteria, considering the development form or the necessary alterations to the surrounding landscape, weather conditions, economy, and accessibility. Due to apparent similarities, pre-existing helicopter landing pads have served as a basis for the design of vertiports (NiklaB et al., 2020). However, most helipads do not provide the capacities necessary for the widespread implementation of UAM because they lack the infrastructure consumers require (e.g., waiting areas, food and drink, customer service, etc.).

The ICAO-published heliport manual requires that heliport locations allow for land transport accessibility and parking options and consider noise-sensitive sites (i.e., noise pollution). Several studies have investigated vertiports in urban areas. However, their usability in various locations has not been thoroughly explored. To determine vertiport usability, it is desirable to create a valid quantitative scale that can accurately assess the various components of vertiports and provide consumers, designers, and engineers with a common language to judge multiple potential vertiports.

Usability

Usability can be described as the quality of a user's experience when using a product. Bevan et al. (1991) define usability as "the ease of use and acceptability of a product for a particular class of users carrying out specific tasks in a specific environment." (p. 24). One of the most widely used scales is the System Usability Scale (SUS), which is represented in approximately 43% of industrial usability studies (Lewis, 2018; Sauro & Lewis, 2009). The SUS contains ten questions that range from frequency of use to complexity to learning associated with use. Bangor et al. (2008) describe the SUS as very flexible and unaffected by minor word changes. However, one of the limitations of the SUS is that it does not provide a practical way for users to assess a product that does not exist yet. Another limitation is that it is not explicitly tailored to vertiports. Therefore, although the items from the SUS will be used in the item generation phase of the current study, creating a new scale specific to vertiport usability is warranted for the present study.

Previous Studies

A previous study conducted by Winter et al. (2020) explores the concept of air taxis and develops a statistical model to identify factors related to consumers' willingness to fly. It assessed 16 different predictors to assess a consumer's willingness to fly in an automated aircraft. The research also concludes that increasing awareness of the existence of the concepts of UAM, as well as their implementation in the future, will increase willingness for consumers to adopt new technology. A second study by Rice et al. (2022) explored vertiport and air taxi features valued by consumers in the United States and India. The primary concerns of users were safety and security. The top five features of a vertiport in the United States were emergency exits, restrooms, security cameras, security personnel, and an emergency phone. Consumers from India had similar concerns among their top five vertiport items: emergency services, emergency exits, healthy food, emergency alarms, and first aid kits. This research suggests that consumers

are concerned with safety (emergency exits, cameras, and first aid kits), security (guards and alarms), and convenience (restrooms and food). The findings from Rice et al. (2022) were also used in the item generation stage of the current study.

Adding on to the scope of this research, the factors that also impact people's willingness to fly on a fully autonomous commercial airliner were perception of complexity of aircraft automation, a consumer's familiarity with it, the influence of the fun factor associated with autonomous flying, and even the age and gender of participants (Rice et al., 2019). This study helps showcase perceptions toward adopting autonomous aircraft and the logistics behind making it a reality. Winter et al. (2021) developed a vertiport location scale that focused primarily on determining the ideal location for vertiports during natural disasters or emergencies. This scale can be helpful when deciding where to place a temporary vertiport to deliver food, medicine, news, and other emergency supplies; however, it does not reflect consumer opinions about the usability of the vertiport itself. The current study fills this gap.

The Value of a Validated Instrument

The validity of an instrument is paramount to ensure researchers are conducting appropriate and meaningful research on human participants (Edmonds & Kennedy, 2017; Gawron, 2008). Validity ensures the researcher measures what they intend to measure. For example, if a teacher were attempting to measure their children's writing skills using a scale to measure reading comprehension, they would be using an invalid instrument. Using an invalid instrument increases the likelihood of a Type 1 error (Banerjee et al., 2009).

Using a consensus methodology (Hinkin, 1998) ensures construct validity, while factor analysis provides further validity evidence. In addition to validity, reliability is essential to a valid scale- in fact, it is impossible to have validity without reliability. Consistency is tested via Cronbach's Alpha, while reliability is tested using Guttman's split-half test.

Methodology

The current study developed and validated a scale that can assess public perceptions of the usability of a vertiport. The development of this scale followed a multi-stage consensus method described by Hinkin (1998) and supported by various publications that have successfully utilized this framework to develop valid and reliable scales (Rice et al., 2014; Rice et al., 2015; Rice et al., 2020). The process involves four stages: item generation, nominal paring, Likert-scale paring, and factor analysis and sensitivity testing, which are discussed in detail below.

Stage 1: Item Generation

The item generation stage involved asking participants to complete a short questionnaire listing five words or phrases that are relevant to vertiport usability. In addition to participant responses, researchers reviewed vertiport literature and included all relevant items. Additionally, three subject-matter experts in the field of uncrewed aerial vehicles (UAV) and UAM reviewed the current list to determine whether additional words or phrases should be added.

Participants

The first set of participants included one hundred and ninety-four adults (92 males; 102 females) who completed the questionnaire via a convenience sample using Amazon's *Mechanical Turk* (MTurk). The average age of participants was 38.78 ($SD = 11.52$) years old, with 81% reporting as Caucasian, 6% as African descent, 5% as Asian descent, 4% as Hispanic descent, and 4% as Other. Participants were limited to those residing in the United States, had completed at least 500 prior tasks on MTurk, and had approval ratings of 98% or higher.

Procedure, Materials, and Stimuli

Participants in the initial group of respondents were directed to Google Forms to complete the questionnaire. Before providing their list of five words or phrases, they were provided with a brief description of vertiports: *A vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft. The UAM aircraft can be either remotely operated or a fully automated aerial vehicle, such as an air taxi.* Participants then received the following instructions: *In the context of usability related to a vertiport, please enter 5 words or phrases that you feel are strongly relevant to the concept of vertiport USABILITY. In other words, what items or phrases would make the vertiport more user friendly? For example, a vertiport should be convenient, accessible, safe, etc. Each answer should include only a one word or one sentence phrase.*

Results

The first phase of scale development generated 131 words or phrases.

Stage 2: Nominal Paring

The second stage of scale development involved paring down the initial set of 131 words and phrases generated from stage 1. The purpose of this stage was to determine which words/phrases were the most relevant to assessing vertiport usability.

Participants

Two hundred and fourteen participants completed stage 2 of this study (138 males; 76 females). Participants were recruited via a convenience sampling method using MTurk. The average age of participants was 36.40 ($SD = 10.30$) years old, with 84% reporting as Caucasian, 3% as African descent, 9% as Asian descent, 3% as Hispanic descent, and 1% as Other.

Procedure, Materials, and Stimuli

Participants received the following instructions: *You will be presented with 131 terms and asked to rate how relevant or irrelevant those terms are to vertiport USABILITY (being user friendly). The data collection process is anonymous, and your responses will remain confidential.* They were also provided with the following contextual information on UAM: *A*

vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft. The UAM aircraft can be either remotely operated or a fully automated aerial vehicle, such as an air taxi. They were then presented with the 131 words/phrases generated in stage 1, coupled with the following instructions: *In the context of vertiports, please review each term or phrase below and determine whether it is relevant or not relevant to vertiport USABILITY (being user friendly).* Participants rated each word/phrase on a 3-point relevance scale, with relevant, not relevant, or don't know response options.

Results

A cutoff threshold was established *a priori* for a word/phrase to be kept for the next iteration of items; at least 60% of participants had to score the word as *relevant* to vertiport usability to be included in Stage 3. Utilizing this determination criterion, 44 words/phrases were maintained. The researchers added two additional terms based on their expertise: 'compatible with various UAM vehicles' and 'easy to use emergency features.'

Stage 3: Likert-scale Paring

The purpose of Stage 3 was to pare down the list of relevant items further. In this stage, participants were asked to determine how relevant each remaining item was to vertiport usability.

Participants

Three hundred and twenty-four participants completed stage 3 of the study (187 males; 136 females, 1 no response). Again, participants were recruited via a convenience sampling method using MTurk. The average age of participants was 37.85 ($SD = 16.06$) years old, with 74% reporting as Caucasian, 6% as African descent, 13% as Asian descent, 5% as Hispanic descent, and 2% as Other.

Procedure, Materials, and Stimuli

Participants received the same instructions as in Stage 2, except that the participants rated the 44 remaining items on a scale ranging from *Not at all related to vertiport usability (0)* to *Extremely related to vertiport usability (4)*.

Results

Similar to the previous stage, an *a priori* cutoff threshold was established for determining which words/phrases would be kept for the scale. An item was required to obtain a score of 3.0 or higher to be selected for inclusion in the final scale. Seven of the forty-four/phrases met this criterion. The seven items included in the final scale are: *convenient, efficient, functional, good location, high quality, usable, and useful*. These items were transformed into statements (See Appendix A for the final scale) and assessed through factor analysis, consistency and reliability tests, and sensitivity testing.

Stage 4: Factor Analysis and Sensitivity Testing

The purpose of Stage 4 was to assess the final vertiport usability scale for validity, consistency, and reliability. In addition, we wanted to ensure the scale could detect differences in consumer perceptions of usability between vertiports. This stage is often referred to as a sensitivity test of the scale.

Participants

Five hundred and eleven participants completed stage 4 of the study (280 males; 224 females; 7 no response). Participants were recruited via a convenience sampling method using MTurk. The average age of participants was 38.63 ($SD = 11.23$) years old, and 81% reported as Caucasian, 5% African descent, 9% Asian descent, 3% Hispanic descent, and 2% Other.

Procedure, Materials, and Stimuli

Participants received the following instructions: *You will be presented with some scenarios and asked about vertiport USABILITY (being user friendly). The data collection process is anonymous and your responses will remain confidential.* Participants also received brief information on UAM: *A vertiport is the proposed takeoff and landing site for urban air mobility (UAM) aircraft. The UAM aircraft can be either remotely operated or a fully automated aerial vehicle, such as an air taxi.*

Participants were then presented with two scenarios depicting different proposed vertiports. The first scenario presented the following: *Imagine that you live in a major city and want to use a UAM (urban air mobility), also known as an Air Taxi, for a 30-minute flight across the metropolitan area. To use the vertiport, it is an easy 5-minute walk to the location, where you enter the ground-level building. An indoor, air-conditioned waiting area has plenty of comfortable seating, is protected from weather conditions, has a nice choice of food and drinks, along with customer service and WiFi.* The second scenario read as follows: *Imagine that you live in a major city and want to use a UAM (urban air mobility), also known as an Air Taxi, for a 30-minute flight across the metropolitan area. To use the vertiport, you must drive 20 minutes by car to the skyscraper building, find parking, meet with the building security to enter, and travel up the elevator to the top floor. An outdoor waiting area is exposed to the weather conditions, and no customer service is available.* Participants were asked to respond to each of the seven established scale items (see Appendix A) on a scale of *strongly disagree* (-2) to *strongly agree* (2).

Results

Factor Analysis. To determine the factor structure of the proposed scale, a principal components factor analysis with varimax rotation was conducted on each of the vertiport scenarios. The scale had high Kaiser-Meyer-Olkin (KMO) values and significant p -values for Bartlett's sphericity test, supporting the factorizability of the data. Each scale loaded onto one factor and accounted for over 45% of the data's variance. All Cronbach's alpha values were well

above the minimum threshold of .7, indicating high internal consistency. Guttman's split-half tests also revealed values well above .7, further supporting the scale's reliability. The full results can be found in Table 1 and item loadings in Table 2. The scree plots can be found in Figures 1 and 2.

Table 1

Validity, Consistency, and Reliability Metrics for the Vertiport Usability Scale

	Scenario 1	Scenario 2
Variance Explained	45.03%	58.53%
Number of Factors (Validity)	1	1
Cronbach's Alpha (Consistency)	.796	.882
Guttman's Split-Half (Reliability)	.799	.843

Table 2

Individual Item Loadings

Items	Scenario 1	Scenario 2
Convenient	.620	.807
Efficient	.675	.788
Functional	.636	.676
Good Location	.697	.796
High Quality	.671	.751
Usable	.687	.749
Useful	.707	.780

Figure 1

Scree Plot of the Factor Analysis from Scenario 1

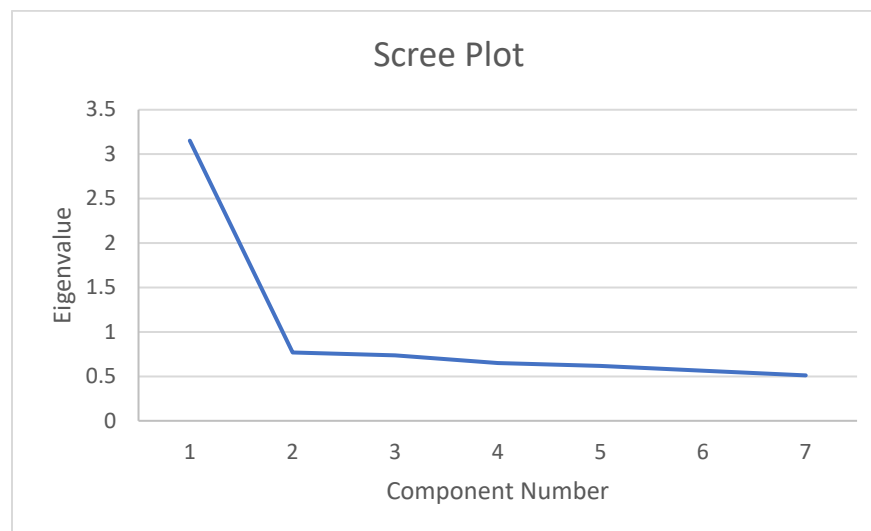
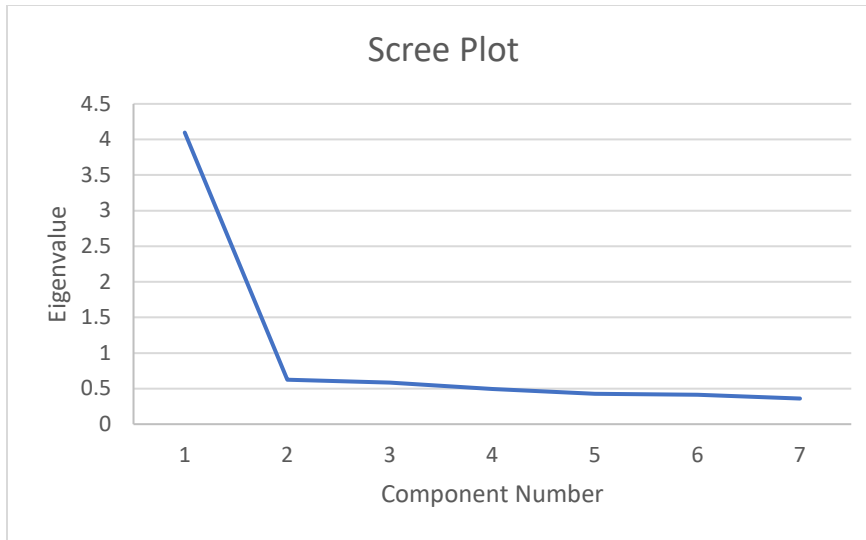


Figure 2*Scree Plot of the Factor Analysis from Scenario 2*

Sensitivity. To conduct the sensitivity analysis, the scores from each scale were averaged for the vertiport usability score. The scores of the two scenarios were then compared using a paired samples *t*-test, $t(510) = 9.157, p < .001, d = .41$. These results indicate that participants rated the first vertiport as having better usability compared to the second vertiport. More so, it provides evidence of the scale's sensitivity to differences in data.

Discussion

The primary objective of this study was to develop a psychometrically valid instrument capable of assessing vertiport usability, a critical component in the UAM infrastructure. The Vertiport Usability Scale was created through a rigorous multi-stage process. Initial stages focused on generating and refining a list of descriptive items that captured key usability dimensions. Subsequent stages employed factor analysis and sensitivity analysis to evaluate the scale's structure and performance. These statistical methods demonstrated the scale's validity and its ability to detect meaningful differences among vertiport designs. The final product was a concise, single-factor model consisting of seven items, offering both reliability and practical utility.

The final items included in the Vertiport Usability Scale, convenient, efficient, functional, good location, high quality, usable, and useful, reflect key dimensions of consumer expectations and operational practicality. *Convenient* suggests that users are considering potential barriers to accessing the vertiport, such as proximity to their departure or arrival points. A vertiport that is conveniently located may significantly influence perceptions of usability, especially for passengers seeking seamless integration with other modes of transportation. *Efficient* complements convenience by emphasizing the importance of minimizing delays and wait times. This item reflects a desire for a streamlined experience, akin to using a

taxi, subway, or metro system, where speed and ease of movement are paramount.

Functional indicates that users expect vertiports to be equipped with essential amenities that support comfort and utility. Features such as temperature-controlled restrooms, sheltered waiting areas, and clear signage contribute to a facility's perceived functionality. *Good location*, while closely related to convenience, carries additional weight when considering strategic placement, such as near international airports, business districts, or resort areas, where demand for UAM services may be highest. *High quality* conveys a preference for modern, well-constructed facilities over temporary or minimal structures, suggesting that aesthetics and durability influence user confidence. Finally, *usable* and *useful* capture the overarching expectation that vertiports should meet consumer needs without introducing unnecessary complexity. These items collectively underscore the importance of designing vertiports that are not only operationally sound but also aligned with user-centered principles.

A well-constructed scale is essential for advancing research in emerging fields like UAM. In this context, the Vertiport Usability Scale meets the dual criteria of psychometric robustness and operational efficiency. Drawing from best practices in scale development (e.g., Rice et al., 2020), the instrument includes multiple items that measure the same construct, thereby enhancing reliability. At the same time, its brevity ensures ease of administration, making it suitable for a variety of research designs and participant populations. The scale's demonstrated sensitivity to group differences further supports its application in comparative studies, allowing researchers to evaluate how different vertiport configurations are perceived by users.

Importantly, the development of this scale addresses a significant gap in the literature. Until now, there has been no standardized tool for evaluating vertiport usability, which has limited the scope and impact of research in this area. Without such a tool, efforts to design and implement vertiports, an essential foundation for widespread UAM adoption, have lacked empirical grounding. The Vertiport Usability Scale not only enables researchers to assess existing designs but also provides an instrument for identifying optimal configurations under varying conditions. Moving forward, this instrument can be used to explore consumer preferences, inform policy decisions, and guide infrastructure development. It also supports future studies to examine additional factors influencing vertiport adoption, such as pricing, routing, frequency, and public sentiment, thereby contributing to a more holistic understanding of UAM readiness.

Future Research and Limitations

This study produced a validated instrument for assessing vertiport usability, marking a significant step forward in the operationalization of infrastructure for UAM. However, the logical progression of this research involves applying the scale in real-world or simulated contexts. Future studies could present participants with a variety of vertiport designs and layouts to evaluate which configurations score highest in terms of usability. This approach would not only test the robustness of the scale but also provide actionable insights for designers and policymakers. Additionally, it is essential to continue monitoring public perceptions and willingness to support UAM initiatives. Public acceptance is likely to be a critical driver in the successful implementation and scaling of UAM systems, and understanding the factors that influence this support will be key to guiding future development.

Despite its contributions, the study has limitations that should be addressed in subsequent research. The use of a convenience sampling method via MTurk restricts the external validity of the findings, as the participant pool may not be representative of the broader population. In addition, the lack of environmental control during data collection introduces potential variability that could affect the reliability of responses. The cross-sectional nature of the study also prevents the analysis of evolving trends in consumer attitudes toward UAM and vertiports. Given that these concepts are still emerging, public opinions are likely to shift as awareness and technological maturity increase. Future research should consider longitudinal designs and explore additional variables that may influence consumer adoption, such as pricing models, route accessibility, and service frequency. These factors could significantly impact the perceived value and practicality of AAM systems from the user's perspective.

Conclusions

A major component of the successful deployment of UAM and AAM is the development of facilities where these vehicles will take off and land. While UAM and AAM remain largely conceptual at this stage, the transition from vision to reality requires robust planning tools. One such tool is the Vertiport Usability Scale developed in this study, which can play a critical role in guiding implementation efforts. By offering a structured instrument to assess usability from the perspective of end users, this scale helps bridge the gap between theoretical models and practical infrastructure development.

The creation of the Vertiport Usability Scale introduces a validated instrument that can be leveraged in future research to enhance vertiport design and functionality. Comprising seven items, the scale is versatile enough to be applied across various study designs, making it a valuable asset for both academic inquiry and industry application. Its ability to operationalize user-centered metrics not only fills a notable gap in the existing literature but also supports the broader goal of making UAM and AAM systems more accessible, efficient, and responsive to stakeholder needs.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used AI to revise and clarify writing after initial drafts were produced.

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Appendix A

Vertiport Usability Scale

Instructions: Please indicate how strongly you agree or disagree with the following statements on a scale from Strongly Disagree (-2) to Strongly Agree (+2), with a neutral option of 0.

- 1) The vertiport is convenient for me.
- 2) The vertiport is efficient.
- 3) The vertiport is functional.
- 4) The vertiport is in a good location.
- 5) The vertiport is of high quality.
- 6) The vertiport is usable by consumers.
- 7) The vertiport is useful to consumers.

12-06-2025

Methods for Preventing the Degradation of Manual Flying Skills in an Automated Cockpit Environment

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Abstract: Modern commercial aviation increasingly relies on advanced automation, which helps to reduce pilot workload and improves overall flight safety. However, the growing reliance on automation has reduced pilots' opportunities for manual flying practice, leading to a degradation of those skills. This article analyzes recent data on Loss of Control In-flight (LOC-I) cases and human factors, highlighting that insufficient manual flying experience has been a contributing factor in several incidents and accidents. An original methodology is proposed to maintain and improve airline pilots' manual flying skills through balanced automation use, regular manual flying exercises in training sessions, and during line operations under safe conditions. The Results section provides a detailed structure of the training program including Upset Prevention and Recovery Training (UPRT), exercise examples, and mathematical models of skill degradation. The Discussion compares the proposed approach with leading aviation organizations (ICAO, FAA, EASA, IATA, Airbus, Boeing), highlighting implementation strategies and potential outcomes. The findings confirm the need to revise simulator and line training programs for pilots with a greater focus on manual flying skills, which will help prevent further competency erosion and reduce LOC-I accident risk.

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Introduction

Automatic flight control systems have significantly transformed pilot operations over the past decades. Modern aircraft are equipped with autopilot systems, electronic displays, and integrated decision-support tools that handle many routine piloting tasks. These advancements have reduced crew workload and improved trajectory accuracy, thereby enhancing overall flight safety. However, a high level of automation also presents a downside. Pilots are now less frequently engaged in manual flying, resulting in fewer opportunities to maintain and refine their manual flying skills. According to ICAO (2019), although automation has generally increased safety levels, it has also led to a lack of manual flying practice and the potential degradation of corresponding skills among pilots. The U.S. Federal Aviation Administration (FAA, 2013), concluded that continuous use of autopilot does not promote the retention of manual flying proficiency. On the contrary, over-reliance on automation may weaken a pilot's ability to promptly regain aircraft control in non-standard or emergency situations.

One of the critical issues related to the decline in manual flying skills is a category of accidents known as Loss of Control In Flight (LOC-I), defined as situations where the aircraft unintentionally deviates from its intended flight path due to loss of control over pitch, roll, airspeed, or altitude parameters. Despite major advancements in avionics, LOC-I remains the leading cause of fatal air accidents. According to IATA (2020), during 2012-2016, only about 3% of all aviation incidents were attributed to loss of control, yet these accounted for nearly one-third of all fatal accidents. Over those five years, there were 30 LOC-I accidents, 27 of which involved fatalities, resulting in 949 deaths. Airbus (2022) identified loss of control in flight as the leading cause of fatal incidents in commercial aviation over the past two decades. Although modern next-generation aircraft equipped with fly-by-wire control systems feature protections to prevent exceeding safe flight parameters, the LOC-I problem remains highly relevant. This is largely because such accidents are typically not caused by equipment failure, but rather by human factors—namely, incorrect actions by the flight crew in critical situations (Airbus, 2022; ICAO, 2019). Incident reports involving LOC-I frequently cite insufficient monitoring of flight parameters or improper manual actions by pilots following the failure of automated systems (ICAO, 2019, 2020). Experts note that in many accidents, the outcome could have been different if the pilots had possessed stronger manual flying skills and better situational awareness at the critical moment (Airbus, 2022).

While substantial research exists on Loss of Control in General Aviation contexts, commercial aviation presents distinct challenges due to higher levels of automation, different crew composition, and varied training paradigms. General aviation LOC-I incidents often stem from visual flight conditions transitioning to inadvertent instrument meteorological conditions (IMC), spatial disorientation, and low-time pilot error (Boyd, 2015; Gibb et al., 2010; Mortimer, 2019). Nevertheless, fundamental principles of manual skill degradation identified in GA research—such as the importance of regular practice and scenario-based training—remain applicable to commercial operations. The transfer from GA to commercial aviation training reveals that pilots with diverse flight experience, including extensive hand-flying in GA aircraft, often demonstrate stronger foundational manual skills when transitioning to automated cockpits (Koglbauer, 2016; Winter et al., 2015).

The degradation of pilots' manual skills due to automation is evident not only in incident statistics but also in studies on psychophysiology and human factors. Different types of flying skills decay at different rates. Classic research from the 1970s showed that after a break from flying, pilots generally retained motor skills related to instrument flight if those skills had been well-developed (Prophet, 1976). In contrast, cognitive skills—such as executing procedures from memory, calculating parameters, and maintaining spatial awareness—deteriorated significantly after just a few months without practice. Recent experiments by Casner et al. (2014) confirm these findings in the context of the modern *glass cockpit*. In one NASA study, experienced pilots flew a Boeing 747 simulator under varying automation levels. When navigation systems were disabled, there was a sharp decline in cognitive task performance. Pilots struggled to maintain situational awareness and diagnose problems quickly. However, manual flying performance—such as maintaining altitude and heading—remained largely unaffected, even after extended periods without hands-on flying. Fundamental manual flying skills (aircraft stabilization, basic instrument scan) are more resistant to skill decay, whereas mental skills—situational awareness, mental computation, and planning without automation—are much more vulnerable when not regularly practiced. This phenomenon poses a unique challenge. In an automated cockpit, a pilot may remain confident in physical control abilities but may be unprepared to rapidly comprehend the situation and make the correct decisions following an automation failure (Ebbatson et al., 2010; Schutte & Trujillo, 1996). Recent studies have observed that while high levels of automation improve average flight path accuracy and reduce workload, they also lead to reduced pilot alertness. Simulation experiments under different automation modes revealed that pilots who placed full trust in the autopilot exhibited decreased attention to key instruments such as attitude indicators and engine parameters (Causse et al., 2024; Dehais et al., 2012). There are growing concerns that excessive automation may dull pilots' active flight monitoring skills.

Aviation authorities and the professional community are well aware of the risks associated with declining manual flying proficiency. As early as 2013, the European Union Aviation Safety Agency (EASA) issued a dedicated Safety Information Bulletin emphasizing manual flying skills importance. The agency recommended incorporating manual flying exercises into every pilot's recurrent training program and, where operationally feasible, encouraged line pilots to manually fly during routine operations. EASA's objective was promoting appropriate balance between automated systems use and manual flight control skills maintenance (EASA, 2013). In the United States, regulatory attention intensified following several incidents, including the 2009 crash of a DHC-8 near Buffalo, where incorrect manual inputs during stall recovery resulted in a fatal accident. The FAA increased focus on this issue through various directives and safety alerts. The FAA (2013) explicitly emphasized the need to provide pilots with opportunities to fly manually and to train in properly managing the transition between automated and manual flight modes. In 2017, the FAA issued a Safety Alert for Operators (SAFO) recommending pilots be allowed and even encouraged to disconnect the autopilot as often as safely and operationally possible during regular flights. Major aircraft manufacturers support these initiatives. Airbus (2020) stated that considers critically important for pilots to regularly fly manually during line operations to reduce overreliance on automation and strengthen their ability to manage abnormal situations. Boeing (2019), in its safety reports and simulator-based LOC-I prevention training materials, underscores the key role of the human factor and the necessity of high-quality flight training to prevent loss of control in flight (FAA, 2022).

Current Training Requirements and Assessment

Current regulatory frameworks establish baseline training requirements for commercial pilots. Under FAA Part 121 operations, pilots must complete annual proficiency checks including simulator evaluations and line checks conducted by qualified check airmen. EASA requires pilots to undergo recurrent training and proficiency checks for type rating revalidation every 12 months. ICAO Annex 1 establishes international licensing standards that member states incorporate into national regulations. Since 2019, Upset Prevention and Recovery Training (UPRT) has become mandatory in both initial type rating and recurrent training programs (EASA, 2019; FAA, 2019). However, current requirements do not specifically mandate regular manual flying practice intervals shorter than annual proficiency checks, nor do they consistently assess manual flying proficiency independently of automation management. While simulators are used to evaluate emergency procedures, the emphasis often remains on proper automation management rather than sustained manual flight capability. Line checks, conducted every six to twelve months depending on jurisdiction and operator, primarily assess standard operating procedure compliance and crew resource management rather than pure manual flying skill. This creates a significant gap. Pilots may demonstrate competence during brief manual flying segments in annual checks while lacking sustained practice throughout the year. Manual skill assessment is typically brief and incorporated into larger scenarios rather than evaluated as a standalone competency domain (FAA, 2022; ICAO, 2019).

Thus, the problem of pilot manual skill degradation due to increasing automation is supported by both accident statistics and empirical research. This growing trend has raised concerns among regulatory authorities and industry stakeholders, as a flight crew's ability to manage abnormal situations—when automation fails or behaves unpredictably—depends directly on their manual flying proficiency. The purpose of this paper is to justify the need for actively maintaining manual flying skills and to propose a comprehensive training methodology aimed at preventing further decline in these critical abilities. To achieve this objective, the study addresses the following key areas:

1. A review of current data on the impact of automation on pilot competence and the frequency of LOC-I incidents;
2. An overview of existing countermeasures, including regulatory requirements and training programs developed by leading aviation organizations;
3. The development of an original manual flying training program, featuring specific techniques and exercises;
4. An analysis of the expected outcomes of implementing such a program, along with potential challenges.

This research is based on an interdisciplinary approach—drawing from flight safety analysis, human factors, and learning theory—and aims to enhance aviation safety by optimizing flight crew training and skill retention.

Methodology

Materials and Methods

This study is an applied scientific investigation in the field of flight safety, with specific focus on commercial passenger airline operations utilizing turbine-powered transport category aircraft with advanced automation systems. The primary methods employed include analysis of accident statistics, a comprehensive review of academic and regulatory literature, and synthesis and modeling of a flight training methodology.

In the first stage, statistical reports from IATA, ICAO, Boeing, and Airbus were analyzed to identify causes of aviation incidents over the past 15 years (2010-2024), with a specific focus on Loss of Control In Flight (LOC-I) and the role of human factors. Simultaneously, a review was conducted of scholarly publications in human factors, ergonomics, and pilot psychology examining the effects of automation on pilot skills and proposing solutions to skill decay. The literature review employed the following methodology:

1. Database searches: Web of Science, PubMed, Google Scholar, and EBSCO Aviation Database
2. Search terms: 'manual flying skills,' 'automation dependency,' 'pilot skill retention,' 'LOC-I,' 'upset recovery training,' 'cognitive skill degradation'
3. Inclusion criteria: Publication date 2010-2024, English language, peer-reviewed articles or official regulatory/manufacturer reports, focus on commercial aviation or transferable findings
4. Exclusion criteria: Non-empirical opinion pieces, studies focused solely on ab initio training, research on military aviation without commercial applicability

This systematic search yielded 47 relevant sources, of which 28 were included in the final analysis. Special attention was given to recent studies reflecting the current state of the aviation industry.

In the second stage, existing recommendations and requirements from various aviation authorities regarding the maintenance of manual flying skills were compared. Documents analyzed included EASA (2013) and FAA (2017, 2022) bulletins on manual flying, ICAO guidance, Commercial Aviation Safety Team (CAST) working group findings, Flight Safety Foundation reports, and training materials from aircraft manufacturers including Airbus's Upset Recovery manual and Boeing's Statistical Summary of Commercial Jet Airplane Accidents. This stage involved qualitative content analysis, comparing key points, justifications, and areas of applicability across different sources. This methodology provided foundation for identifying a wide range of proposed measures—from revisions in recurrent training programs to airline-level policies on automation use.

The third stage involved the development of a custom-designed manual flying training methodology, based on the identified problem areas and best industry practices. Program design principles were formulated, and appropriate training modules and exercises were selected. To justify the recommended frequency of training sessions, findings from scientific research on skill retention and forgetting were incorporated (Casner et al., 2014; Prophet, 1976). Simplified mathematical modeling of skill dynamics under different training intensities was also conducted.

Exponential skill decay models (analogous to forgetting curves) were used to estimate the required frequency of practice sessions necessary to maintain a target proficiency levels. Elements of the expert evaluation method were applied through informal discussions with active pilot-instructors in professional settings. Their feedback and recommendations were considered during methodology refinement.

Data Collection and Sample Characteristics

Statistical safety data were sourced from publicly available IATA and Airbus safety reports concerning commercial passenger jet operations from 2010 through 2024. Specifically, the following reports were analyzed:

1. IATA Safety Report (annual editions 2011-2023)
2. IATA Aircraft Handling and Manual Flying Skills Survey Report (2020)
3. Airbus A Statistical Analysis of Commercial Aviation Accidents (2018-2022 editions)
4. Boeing Statistical Summary of Commercial Jet Airplane Accidents (2015-2019 editions)
5. ICAO State of Global Aviation Safety reports (2015-2023)

These reports collectively cover approximately 450 million flight hours and encompass worldwide commercial jet operations. From this data, 73 LOC-I incidents and accidents were identified over the 15-year period. Of these, 41 incidents (56%) cited manual flying skill deficiency, delayed recognition of aircraft state, or improper control inputs as contributing factors. It should be noted that isolating the precise quantitative impact of manual skill erosion on accident rates is difficult due to the complex interplay of contributing factors. Therefore, this study relies on indirect indicators—such as LOC-I incident frequency and the prevalence of manual skill references in accident reports. The scope is limited to commercial passenger jet operations equivalent to FAA Part 121 or EASA Air Operator Certificate standards.

Analysis Methods

To process the literature, comparative analysis was conducted by organizing information into thematic categories: (1) the role of manual flying skills in flight safety; (2) the impact of automation on pilot competence; (3) recommended measures for skill maintenance. Accident statistics were consolidated and analyzed descriptively. Skill retention modeling was carried out using the exponential decay formula:

$$R_{(t)} = R_{(0)} \cdot e^{-\lambda t} \quad (1)$$

where $R_{(t)}$ is the notional skill level (proficiency coefficient) after time t without practice, and λ is the forgetting rate constant. Parameter values were estimated based on research data. Specifically, Casner et al. (2014) found that cognitive skills related to manual flight showed approximately 30% decline over four months without practice. Prophet's (1976) classic study on pilot skill retention indicated motor skills decay more slowly than cognitive skills, with significant motor skill retention observed even after six months without practice. From these empirical findings, decay coefficients were derived for modeling purposes. The minimum acceptable skill threshold of 80% ($R_{\min} = 0.8R_{(0)}$) represents a conservative standard commonly used in training effectiveness research and is consistent with proficiency maintenance goals

established in aviation training literature (FAA, 2022; Ericsson et al., 1993). The resulting curves were used to derive training frequency recommendations.

Results

Literature Review Findings

The systematic literature review revealed several consistent themes regarding automation effects on pilot manual flying skills. First, multiple studies documented measurable decline in manual control proficiency among pilots with limited recent hands-on flying experience (Casner et al., 2014; Ebbatson et al., 2010; Koglbauer, 2016). Second, cognitive skills—particularly situational awareness, mental calculation, and manual flight path planning—were found to degrade more rapidly than basic motor skills (Prophet, 1976; Schutte & Trujillo, 1996). Third, automation dependency was identified as creating monitoring complacency, where pilots become passive observers rather than active participants in aircraft control (Causse et al., 2024; Dehais et al., 2012). Fourth, scenario-based training incorporating realistic automation failures showed effectiveness in maintaining manual skills and improving pilot confidence (Bainbridge, 1983; Landman et al., 2017; Lenhart et al., 2021).

Analysis of safety data from 2010-2024 revealed that LOC-I incidents disproportionately occurred during phases requiring manual intervention following automation discontinuation. Table 1 presents the distribution of LOC-I incidents by flight phase and contributory factors.

Table 1

LOC-I Incident Analysis from Safety Reports (2010-2024)

Flight Phase	Incidents (n)	% of total	Manual Skill Factor
Cruise/high altitude	18	25%	12 (67%)
Approach	31	42%	19 (61%)
Go-around	14	19%	7 (50%)
Other phases	10	14%	3 (30%)
Total	73	100%	41 (56%)

Note: Data compiled from IATA Safety Reports (2011-2023), Airbus Statistical Analysis (2018-2022), Boeing Statistical Summary (2015-2019), and ICAO State of Global Aviation Safety reports (2015-2023). Manual Skill Factor indicates incidents where manual flying deficiency, delayed recognition, or improper control inputs were cited as contributing factors.

These findings informed the design of the proposed training program, particularly the emphasis on high-altitude manual control scenarios, approach stabilization without automation, and go-around execution under manual flight conditions. The data reveal that manual flying skill deficiency contributes to over half of LOC-I incidents, providing strong justification for systematic manual skill maintenance programs.

Proposed Training Program Structure

Based on the conducted analysis, a comprehensive training program was developed to support and maintain manual flight control skills. This methodology is designed for implementation within airline training systems and can be integrated both into recurrent simulator training programs and into line operations under favorable conditions.

Overall Program Concept

The primary objective is preventing loss of pilots' manual flying skills and the associated cognitive abilities, such as situational awareness. The methodology is based on the well-established *use it or lose it* principle, which applies to both motor and cognitive skills. The core idea is systematically creating regular opportunities for pilots to practice manual aircraft control in a variety of flight conditions. The program consists of two complementary components: (1) Simulator-Based Training including scheduled sessions on full-flight simulators (FFS) focusing on manual control in non-normal, degraded, or emergency scenarios; (2) Line Practice involving manual flying of specific flight segments during real-world operations when safe and compliant with standard operating procedures. An important component is theoretical refresher training and structured briefing sessions reinforcing fundamental principles of flight control, aerodynamics, energy management, and limitations of highly automated systems. This integration of hands-on practice, structured simulation, and cognitive reinforcement forms a holistic approach to preserving and improving manual flying proficiency in the age of increasing cockpit automation.

Training Modules

The training program is designed around a notional one-year cycle integrated into recurrent training schedules. It is divided into five modules, each addressing specific manual flying competencies.

Module A: Core Manual Flying Skills. Frequency: Quarterly (every 3 months). Format: Simulator-based. This module focuses on foundational manual flying exercises performed without autopilot or flight director guidance. Scenarios include maintaining straight-and-level flight using basic instruments, standard rate turns with coordinated control, climb and descent at specified vertical speeds, low-speed maneuvering, and heading/course tracking without navigation aids (raw data flying). The objective is maintaining and reinforcing pilots' muscle memory and basic instrument scan coordination. These exercises act as a skill calibration to ensure continued competence in basic aircraft handling without automation.

Module B: Advanced Handling and Unexpected Scenarios. Frequency: Annually (minimum). Format: Standalone simulator session or integrated into regular proficiency checks. This module incorporates Upset Prevention and Recovery Training (UPRT) elements, focusing on non-routine, high-risk scenarios where pilots must rely solely on manual flying skills. Training includes stall recovery at high altitude with autopilot disengaged, upset scenarios involving abrupt pitch or roll changes, manual recovery from unusual attitudes, flight with complete automation failure requiring manual control of pitch, roll, and thrust in adverse conditions, and non-precision or precision approaches flown without autopilot or flight director.

The objective is developing and reinforcing pilots' ability to manage the aircraft manually in degraded, high-stress environments while maintaining proper flying technique, situational control, and calm response under pressure.

Module C: Cognitive Skills and Monitoring. Frequency: Annually or semi-annually. Format: Classroom or simulator-based. This module focuses on maintaining the pilot's mental workload skills essential in the absence of automation or visual cues. Key elements include mental navigation exercises where pilots track aircraft position without moving maps or electronic displays using conventional tools, manual descent planning without FMS or automated descent profiles to enhance situational awareness, flight monitoring training where Pilot Monitoring identifies deviations during manual flight. The objective is sharpening situational awareness, attention management, and mental modeling of aircraft performance.

Module D: Line Flying with Manual Flight Elements. Frequency: Ongoing in regular line operations. Format: Integrated into real-world flight activity. This module promotes manual flying use during live operations in accordance with company policy and regulatory guidance. Based on FAA (2017) recommendations, companies are encouraged to adopt policies supporting safe manual flying during suitable flight phases. Examples include manual takeoff followed by initial climb, manual descent and approach to landing under visual meteorological conditions, full hand-flown approaches without autopilot or autothrottle in low-complexity environments. The aim is to fostering positive safety culture where pilots feel comfortable disengaging automation when appropriate.

Module E: Data Analysis and Individualized Feedback. Frequency: Continuous. Format: Ongoing monitoring and targeted coaching. This module integrates Flight Operational Quality Assurance (FOQA) data to monitor pilot manual flying performance and engagement. Core activities include tracking manual flight metrics based on approach stability, control smoothness, and deviation management; trigger-based interventions when pilots show limited manual flying activity; and structured debriefing after each simulator or training session where instructors provide detailed feedback. The objective is enabling personalized skill development through evidence-based feedback, fostering continuous improvement and awareness of individual performance trends.

Mathematical Justification for Training Intervals

The program defines specific intervals for simulator sessions (e.g., quarterly, annually), and these intervals are grounded in research on skill degradation rate over time. Using the exponential decay model described in the Methodology section (Equation 1), we can derive optimal training frequency. To ensure skill does not fall below the minimum acceptable threshold, we solve for the maximum allowed interval without practice:

$$\Delta t = \frac{1}{\lambda} \cdot \ln \left(\frac{R(0)}{R(t)} \right) \quad (2)$$

Studies suggest motor skills decay slowly and can be retained for several months, while cognitive skills degrade more quickly. Casner et al. (2014) documented that cognitive skills related to

manual flight planning and situational awareness showed approximately 30% decline after four months without practice. If cognitive skills drop to 50% after 4 months, λ is estimated as:

$$\lambda = \frac{-\ln(0.5)}{4} \approx 0.17 \text{ month}^{-1} \quad (3)$$

Assuming $R_{\min} = 0.8$ (representing an 80% minimum acceptable skill threshold based on industry training standards), the maximum permissible interval is:

$$\Delta t = \frac{1}{0.17} \cdot \ln\left(\frac{1.0}{0.8}\right) \approx 1.3 \text{ months} \quad (4)$$

This result suggests that for cognitive skills, retraining should ideally occur every 1–1.5 months to retain at least 80% of the trained proficiency. Since such frequent training may not be operationally feasible, the program compensates by focusing quarterly simulator sessions on motor skills (which degrade more slowly), integrating cognitive exercises into both simulator and classroom environments, encouraging ongoing manual practice during line operations, and supporting this with data monitoring and individual coaching (Module E). These measures allow the program to maintain an acceptable overall level of pilot proficiency without imposing unrealistic training burdens.

Table 2 presents sensitivity analysis demonstrating how training interval recommendations vary with different decay coefficients. This analysis accounts for individual variability in skill retention based on pilot experience, recency of practice, and learning characteristics.

Table 2

Sensitivity Analysis of Training Intervals Based on Decay Coefficients

Decay Rate λ	50% Loss (months)	Training Interval	Pilot Characteristics
0.10	6.9	4-5 months	Experienced, recent practice
0.173	4.0	2.5-3 months	Average (base case)
0.25	2.8	1.5-2 months	Limited experience, rare practice

Note: Training interval calculated for 80% minimum retention threshold. Decay coefficients represent variability based on pilot populations. Even with $\pm 40\%$ variation in decay rates, quarterly training (3 months) remains appropriate for maintaining acceptable proficiency levels.

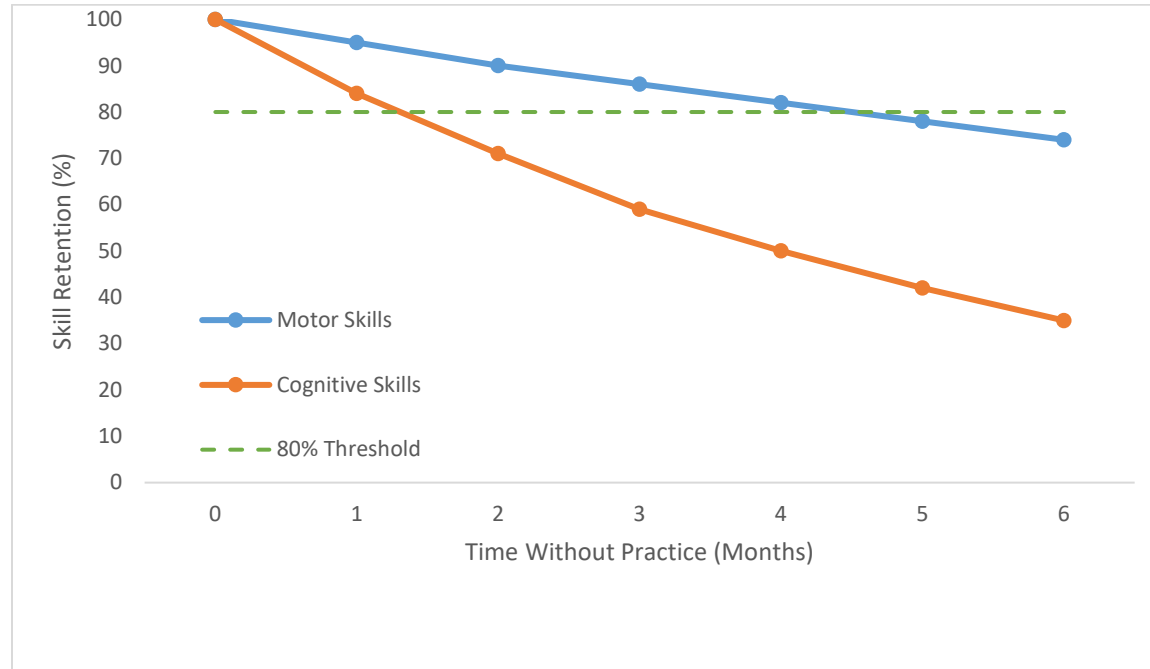
Table 3 presents degradation dynamics of pilots' motor and cognitive skills without practice, illustrating the differential decay rates that inform the training program structure.

Table 3*Degradation Dynamics of Pilots' Motor and Cognitive Skills Without Practice*

Time (Months)	Motor Skills (%)	Cognitive Skills (%)
0	100	100
1	95	84
2	90	71
3	86	59
4	82	50
5	78	42
6	74	35

Note: Theoretical model based on exponential decay equation with motor skill decay $\lambda = 0.05$ and cognitive skill decay $\lambda = 0.173$ per month. Parameters derived from Casner et al. (2014) and Prophet (1976). Values represent percentage of initial skill level retained.

Figure 1 provides graphical representation of the exponential skill degradation model, illustrating the more rapid decline of cognitive skills compared to motor skills and the 80% threshold that determines training interval recommendations.

Figure 1*Exponential Degradation of Pilot Skills*

To ensure pilots maintain both motor and cognitive manual flying skills, basic training exercises (Module A) are scheduled every three months. While motor skills alone may not require such frequent refreshers, quarterly simulator sessions provide essential reinforcement of cognitive abilities related to manual control. Advanced and high-stress scenarios (Module B) are

conducted annually. This frequency reflects logistical considerations and the fact that once the skills required to recover from unusual attitudes are initially acquired, annual reinforcement is generally sufficient. Nevertheless, where possible, UPRT elements should ideally be practiced every six months, a frequency already adopted by some airlines. Thus, the proposed schedule represents a balanced compromise, leaning toward more frequent training than traditional programs while remaining operationally feasible.

Discussion

Alignment with International Aviation Practices

The methodology proposed in this paper aligns closely with global aviation initiatives aimed at addressing degradation of manual flying skills. In recent years, concerns over automation dependency have gained traction at the highest levels of the aviation community. The ICAO Assembly (2019) formally recognized this issue and issued recommendations encouraging member states to support manual flight trajectory management by defining core competencies and updating training standards. In Europe, efforts to mitigate LOC-I have been integrated into EASA regulations. Since 2019, UPRT has become a mandatory in both ATPL training and airline simulator programs, aligning directly with our Module B of this proposed methodology (EASA, 2019). In the United States, several high-profile incidents prompted regulatory review resulting in FAA Advisory Circular 120-123 (2022), which establishes the Flight Path Management framework emphasizing balanced proficiency in manual flying, automation management, and monitoring skills. The circular states that manual flight is the foundation upon which all other technical flying skills are built (FAA, 2022). This philosophy reflects the core principle of our program: manual control is not ancillary but foundational to pilot competence. Additionally, the FAA (2017, 2022) recommends operators revise their policies to encourage varied combinations of manual flying, including operations without autopilot, autothrust, or flight directors — an approach directly mirrored in our training Modules A, B, and D of this training program.

Comparison with Existing Training Programs

To contextualize the proposed methodology, Table 4 compares its key features with traditional recurrent training approaches and current regulatory requirements.

Table 4

Comparison of Proposed Training Program with Current Industry Standards

Element	Traditional Approach	Current UPRT Requirements	Proposed Program
Training Frequency	Annual proficiency check	Annual UPRT module	Quarterly basics + Annual advanced
Manual Flight Focus	Limited, automation-centric	Upset scenarios only	Comprehensive across all modules
Cognitive Skills Emphasis	Minimal	Some situational awareness	Strong emphasis (Module C)
Line Integration	Often discouraged	Not addressed	Actively encouraged (Module D)
Individual Feedback	Limited, standardized	Standard debriefing	Data-driven, personalized (Module E)
Theoretical Component	Minimal ground school	Some theory included	Regular cognitive refreshers

Note: Comparison based on typical Part 121/EASA commercial airline training programs as of 2024. Individual airline implementations may vary.

The comparison reveals that the proposed program offers several novel elements: increased training frequency for foundational skills, explicit cognitive skill development, integration of manual flying into line operations, and data-driven individualized feedback. These features address gaps in current training approaches where manual flying may be relegated to brief annual checks without sustained practice throughout the year.

Expected Outcomes and Implementation Challenges

The implementation of this methodology is expected to yield several tangible benefits. Improved pilot proficiency through regular manual flying practice should enhance pilot confidence. According to a global IATA (2020) survey, 96% of pilots agreed that strong manual skills are essential for flight safety, yet 55% reported having very limited opportunities to hand-fly in routine operations. This program is designed to address that gap. Reduction in automation-related incidents is anticipated. The frequency of events like airspeed decay at altitude or inappropriate stall recovery responses should decline. Although LOC-I incidents are statistically rare, simulator assessment scores and indirect indicators should reflect measurable improvement. Better crew coordination is expected when one pilot flies manually and the other actively monitors, reinforcing CRM and mutual awareness. IATA (2020) found that 67% of pilots believe manual flying enhances crew coordination, a benefit this program explicitly targets.

Some risks and concerns must be addressed:

- Potential for parameter deviations exists, as increased manual flying could lead to minor altitude or heading deviations. This risk is mitigated by rigorous simulator-based preparation before any operational application.
- Training costs including simulator time and pilot release incur expenses. However, these are minimal compared to the financial and human costs of a major incident. Moreover, regulatory mandates already require dedicated UPRT time. This proposal primarily reorganizes existing training, possibly adding just one additional simulator session per year.
- Instructor readiness is essential. Instructors must exemplify strong manual flying and possess modern instructional skills, potentially necessitating dedicated seminars and refresher courses.
- Variable pilot performance means some pilots may show rapid improvement while others struggle. Management must provide additional support and patience, including remedial simulator access.

Approaches to manual skill retention vary globally. In the U.S., following the Colgan Air (2009) and Asiana (2013) accidents, regulatory reforms included stricter hour and skill requirements for Part 121 pilots and mandatory stall recovery training. In Europe, EASA has issued UPRT bulletins and supported LOC-I research programs. In Asia, some carriers revised training programs after incidents like Asiana 214 (2013), where incorrect autothrust configuration and weak visual approach skills led to late recognition of airspeed decay and a fatal crash. While ICAO has introduced standardized UPRT requirements, operator culture still varies. North American pilots often come from general aviation backgrounds with extensive manual flying experience, while in some regions pilots train directly on highly automated jets, leading to reduced manual exposure. The proposed methodology is flexible and regionally adaptable, but its rollout may vary in scope depending on local pilot experience and cultural norms.

This methodology reflects a modern, safety-oriented approach to pilot development. It complements—not contradicts—the benefits of automation. As aviation experts note, automation is most effective when pilots retain the skills and awareness to supervise and, when necessary, override it (Boeing, 2019). The expected benefits—better-prepared crews, fewer LOC-I risks, and a return to the art of flying—justify the investment. Ultimately, the goal is clear: to ensure that pilots do not lose the ability to fly, even when commanding the most advanced aircraft ever built.

Conclusion

This paper addresses the increasingly relevant issue of manual flying skill degradation among commercial airline pilots in the context of rising cockpit automation. The analysis reveals that growing reliance on automated systems may lead to a decline in pilots' practical ability to control the aircraft manually. In critical situations, this loss of proficiency increases the risk of Loss of Control In-Flight events. Despite their relative rarity, LOC-I accidents remain the leading cause of fatalities in commercial aviation (Airbus, 2022; IATA, 2020). Incident

investigations consistently show that in many cases, pilots failed to intervene effectively due to a lack of recent experience with manual control.

To counter this threat, we propose a comprehensive training methodology for maintaining and enhancing manual flying skills, designed for implementation by airlines and training centers. The core features of this approach include regularity through scheduled training every few months, scenario diversity from basic maneuvers to emergency situations, line integration promoting manual flying during actual operations where feasible, and progress monitoring through data analysis and individualized debriefing. Particular emphasis is placed on cognitive proficiency—the pilot's ability to make autonomous decisions and maintain situational awareness without relying on automated prompts. These high-order skills tend to degrade the fastest when automation dominates flight operations (Casner et al., 2014). The proposed methodology is grounded in learning theory principles, including the concept of skill decay. Mathematical modeling demonstrates that scheduling training at three-month intervals helps sustain proficiency at high levels while remaining operationally feasible.

This study systematically addressed the four objectives established in the Introduction. First, a comprehensive review of current data on automation's impact and LOC-I frequency was conducted, analyzing 73 incidents from 2010-2024 and revealing that 56% cited manual skill deficiency as a contributing factor. Second, an overview of existing countermeasures was provided, comparing regulatory requirements and training programs from ICAO, FAA, EASA, and major manufacturers. Third, an original manual flying training program was developed featuring five complementary modules addressing motor skills, advanced scenarios, cognitive abilities, line operations, and individualized feedback. Fourth, analysis of expected outcomes and implementation challenges was presented, including comparison with existing approaches and discussion of operational, cost, and cultural considerations.

Our methodology is aligned with the latest international standards and regulatory guidelines from organizations such as ICAO, EASA, and FAA, enhancing its feasibility and relevance. It complements existing UPRT programs and promotes a consistent strategy for sustaining pilot competence across all career phases. While implementing this system requires organizational commitment, the anticipated benefits—higher-quality manual flying, reduced incident rates, and improved operational safety—make it highly relevant. Additionally, the program fosters a stronger operational culture where pilots are engaged and active participants in aircraft control rather than passive monitors of automation. This shift supports greater professionalism and a heightened sense of responsibility.

The primary conclusion of this study is that advanced cockpit automation does not eliminate the need for a highly skilled pilot. Automation is a powerful tool whose effectiveness depends on how and when it is used by the flight crew. A pilot who retains manual flying proficiency and a solid understanding of flight dynamics can make optimal use of automation and take control when required. Conversely, a loss of manual skill can reduce the pilot to a bystander of technology, undermining safety. To prevent this, we must rethink conventional training paradigms. Automation training must be integrated with the ongoing development of manual flying abilities. The methodology presented here contributes to this effort by offering a structured action plan. These recommendations can be adopted by flight schools, airline safety

departments, and regulatory authorities when revising training requirements. However, it is also important to acknowledge the limitations of this study. These constraints qualify our conclusions and point to areas that require further investigation.

Limitations

An important limitation of this research is that the proposed training methodology remains conceptual and has not undergone empirical validation through controlled implementation. The projected effectiveness is based on established learning theory, existing research on skill retention (Casner et al., 2014; Prophet, 1976), and alignment with current regulatory best practices. However, actual pilot performance data demonstrating improved manual flying proficiency following this specific training program has not yet been collected. The methodology has not been tested through pre- and post-training assessments, controlled comparison with traditional approaches, or long-term tracking studies. Future research should include controlled pilot implementation studies with performance assessments, comparison of trained versus control groups, and cost-benefit analysis of implementation. Additionally, the mathematical model parameters represent average estimates. Individual pilots may experience faster or slower skill degradation depending on factors such as total flight experience, recency of manual flying practice, aircraft type differences, and individual learning characteristics. The literature review was limited to English-language sources primarily published after 2010. While the proposed methodology incorporates proven components from established UPRT programs and aligns with current regulatory trends, its effectiveness remains a hypothesis requiring empirical validation.

Future Research

Future research should focus on empirical validation of the proposed training methodology through controlled implementation studies. Recommended approaches include:

- Pilot implementation study: Deploy the program at a partner airline and conduct pre- and post-training assessments of manual flying proficiency using standardized simulator evaluation protocols
- Controlled comparison: Compare pilot groups receiving the proposed training versus those following traditional recurrent training, measuring performance on manual flying tasks, situational awareness, and incident rates
- Long-term tracking: Monitor manual flying proficiency metrics over 2-3 year periods to validate predicted decay rates and optimize training interval recommendations
- Cost-benefit analysis: Quantify implementation costs (simulator time, instructor training, scheduling) versus safety benefits (incident reduction, insurance impacts, pilot confidence)
- Individual variability studies: Investigate how pilot experience level, aircraft type, and personal learning characteristics influence skill decay rates, enabling more personalized training recommendations

Additionally, research could explore optimizing the balance between time spent on automation training and manual skill development, tailored to pilot experience level and aircraft type. Integration of emerging technologies such as virtual reality home simulators, adaptive training systems, and biometric feedback could further enhance program effectiveness.

To conclude, aviation has always been—and remains—a domain that places exceptional demands on the human element. While technology continues to evolve, the responsibility for flight safety still rests with the pilot. Maintaining and advancing pilot craftsmanship—including the ability to confidently fly the aircraft manually—remains a non-negotiable prerequisite for accident prevention. The proposed training framework is designed to ensure that every pilot, sitting at the controls of a highly automated airliner, remains above all a pilot—capable of taking command and ensuring a safe outcome under any circumstances.

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Effect of a Safety Event on Perceptions of Safety Culture in Collegiate Flight Training

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Abstract: A collegiate aviation flight program experienced a series of engine-related issues, leading to the grounding of the entire single-engine fleet. Students' perceptions of safety culture were analyzed using data from the program's annual safety culture perception surveys. Data from before and after the safety event showed that five survey items on the safety culture perception survey indicated a positive statistically significant change, while one item showed a negative statistically significant change. Perceptions of lowerclassmen and upperclassmen were also analyzed to determine if there was any variance between the two groups. Results indicated that only one survey item was statistically significant.

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Introduction

In the fall of 2024, a large collegiate flight school with over 600 flight students grounded all single-engine training aircraft due to engine issues that led to “a partial loss of engine power” (Donnelly, 2024). The issue was a faulty fuel servo, and even though it is a relatively small component in the engine, it caused an outsized problem. Eventually, almost all 44 single-engine aircraft were found with contaminated fuel servos (Donnelly, 2024). Due to issues in acquiring parts and a manufacturer’s denied request to outsource the parts, the entire fleet was grounded for almost two months. Prior to the fleet grounding, there were multiple reports of engine issues. A common manifestation of the engine issue was losing power in flight, engine roughness, oil pressure abnormalities, and engine failure.

The decision to ground the fleet, thus affecting students’ training progress, was made in the interest of safety, and the director of the program expressed a strong focus on safety and the continuous airworthiness of training aircraft (Donnelly, 2024). Safety actions taken during this time by management included grounding the fleet, openly communicating issues and progress with students and staff, and increasing maintenance staff to ensure the safety and airworthiness of training aircraft (Donnelly, 2024). The issue was resolved and the training aircraft returned to service in late 2024. An annual safety culture perception survey was distributed to all students in spring 2025.

Evaluating safety culture perception data following a safety event is critical in providing management the ability to adjust safety policies to improve safety culture (Byrnes et al., 2022). Byrnes et al. (2022) found that the safety culture and climate perceptions in a collegiate flight school were reduced during a safety crisis (COVID-19). Similarly, our study examined the impact of the string of engine issues and the subsequent actions taken by the management team on students’ perceptions of safety culture in a collegiate aviation flight school. Safety culture perception survey results before the safety event and after the safety event were analyzed to determine if there was a change in students’ perceptions of safety culture, and if so, was the change positive or negative.

Research Questions

Research Question 1: Did the actions taken by management during the safety event affect students’ perception of safety culture?

Null hypothesis: There is no difference in students’ perception of safety culture.

Research Question 2: Is there a difference of the perception of safety culture between lowerclassmen (freshmen and sophomores) and upperclassmen (juniors and seniors)?

Null hypothesis: There is no difference in the perception of safety culture between lowerclassmen and upperclassmen.

Literature Review

Organizational culture is defined as “the set of shared values and norms that control organizational members’ interactions with each other and with suppliers, customers, and other people outside the organization” (Jones & Mathew, 2018, p. 188). Importantly, organizational culture “controls the way members make decisions” (Jones & Mathew, 2018, p. 188). Organizational culture and safety culture are inextricably linked: Safety culture is generally considered as a subset of organizational culture (Goodheart, 2017). Thus, in the context of aviation safety management, an organization that values safety will incorporate safety values into its policies and practices, and safety will be supported by management (International Civil Aviation Organization [ICAO], 2018). The result of management’s actions will be perceived by front-line employees, as they feel the shared responsibility of fulfilling the organization’s safety objectives (ICAO, 2018). There is also a high level of trust among employees of all levels and ranks (ICAO, 2018). Positive safety cultures have a direct impact on an organization’s safety performance (ICAO, 2018; Kim et al., 2019).

Safety culture is not stagnant. There are many factors that can cause safety culture to change or shift—in a positive or negative direction—and one prominent factor is the role of management in cultivating a positive safety culture (Byrnes et al., 2022; ICAO, 2018). Management can foster a positive safety culture by their actions, such as demonstrating a commitment to safety, being adaptable, and maintaining awareness of risks (ICAO, 2018).

Culture change can be driven by internal and external forces (Cummings & Worley, 2007), such as safety events, organizational changes, and systems changes (Byrnes et al., 2022). Measuring safety culture in an organization should be a component of safety management efforts (Goodheart, 2017). An initial assessment of safety culture provides the safety practitioner with a baseline understanding of the safety culture, and it is the first step to developing organizational safety culture (Wheeler et al., 2019). However, safety culture evaluations do not stop there. Continuous safety culture assessments are also crucial in monitoring how safety culture is affected by various forces (Byrnes et al., 2022).

Safety culture measurements are used in many industries, including aviation, as a component of managing safety and controlling risk (Robertson, 2016; Tear et al., 2020). There are many ways to measure safety systems, such as accident records, audits, and safety culture perception surveys (Byrnes, 2022; Goodheart, 2017). Understanding safety culture perceptions is important, as safety culture perceptions affects safety behavior (Adjekum et al., 2015; Tear et al., 2020) and is one of the predictors of safety reporting behavior (Byrnes, 2022). Many safety culture studies have been conducted in collegiate aviation, many of which utilize safety perception surveys (e.g., Adjekum, 2014; Anderson et al., 2024; Beckman et al., 2019; Robertson, 2016). Various surveys have also been developed or adapted for use in collegiate aviation safety culture studies: The Collegiate Aviation Program Safety Culture Assessment Survey (CAPSCAS) was modified from the Commercial Aviation Safety Survey (CASS; von Thaden & Gibbons, 2008), which was modified by Adjekum (2014). Another derivative of CASS is the Safety Culture Indicator Scale Measurement System (SCISMS; Anderson et al., 2024).

While safety culture perception surveys are important components of cultivating a positive safety culture, the information learned from surveys requires management action. Management commitment to safety is crucial in fostering a positive safety culture. Management must model safe practices, which eventually becomes the norm for the organization (ICAO, 2018). In ICAO's Safety Management Manual (2018), there are six elements of management and employee actions that either promote or degrade safety culture, but of those six, four are of interest to our study. The elements, along with some of its positive aspects, are reported below:

Commitment to Safety: Management leads safety culture and is actively motivating its employees to care for safety, not only by talking but by acting as role models.

Adaptability: Employee input is actively encouraged when addressing safety issues; all incidents and audit findings are investigated and acted upon; organizational processes and procedures are questioned for their safety impact; and a clear proactive approach to safety is demonstrated and followed.

Awareness: Investigators seek to establish the root cause; and the organization systematically evaluates if safety improvements are implemented and working as intended.

Behaviour [*sic.*] with respect to safety: Continuous monitoring of safe behaviour [*sic.*] is practised [*sic.*]; and the working conditions support aviation safety at all times. (ICAO, 2018, pp. 3-5, 3-6)

Methodology

This study used questions extracted from the CAPSCAS as it related to students' perceptions of management's safety commitment. This is a validated survey instrument (Adjekum, 2014; von Thadden & Gibbons, 2008). This study was approved by the IRB, and data for this study were collected at the end of the spring 2024 semester and the end of the spring 2025 semester. This is an annual survey sent to all students in the department, including students who are not professional flight. The rationale behind sending it to all students instead of flight students only is because some of the management students switched from professional flight. Those who switched from professional flight to management were invited to participate if they have conducted some flight training at the flight school. Initial screening questions prevented management students who have never conducted training at the flight school from completing the survey. Those who indicated that they were not professional flight students were asked a follow-up question: "Have you conducted any flight training at the university's flight school." Students who selected "Yes, I have conducted flight training at the university's flight school" were allowed to continue the survey.

The administration of this survey is part of the effort to ensure continuous improvement and assessment of safety culture. A request to participate in completing the survey was sent to all students and participation was voluntary. No student information was tracked. This study was approved by the IRB. Survey results were downloaded from Qualtrics, and statistical analyses were conducted using *R*.

Results

For both 2024 and 2025, there were over 800 total students in the department with over 600 students enrolled in flight. For 2024, 102 students started the survey, and 64 completed the survey. For 2025, 113 students started the survey, and 75 completed the survey. Many participants started the survey but were prevented from continuing past the initial screening questions. These participants were presumed to be management students who have conducted no flight training at the university. See Table 1 for a breakdown of the classification of participants.

Table 1

Classification of Participants

Classification	2024		2025	
	<i>n</i>	%	<i>n</i>	%
Freshman	5	8%	17	23%
Sophomore	12	19%	21	28%
Junior	13	20%	12	16%
Senior	34	53%	25	33%
Total	64	---	75	---

Research Question 1

Research Question 1: Did the actions taken by management during the safety event affect students' perception of safety culture? Responses from 2024 and 2025 were analyzed. Normal distribution was assumed based on the central limit theorem (Sheposh, 2024; West, 2021). Welch's two sample *t*-tests were used for analysis. Welch's *t*-test does not assume homogeneity of variance (Derrick et al., 2016; West, 2021). Participants rated their agreement to the statements for items 1 – 18: 1 for strongly disagree, 2 for disagree, 3 for neutral, 4 for agree, and 5 for strongly agree. For items 19 and 20, participants rated the frequency of the statement: 1 for never, 2 for once in the last six months, 3 for two to four times in the last six months, 4 for five to ten times in the last six months, and 5 for more than ten times in the last six months. There were four questions in the survey that contained negatively worded statements. These questions were reverse-coded: Questions 4, 5, 6, and 18 (see Tables 2 and 3). Table 2 presents the findings of this analysis.

Table 2

Independent t-tests for Research Question 1

No.	Item	2024 [1]		2025 [2]		Difference [2] – [1]
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
1	Pilots can report safety discrepancies without fear of negative consequences	3.45	1.30	3.81	1.19	0.36
2	When pilots make a mistake or do something wrong, they are dealt with fairly by management	2.85	1.11	3.00	0.97	0.15
3	Safety is a core value of the program	3.56	1.15	4.06	1.16	0.50* ^a

4	Management is more concerned with making more money than being safe (reverse)	2.44	1.24	2.93	1.26	0.49* ^b
5	Management expects pilots to push for on time performance, even if it means compromising safety (reverse)	2.53	1.24	2.55	1.27	0.02
6	Management doesn't show much concern for safety until there is an accident or incident (reverse)	2.62	1.21	3.10	1.29	0.48* ^c
7	Management does not cut corners where safety is concerned	3.10	1.04	3.32	1.05	0.22
8	Safety issues raised by pilots are communicated regularly to all other pilots in this program	2.48	1.36	2.99	1.19	0.51* ^d
9	When a pilot reports a safety problem, it is corrected in a timely manner	3.05	0.98	3.14	0.99	0.09
10	Pilots are satisfied with the way management deals with safety reports	2.73	0.99	3.06	1.05	0.33
11	The flight school is willing to invest money, resources, and effort to improve safety	3.27	1.25	3.70	1.15	0.43* ^e
12	The flight school is committed to equipping aircraft with up-to-date technology	4.63	0.61	4.36	0.80	-0.27* ^f
13	The flight school ensures that maintenance on aircraft is adequately performed	3.23	1.48	3.48	1.21	0.25
14	The flight school ensures that aircraft are safe to operate	3.53	1.33	3.81	1.05	0.28
15	Students are actively involved in identifying and resolving safety concerns	3.33	1.20	3.46	1.04	0.13
16	Safety is consistently emphasized in all stages of practical training	3.88	1.21	4.00	1.07	0.12
17	Management goes above and beyond regulatory minimums when it comes to issues of flight safety	3.18	1.09	3.38	1.13	0.20
18	Management tries to get around safety requirements whenever they get the chance (reverse)	3.56	1.09	3.75	1.06	0.19
19	Have you ever felt pressured to fly a university aircraft you believed was in an unsafe condition?	1.34	1.34	1.45	0.83	0.11
20	Have others in the flight school ever felt pressured to fly a university aircraft they believed was in an unsafe condition?	2.21	2.21	1.90	1.38	-0.31

Note. ^a $d = 0.43$. ^b $d = 0.40$. ^c $d = 0.38$. ^d $d = 0.39$. ^e $d = 0.36$. ^f $d = 0.38$.

*Significant at 0.05. No differences were significant at 0.01 or 0.001 level.

Of the 20 questions, six questions showed significant statistical difference at $p < 0.05$. Five of the six questions showed a difference in the positive direction in that participants had a more positive perception of safety culture in 2025 than participants in 2024. Only one item had a statistically significant change in the negative direction: "The flight school is committed to equipping aircraft with up-to-date technology." Of the items that were not statistically significant, all but one question changed in the positive direction.

Research Question 2

Research Question 2: "Was there a difference of the perception of safety culture between lowerclassmen (freshmen and sophomores) and upperclassmen (juniors and seniors)?" The responses from 2025 were analyzed ($n = 75$), and the participants were divided into two groups: lowerclassmen ($n = 38$) and upperclassmen ($n = 37$). Welch's two-sample t -tests were conducted. Out of the twenty items, only one item was statistically significant: Item 15, "Students are actively involved in identifying and resolving safety concerns." For this question, the perceptions of the upperclassmen were lower than that of the lowerclassmen. The results of the t -tests are presented in Table 3.

Table 3*Independent t-tests for Research Question 2*

No.	Item	Lower [1]		Upper [2]		Difference [2] – [1]
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
1	Pilots can report safety discrepancies without fear of negative consequences	3.79	1.14	3.83	1.25	0.04
2	When pilots make a mistake or do something wrong, they are dealt with fairly by management	3.00	1.03	3.00	0.93	0.00
3	Safety is a core value of the program	4.06	1.19	4.06	1.14	0.00
4	Management is more concerned with making more money than being safe (reverse)	3.06	1.17	2.80	1.35	-0.26
5	Management expects pilots to push for on time performance, even if it means compromising safety (reverse)	2.64	1.33	2.46	1.22	-0.18
6	Management doesn't show much concern for safety until there is an accident or incident (reverse)	3.28	1.30	2.91	1.27	-0.37
7	Management does not cut corners where safety is concerned	3.36	1.10	3.29	1.02	-0.07
8	Safety issues raised by pilots are communicated regularly to all other pilots in this program	3.08	1.11	2.89	1.28	-0.19
9	When a pilot reports a safety problem, it is corrected in a timely manner	3.03	0.91	3.26	1.07	0.23
10	Pilots are satisfied with the way management deals with safety reports	3.17	0.91	2.94	1.19	-0.23
11	The flight school is willing to invest money, resources, and effort to improve safety	3.83	1.10	3.56	1.21	-0.27
12	The flight school is committed to equipping aircraft with up-to-date technology	4.34	0.68	4.38	0.92	0.04
13	The flight school ensures that maintenance on aircraft is adequately performed	3.66	1.11	3.29	1.29	-0.37
14	The flight school ensures that aircraft are safe to operate	3.89	1.02	3.74	1.08	-0.15
15	Students are actively involved in identifying and resolving safety concerns	3.80	1.02	3.12	0.95	-0.68** a
16	Safety is consistently emphasized in all stages of practical training	4.09	1.09	3.91	1.06	-0.18
17	Management goes above and beyond regulatory minimums when it comes to issues of flight safety	3.43	1.17	3.32	1.09	-0.11
18	Management tries to get around safety requirements whenever they get the chance (reverse)	3.71	1.15	3.79	0.98	0.08
19	Have you ever felt pressured to fly a university aircraft you believed was in an unsafe condition?	1.27	0.63	1.62	0.98	0.35
20	Have others in the flight school ever felt pressured to fly a university aircraft they believed was in an unsafe condition?	1.88	1.39	1.94	1.39	0.06

Note. ^a $d = 0.69$.

*Significant at 0.05. **Significant at 0.01.

Discussion

When comparing the perceptions of safety culture between 2024 and 2025, there were five statistically significant items that changed in the positive direction, and these items saw a dramatic shift between the two years, changing anywhere from 0.43 to 0.51 on a five-point scale. Item 3, “Safety is a core value of the program,” changed 0.50 between 2024 ($M = 3.56$, $SD = 1.15$) and 2025 ($M = 4.06$, $SD = 1.16$). This item surveys the overall perception of the safety culture of the program. Values are “general criteria, standards, or guiding principles that people use to determine which types of behaviors, events, situations, and outcomes are desirable or undesirable” (Jones & Mathew, 2018, p. 188). Further narrowing that definition, core value is

defined as “those ideals that form the foundation on which the organization conducts itself” (Stolzer et al., 2013, p. 206). If safety is a core value, then the organization will conduct itself with safety as a priority. This is manifest in the policies and actions taken by management.

The survey results indicate that students felt more strongly about safety as a core value in 2025 than they did in 2024. It also seems to suggest that the string of mechanical issues with the fuel servos did not lead to a negative perception of safety as a core value of the organization; instead, the actions taken by management to ground the fleet led to a more positive perception of safety as a core value. Students did not feel that the fuel servo issues were due to the organization’s neglect of safety, rather, they felt that safety was more of a priority because of management’s decision to ground the fleet.

In addition to a more positive view of safety as a core value, four other items also showed statistically significant differences in the positive direction. Students’ perceptions that management is more concerned about safety than about cost (Item 4) and management is proactive in caring about safety (Item 6) were both more positive in 2025 than in 2024. Related to those two questions, students had a more positive perception of the flight school being willing to invest money, resources, and effort to improve safety (Item 11). While the cost to fix the fuel servo failure was relatively inexpensive, the cost of grounding the fleet for an extended period was significant. The loss of revenue from flight training was compounded by the cost of maintaining the building and staff. This tremendous cost burden shouldered by the flight school was seemingly not lost on the students. Furthermore, placing safety over cost reduction and being proactive about safety, rather than acting in response to safety failures, are enablers of a positive safety culture (ICAO, 2018).

Lastly, students also felt that the flight school did a better job of communicating safety issues raised by pilots to other pilots in the program (Item 8). There were regular communications between administration and students when the fuel servo issue was first discovered and throughout the fleet grounding. Effective communications play an important part in organizations with positive safety culture (ICAO, 2018; Mendonca & Carney, 2017).

There was one survey item that showed a statistically significant difference in the negative direction. Item 12, “The flight school is committed to equipping aircraft with up-to-date technology,” changed -0.27 between 2024 ($M = 4.63$, $SD = 0.61$) and 2025 ($M = 4.36$, $SD = 0.80$). This may be due to a misconception that the fuel servo failure was caused by inadequate technology. Other items on the topic of equipment safety and maintenance were either not statistically significant, or statistically significant in the positive direction. For example, there was no change for Item 13, “The flight school ensures that maintenance on aircraft is adequately performed,” or for Item 14, “The flight school ensures that aircraft are safe to operate.” A closely related question, Item 11, showed statistically significant difference in the positive direction: “The flight school is willing to invest money, resources, and effort to improve safety.”

When comparing the 2025 results of upperclassmen and lowerclassmen, there was only one question that was statistically significant: Item 15, “Students are actively involved in identifying and resolving safety concerns.” While it may be expected that all students are operating under the same flight school and the same policies share the same perception of safety

culture, that is not always the case. Adjekum (2014) found variances in students' perception of safety culture among different classification (freshman, sophomore, junior, and senior).

In our study, the upperclassmen had a far more negative view of this item than lowerclassmen. Having been in the program longer, upperclassmen's perception is shaped by their lived experiences, and our results suggest that more experience and time in the program led to a lower view that the program includes students in addressing safety concerns. Perhaps over time they have realized that their safety concerns were not addressed, an experience not shared by lowerclassmen due to insufficient time in the program.

This could have a negative impact on safety culture for three reasons. First, a healthy safety culture invites employee input in addressing safety issues (ICAO, 2018). Second, culture can be changed by the people who lead the organization (Jones & Mathew, 2018), and if lowerclassmen look up to upperclassmen, they could be influenced negatively. And third, subcultures could develop when experiences differ (Daft, 2021). Subcultures are formed when a group of people within an organization form their own culture based on shared similar experiences (Daft, 2021).

While Byrnes et al. (2022) found a decrease in safety culture perception during a prolonged safety crisis (COVID-19), we found that management's safety-oriented actions during a shorter safety crisis boosted the overall safety culture perception of students. Taken together, while the prolonged fleet grounding posed as an inconvenience to many students in terms of flight training progress, our results indicate that they understood it to be a decision made in the best interest of safety.

Limitations

While response rates increased slightly between the two years, the response rates were relatively low. With low response rates, nonresponse bias, which is not always possible to measure, becomes a concern (Bose, 2001). Additionally, this study was conducted at one collegiate flight school covering one full year, which limits the generalizability of the results. Other, smaller safety events experienced by individuals or smaller groups of students may influence the changes in perceptions of safety.

Recommendations for Future Research

There are several recommendations for future studies. First, this survey is sent annually to all students in the spring semester. Some students started the survey but did not complete it. The length of the survey may be a contributing factor. Reducing the length of the survey may increase response rate. Second, there was a negative shift in perception on the technology question between the two years (see Table 2). Future studies into this phenomenon may explain how students view technology as a component of safety. Third, the development of subcultures in the flight school between upper and lowerclassmen should be studied longitudinally to examine safety culture trends among different groups of students.

Conclusion

The safety culture perceptions of the students at a collegiate aviation flight school changed between 2024 and 2025. In between the two years, the flight school experienced a major safety event, where there were multiple reports of engine issues. These issues ultimately led to the voluntary grounding of the entire single-engine fleet. The prolonged fleet grounding posed a great deal of inconvenience and setback for students in flight training. However, the actions taken by management were mostly viewed favorably by students. While many safety culture perception indicators remained unchanged between 2024 and 2025, five out of six items that were statistically significant showed a change in the positive direction. When comparing the safety culture perceptions of lowerclassmen and upperclassmen, most of the safety culture items were similar between the two groups, showing no statistically significant difference. However, the one item that was statistically significant showed that upperclassmen had a more negative view than lowerclassmen.

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A Study on Prohibited Items at Airport Screening Checkpoints: Examining the Relationship with Passenger Volume and Its Economic Impact

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Abstract: Evolving aviation threats and methods of attack have led to an increase in both the variety and number of prohibited items detected at airport screening checkpoints. While security measures are essential for safeguarding passengers and infrastructure, procedures such as manual bag searches require additional resources, increase operational costs, and may disrupt efficiency. Despite ongoing efforts by security authorities to improve screening processes and enhance public awareness, a substantial number of prohibited items continue to be intercepted. This trend may be driven by growing air traffic volumes, but it may also reflect limitations in current public outreach campaigns and operational strategies. This study employs statistical analysis to examine the relationship between passenger volume and the number of confiscated items, using historical data from the United States and the Republic of Korea. The results reveal a strong positive correlation between passenger volume and the number of confiscated items, with the average cost of a manual bag search—when the selected bag contains prohibited items—estimated at \$1.58 per bag search, based solely on time-related losses. These findings show the part of the operational and economic loss posed by prohibited items. As global air travel expands, it is crucial to incorporate multiple perspectives into aviation security policies to maintain safety and efficiency, especially by considering sustainability as essential for reducing aviation’s environmental footprint and supporting the industry’s long-term viability. Such integration supports long-term resource management and strengthens overall security resilience.

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Introduction

Aviation security is essential for protecting passengers, employees, and the overall aviation industry. Over time, evolving security threats have led to stricter regulations and expanded screening measures to prevent unlawful activities. For instance, following a foiled terrorist plot involving liquid explosives in 2006, authorities imposed restrictions on the quantity of liquids allowed on international flights (Wong & Brooks, 2015). Security measures are essential for protecting people and property from attacks and cannot be compromised for any reason. However, screening for a large number of prohibited items requires additional human and material resources and introduce operational challenges, potentially delaying screening processes and increasing passenger inconvenience and complaints.

The aviation industry is recovering from the significant impacts of COVID-19 (IATA, 2024), and passenger numbers are projected to increase from 4.6 billion in 2019 to an estimated 12.4 billion by 2050 (ICAO, n.d.-b). This ongoing increase in air traffic could lead to more prohibited items being intercepted at airport security checkpoints, potentially causing operational delays if proper preparations are not made. To facilitate the security process, authorities and operators keep improving screening procedures through technological advances and inform passengers about prohibited items via media campaigns and public awareness initiatives. Despite these efforts, the effectiveness of such measures remains uncertain, as a substantial number of prohibited items continue to be intercepted. Therefore, the aviation industry must proactively prepare for future challenges related to prohibited items and their impact on security operations to accommodate the rising volume of air travelers.

However, research on the implications of confiscated items for security checkpoint operations remains limited. One of the main challenges in studying this issue is the lack of accessible data on confiscated items, which may stem from security concerns regarding public disclosure or from the logistical difficulty of tracking the large volume of items confiscated daily. Despite these limitations, this study gathered several years of publicly available data from the U.S. Transportation Security Administration (TSA) and Incheon International Airport in South Korea. According to the U.S. Bureau of Transportation Statistics, over 54 million prohibited items were intercepted at U.S. airports between 2002 and 2008 (U.S. Bureau of Transportation Statistics, n.d.). The Transportation Security Administration (TSA) discontinued the collection of data on prohibited items (except firearms) after 2010, and there is currently no official comprehensive dataset available detailing the total number of prohibited items intercepted at U.S. airports. Although the Republic of Korea does not publish data on prohibited items, information from Incheon International Airport regarding prohibited items from 2013 to 2023 was available through sources provided by the airport authority. Datasets from two countries were used to perform statistical analyses aimed at examining the relationship between passenger volume and the number of confiscated items at screening checkpoints.

Given that restrictions on certain items remain a critical and non-negotiable aspect of aviation security policy, it is essential to examine the impact of prohibited items on airport operations in order to enhance the procedures for handling and disposing of confiscated items while maintaining high levels of security. These impacts stem from various factors, including socio-economic, operational, and environmental considerations, which are closely aligned with

the EONS framework, a recognized sustainability model. EONS stands for Economic Vitality, Operational Efficiency, Natural Resources, and Social Responsibility (ACI-NA, 2006). This framework has been widely adopted by the airport community to support strategic improvements, enhance operations, and facilitate sustainable growth (Martin-Nagle & Kluber, 2015). While sustainability has not yet received significant attention in the field of aviation security, it is crucial for future preparedness. Integrating sustainability considerations into various operational aspects of aviation security, such as managing and discarding prohibited items or optimizing screening effectiveness, may not only enhance aviation security but also improve airport efficiency, enrich the passenger experience, and optimize resource management.

This paper first examines the relationship between passenger traffic and the number of confiscated items. The first research question is *What is the relationship between the amount of passenger traffic and the number of confiscated items?* The corresponding null hypothesis is that there is no statistically significant correlation between passenger traffic volume and the number of confiscated items at airport security checkpoints; the alternative is that there is a significant correlation between these two variables. The second research question is *What are the estimated economic losses from routine security operations, excluding those resulting from security incidents?* This question seeks to provide quantitative and qualitative analyses into the implications of these items for the sustainable operation of security checkpoints, with a particular focus on economic impacts. The research specifically analyzes economic losses from routine security operations caused by prohibited items, excluding those resulting from security incidents. By exploring these aspects, this study aims to offer new perspectives to enhance aviation security policies, optimize checkpoint efficiency, and develop sustainable methods for managing confiscated items while maintaining high security standards.

Literature Review

The Evolution of Restrictions on Items Aboard Aircraft

In aviation security history, the period from 1968 to 1972 is often called the "Golden Age of hijacking" due to a sharp increase in unlawful interferences. During this time, more than a hundred U.S.-registered aircraft were hijacked (Koerner, B. I., 2013). To combat hijackings, countries including the U.S. started to screen passengers who were selected using metal detectors and implemented 100% passenger and carry-on luggage screening from January 5, 1973 (Klenka, 2019; Ravich, 2005). Also, ICAO adopted the new International Standards and Recommended Practices on Aviation Security (Annex 17) in 1974, which mandates that the Contracting State implement screening for passengers and their cabin baggage (ICAO, n.d.-c). The purpose of screening is to detect items that can be used to harm other people. Metal detectors are typically used to detect metallic items carried by individuals, such as firearms, which can be used for unlawful purposes. However, the 9/11 hijackers concealed weapons such as box cutters and knives on their person or in carry-on luggage and used those to take control of four aircraft (TSA, 2022). According to the 9/11 Commission Report, at the time of the attack, knives with blades under four inches long were allowed in carry-on luggage (U.S. Government Publishing Office, 2004). Therefore, even if box cutters had been detected during the screening procedure, these passengers would have been permitted onboard with the box cutters (Schaper, 2021). Undoubtedly, security measures and the level of security have greatly enhanced since the

9/11 attacks. Various types of sharp objects including box cutters and razors were banned and the list of prohibited items on board aircraft significantly extended (Schaper, 2021).

In addition to the 9/11 attack, various other notable security threats and incidents have prompted heightened security measures. For example, in 2006, UK authorities arrested 21 suspects linked to a plan to target multiple commercial flights from the UK to the US using liquid explosives (Klenka, 2019). Following this, the UK and US governments tightened regulations on liquids, aerosols, and gels (LAGs), and ICAO urged all Contracting States to implement security controls on those items. The guideline restricts passengers to one quart-sized (one-liter) plastic bag filled with liquid containers of no more than 100 ml (3.4 ounces) each (ICAO, 2007). This rule is now enforced on all of the international flights, and domestic flights in some countries.

Generally, certain materials, such as explosives, sharp objects, and blunt weapons, are commonly restricted on aircraft in most countries. However, specific regulations vary by national authorities and may change over time under the circumstances. For instance, the U.S. initially permitted passengers to carry no more than two lighters per person. However, to comply with U.S. Department of Transportation hazardous materials regulations, lighters were added to the prohibited items list and banned from aircraft from March 1, 2005 (National Archives and Records Administration, 2005). Following a threat assessment by U.S. TSA, the restriction was amended in August 2007, allowing passengers to carry one lighter each. (National Archives and Records Administration, 2007).

Frequent changes and implementations in item restrictions aboard aircraft may cause inconvenience to passengers and stakeholders, including security personnel and airlines. Nevertheless, restrictions on certain items remain essential for aviation security. However, they can also reduce operational efficiency at screening checkpoints, potentially affecting overall security effectiveness. Detecting and handling prohibited items prolongs screening times, increases the workload for security personnel, and inconveniences passengers. According to U.S. TSA data, a manual bag search takes an average of 92 seconds, which is approximately 17 times longer than an X-ray screening (5.25 seconds) (Van Boekhold et al., 2013). In addition to the screening, screeners may be required to record and dispose of confiscated items following established procedures, which may add to the workload of the screeners and pose a delay in the process.

Depending on internal policies, confiscated items are typically discarded, donated, or resold. For instance, most liquids intercepted at the U.S. TSA screening checkpoints are discarded, including drinks, cosmetics, and food. Hazardous materials like aerosols are handled through specialized processes, while certain items, such as knives and firearms, are resold through government auctions and sales (Harmon-Marshall, 2025; Newsweek, 2025). In particular, the disposition of those items is directly related to environmental sustainability. To offset some of these expenses, U.S. airports and the U.S. TSA can use the Passenger Facility Charge (PFC) and Security Fee. These fees are collected by airlines from passengers and are included in ticket prices:

- 1) Passenger Facility Charge (PFC): Up to \$4.50 per flight, capped at \$18 per round trip. Airports use these funds to support FAA-approved projects that enhance security, safety, airport capacity, noise mitigation, or increase airline competition (U.S. FAA, n.d.).
- 2) TSA Security Fee: \$5.60 per one-way trip, up to \$11.20 per round trip. This fee has been collected since the 9/11 attacks to support security operations and efficiency improvements (U.S. TSA, n.d.-b).

Sustainability in Airport and Aviation Security

Sustainable growth has garnered global attention over time, emerging as a critical factor for long-term business success. The concept of sustainable development was brought into the core of the business, triggered by the *Brundtland report*, also called *Our Common Future* (Cole et al., 2014). This report was published by the UN in 1987, which defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations, 1987, p. 41). Since then, the international and national attention to sustainable growth has continued, and the UN developed “The 2030 Agenda for Sustainable Development” in 2015, which contains the 17 Sustainable Development Goals (SDGs). These 17 Goals require an urgent call to all Countries (United Nations, n.d.). The SDGs affects many industries and organization including the aviation industry. Subsequently, the concept of the Triple Bottom Line (TBL), proposed in 1994, emphasizes environmental value alongside the social and economic dimensions, highlighted in the Brundtland Report (Elkington, 1994).

As the aviation industry continues to evolve, sustainability has become one of focus for researchers, policymakers, and industry leaders. Especially, the expansion of aviation sustainability initiatives, research projects, and funding since the early 2000s indicates significant growth in these efforts (U.S. National Academies of Sciences, Engineering, and Medicine, 2016). According to the Air Transport Action Group (ATAG), aviation sector contributed 2.05% of global human-generated carbon dioxide (CO₂) emissions in 2023 (ATAG, 2024). However, this estimate accounts only for emissions from jet fuel combustion. It excludes emissions related to airport operations, which generate substantial waste streams such as municipal solid waste, hazardous materials, and construction debris. Security operations are part of these airport activities and therefore contribute indirectly to overall emissions. Data from San Francisco International Airport in 2018 and 2020 indicate that greenhouse gas (GHG) emissions from aviation such as flights and airport activities were distributed in an 85% to 15% ratio, respectively. Even though it is based on one airport's example, it still provides insight into the environmental impact of airport operation. (Greer et al., 2020).

Airports, as critical components of the aviation ecosystem, have a considerable socio-economic and environmental footprint, necessitating sustainable development frameworks to address stakeholder concerns regarding airport operations (Jordao, 2009). To define sustainability in this context, many airports have adopted the EONS framework—Economic Vitality, Operational Efficiency, Natural Resources, and Social Responsibility which was developed by Airports Council International–North America (ACI-NA) (ACI-NA, 2006). This framework extends operational efficiency from the triple bottom line concept (Martin-Nagle & Kluber, 2015). Research on aviation sustainability often emphasizes environmental factors, such

as emissions reduction and energy efficiency (Sreenath et al., 2021). These efforts have resulted in progress and improvements. For instance, the development of sustainable aviation fuel (SAF) has shown the potential to reduce CO₂ emissions by up to 80% compared to conventional fuels (ATAG, 2024). Sustainability considerations extend beyond environmental concerns; however, not all aspects of aviation address sustainability in the same way.

While various dimensions of aviation security may align with the EONS framework, research on sustainability in this field remains scarce. The primary objective of aviation security is to protect civil aviation from unlawful interference through a combination of human and material measures (ICAO, 2022). Due to its nature, aviation security primarily focuses on threat mitigation and safeguarding the aviation industry rather than addressing sustainability concerns. As a specialized agency of the United Nations (UN), ICAO links its Strategic Objectives on aviation security and facilitation activities to nine of the 17 UN Sustainable Development Goals (SDGs). For example, ICAO suggests that enhancing global aviation security contributes to SDG 8 (Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all). Given that the 9/11 attacks resulted in estimated economic losses of approximately \$2 trillion, strengthening aviation security can help prevent significant financial and economic disruptions (ICAO, n.d.-a).

However, ensuring the highest level of security remains a challenge (Jain et al., 2012). Therefore, while considering limited resources and the inconvenience and costs imposed on passengers and operators, it is essential to adopt a rational and acceptable approach to aviation security that maintains effective security measures without compromise (Jackson et al., 2012). This approach requires balancing security with operational efficiency, yet determining the appropriate level remains a complex challenge. A key example is the screening process for prohibited items, such as liquids and sharp objects. While detecting these items is crucial for preventing unlawful use and mitigating security risks, the process often leads to rescreening process and passenger complaints regarding enforcing regulations (Redden, 2021).

Methodology

The methodology seeks to answer two research questions: What is the relationship between the amount of passenger traffic and the number of confiscated items? What are the estimated economic losses from routine security operations, excluding those resulting from security incidents? By exploring these aspects, this study aims to suggest the necessity of adopting new perspectives to enhance aviation security policies, optimize checkpoint efficiency, and develop sustainable methods for managing confiscated items while maintaining high security standards. To answer the questions, the researchers collected data from publicly available sources. The data are from the United States Bureau of Transportation Statistics and published articles containing data provided by Incheon International Airport authority in the Republic of Korea. The collected data are analyzed using statistical techniques that reveal descriptive and inferential characteristics.

Data Collection

Countries tend to not share the detailed numbers and kinds of confiscated items at the airports with the public for various reasons, which is a challenge in this type of data collection. Fortunately, the U.S. Bureau of Transportation Statistics (BTS) provides the U.S. TSA data since 2003 on prohibited items intercepted at airport screening checkpoints (see Table 1). These items are categorized into seven groups: firearms, knives, box cutters, other cutting instruments, clubs, incendiaries, and others, which include tools, self-defense items, lighters, etc. (U.S. Bureau of Transportation Statistics, n.d.). To enhance comparability across years and account for variation in passenger numbers, normalized values were calculated and added for the number of intercepted firearms, expressed as firearms per one million passengers. The firearm detection rate increased from approximately 1.7 firearms per million passengers in 2002 to over 8 firearms per million passengers in 2023, with the highest rates occurring during the COVID-19 period (2020–2021). However, there are two issues with these data. The first issue is that the TSA ceased collecting data on all prohibited items, except for firearms, as of 2010. Moreover, major regulation changes had significantly affected collected data from 2002 to 2009 (e.g., the prohibition of lighters from April 2005 to August 2007 and relaxing regulations on scissors less than 4 inches and tools less than 7 inches from December 2005). The second is that the TSA did not collect data on LAGs (Liquids, Aerosols, Gels). The restriction on LAGs was implemented in 2006, but the data do not reflect this category. The TSA's data on confiscated firearms have been collected consistently. These data have the potential to reveal trends and provide valuable insights in conjunction with other data.

In addition to the U.S. TSA data, the number of confiscated items at Incheon International Airport (ICN) in the Republic of Korea from 2013 to 2022 was collected from publicly available sources, which were provided by the Incheon airport authority (Edaily, 2023; People Power Party, 2018) (see Table 2). Normalized values for prohibited items were calculated and included in the table to enable year-over-year comparison and observe fluctuations, expressed as items per 1,000 passengers. The detection rate ranged from about 41 to 145 items per 1,000 passengers across the years studied, with significantly higher rates in 2021 and 2022, possibly due to the impact of COVID-19. However, since the detailed category descriptions were not provided, it may constrain the data analysis. For instance, between 2013 and 2022, there were no significant changes in Korea's regulations regarding prohibited items, apart from restrictions on Lithium-ion batteries. The restriction on spare Lithium-ion batteries—those not installed in electronic devices—took effect in April 2016 (ICAO, 2016). This regulation may have contributed to an increase in confiscated items. However, the data does not specify which category includes lithium batteries, making it difficult to assess the exact impact of this regulation. Nevertheless, the data provides recent figures and categorizes prohibited items from 2013 to 2017, enabling an analysis of the most commonly confiscated categories. Using U.S. and Korean data, researchers analyzed the relationship between the number of passengers and confiscated items over time.

Table 1*Prohibited Items Intercepted at Airport Screening Checkpoints in the United States*

Year	Total Domestic Passengers	Total Prohibited Items	Firearms ^b	Knives ^c	Box cutters	Other cutting instruments ^d	Clubs ^e	Incendiaries	Other ^f	Firearms per Million Pax
2002	551,899,643	3,775,345 (Apr. to Dec.)	927	1,036,697	32,788	1,846,207	11,131	79,341	768,254	1.68
2003	583,293,766	6,114,612	683	1,961,849	20,991	2,973,413	25,139	494,123	638,414	1.17
2004	629,769,616	7,089,599	650	2,058,652	22,350	3,567,731	28,813	693,649	717,754	1.03
2005	657,261,487	15,886,039	660	1,822,752	21,315	3,276,691	20,531	398,830	10,345,260	1.00
2006	658,362,620	13,710,505	821	1,607,125	15,999	163,419	12,296	113,700	11,797,145	1.25
2007	679,185,450	6,515,409	803	1,056,687	11,908	101,387	9,443	89,623	5,245,558	1.18
2008 ^a	651,710,182	972,834	926	626,182	6,284	59,459	6,447	116,200	157,336	1.42
2009	618,067,255	129,548	976	N	N	N	N	127,176	1,396	1.58
2010	629,537,593	N	1,123	N	N	N	N	N	N	1.78
2011	638,247,667	N	1,320	N	N	N	N	N	N	2.07
2012	642,289,482	N	1,556	N	N	N	N	N	N	2.42
2013	645,677,554	N	1,813	N	N	N	N	N	N	2.81
2014	662,826,955	N	2,212	N	N	N	N	N	N	3.34
2015	696,016,894	N	2,653	N	N	N	N	N	N	3.81
2016	719,996,828	N	3,391	N	N	N	N	N	N	4.71
2017	741,735,098	N	3,957	N	N	N	N	N	N	5.33
2018	777,972,787	N	4,239	N	N	N	N	N	N	5.45
2019	811,545,260	N	4,432	N	N	N	N	N	N	5.46
2020	335,607,840	N	3,257	N	N	N	N	N	N	9.70
2021	605,935,323	N	5,972	N	N	N	N	N	N	9.86
2022	750,535,394	N	6,542	N	N	N	N	N	N	8.72
2023	819,333,204	N	6737	N	N	N	N	N	N	8.22

Note. Adapted from U.S. Bureau of Transportation Statistics, (2023, August 18). *Prohibited Items Intercepted at Airport Screening Checkpoints 2002 – 2022*. <https://www.bts.gov/content/prohibited-items-intercepted-airport-screening-checkpoints>^a and TSA. (2025, January 15). *TSA intercepts 6,678 firearms at airport security checkpoints in 2024*. <https://www.tsa.gov/news/press/releases/2025/01/15/tsa-intercepts-6678-firearms-airport-security-checkpoints-2024>

^a Data for 2008 are up to August, except for Firearms and Incendiaries.

^b Firearms includes any weapon (including a starter gun) that is designed to or may readily be converted to expel a projectile by the action of an explosive, as well as spear guns, BB guns, flare pistols, compressed air guns, and stunning devices.

^c Knives include any length and type except round-bladed, butter, and plastic cutlery.

^d Other cutting instruments include scissors, swords, meat cleavers, and ice axes.

^e Clubs includes baseball bats, night sticks, and billy clubs.

^f Other refers to tools, self-defense items, compressed gas cylinders, bleach, lighters, and certain sporting goods.

Data Analysis

The first research question is *What is the relationship between the amount of passenger traffic and the number of confiscated items?* The corresponding null hypothesis is that there is no statistically significant correlation between passenger traffic volume and the number of confiscated items at airport security checkpoints; the alternative is that there is a significant correlation between these two variables. The Pearson correlation coefficient was used to analyze the correlation between annual passenger volume and intercepted items at U.S. TSA airports and Incheon International Airport (ICN) in the Republic of Korea. As data on other categories has not been collected since 2009, only the number of confiscated firearms was analyzed for TSA. To use a Pearson's correlation coefficient, both variables must be quantitative normally distributed random variables with no outliers, and a relatively linear relationship. A Graphical Summary was generated using commercially available Minitab[®] Statistical Software to verify these assumptions. Following this verification, the Pearson correlation coefficient formula was applied to evaluate the strength and direction of the relationship:

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum(X - \bar{X})^2} \times \sqrt{\sum(Y - \bar{Y})^2}}$$

where X is the annual passenger volume (PAX), Y is the total prohibited items detected, and $\bar{X}$ and $\bar{Y}$ are the means of X and Y , respectively.

The strength of the relationship is determined by the resulting r score. The coefficient ranges from -1 to 1:

- 1) r close to 1 shows a strong positive correlation; as passenger volume increases, intercepted items also rise.
- 2) r close to 0 signifies no correlation, with no clear relationship between the variables
- 3) r close to -1 indicates a strong negative correlation; as one variable increases, the other decreases.

Table 2*Prohibited Items Intercepted at Airport Screening Checkpoints at Incheon International Airport*

Year	Total passengers	Total prohibited items	Firearms	Knives/ scissors	Tools	Incendiaries/ chemicals/ lighters	Inert ammunition	Liquids, aerosols, gels and others	Prohibited Items per 1,000 PAX
2013	40,864,272	1,968,200	590	212,448	27,049	178,109	3,052	1,546,952	48.16
2014	44,900,257	2,092,937	3,603	171,384	20,867	160,820	5,570	1,730,693	46.61
2015	48,663,242	2,048,036	5,238	179,721	21,590	195,250	2,548	1,643,689	42.09
2016	57,040,615	3,071,821	8,237	206,361	29,058	256,695	517	2,570,953	53.85
2017	61,362,514	2,568,764	9,413	208,039	31,197	219,250	79	2,100,786	41.86
2018	67,535,463	3,339,654	N	N	N	N	N	N	49.45
2019	70,467,146	3,527,883	N	N	N	N	N	N	50.06
2020	11,938,096	876,391	N	N	N	N	N	N	73.41
2021	3,164,280	459,543	N	N	N	N	N	N	145.23
2022	17,747,747	1,659,883	N	N	N	N	N	N	93.53
2023 (Jan. to Jul.)	29,558,316	2,283,524	N	N	N	N	N	N	77.25

Note. Adapted from Edaily, (2023, September 21). 공항보안검색서 놓친 ‘칼’ 꺼내도 처벌 못한다? [Knives missed during airport security screening—Can they be penalized?]. <https://www.edaily.co.kr/News/Read?newsId=03683446635742416&mediaCodeNo=257&OutLnkChk=Y> and People Power Party. (2018, November 5). 최근 5 년간 인천공항의 위해물품 적발건수 2,860 건, 기내반입금지물품은 1,385 만건에 달해! [Over the past 5 years, Incheon Airport detected 2,860 hazardous items and 13.85 million prohibited carry-on items]. https://www.peoplepowerparty.kr/news/lawmaker_inspection_view/80492

Correlation Analysis: Annual Passenger Volume and Intercepted Items at Korea ICN

To examine the relationship between passenger volume and intercepted prohibited items at Incheon International Airport (ICN), a regression analysis was conducted. The resulting model, shown in Figure 1, presents a strong positive correlation between total enplanements (millions) and prohibited items (millions), with an R-squared (R^2) value of 87.8%. This indicates that approximately 87.8% of the variation in the number of prohibited items can be explained by changes in passenger volume. The correlation coefficient (r) is approximately 0.937, and the associated p -value is $< .001$, confirming that the relationship is statistically significant at the 0.05 alpha level. This suggests that as passenger traffic increases, the number of confiscated items also rises proportionally (see Figure 1). The regression equation is:

$$\text{Prohibited Items (millions)} = 0.5660 + 0.03899 \times \text{Total Enplanements (millions)}$$

In the scatterplot, the solid black line through the middle of the chart represents the fitted regression line. The dashed red lines show the 95% confidence interval for the mean prediction, while the dashed green lines indicate the 95% prediction interval for individual new observations. Each red dot represents an observed data point.

Figure 2 presents the four-in-one residual plot. The residuals appear to be randomly scattered around zero in the "Versus Fits" and "Versus Order" plots, and the normal probability plot suggests that the residuals are approximately normally distributed. These diagnostics support the assumption of constant variance and normality, validating the use of linear regression for this dataset. Although the model fits the data well, caution is warranted when making predictions beyond the range of the observed data. Nonetheless, the findings clearly suggest that as passenger volume increases, the number of intercepted prohibited items also rises. These underscores the importance of reviewing and enhancing the procedures for prohibited items and the strategies used to raise public awareness. The findings in the regression analysis and correlation analysis are also consistent with expectations, and therefore, indicates face validity.

Figure 1

Correlation Analysis – Incheon International Airport

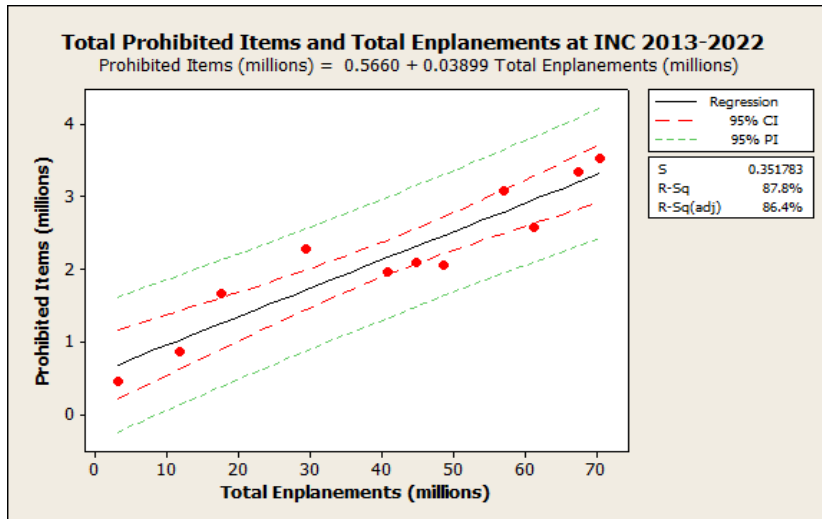
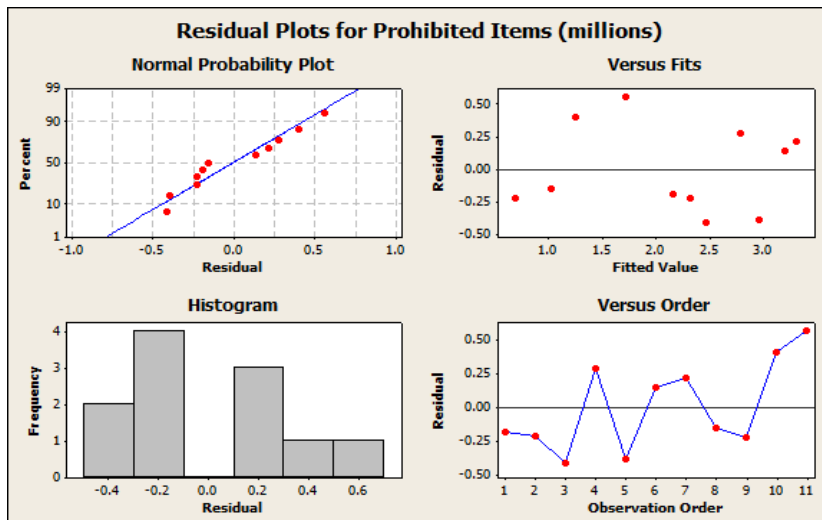


Figure 2

Residual analysis chart – Incheon International Airport



Further analysis of item composition revealed that the category "LAGs (Liquids, Aerosols, and Gels) and others" constituted an average of 81.94% of all intercepted items, implying that LAGs are the most frequently confiscated category (See Table 3).

Table 3

Prohibited Item Composition at Incheon International Airport

Total Prohibited Items	Firearms	Knives/ Scissors	Tools	Incendiaries/ Chemicals/ Lighters	Inert ammunition	LAGs and others
13,853,77	35,375	1,131,985	152,302	1,169,786	12,905	11,351,42
100%	0.26%	8.17%	1.10%	8.44%	0.09%	81.94%

Correlation Analysis: Annual Domestic Passenger and Intercepted Firearms at US TSA

Due to limited data availability, this analysis focused exclusively on the number of confiscated firearms at U.S. TSA checkpoints. The regression analysis for the full dataset spanning 2002–2023 (Figure 3) shows a correlation coefficient of $r=.423$ with $p = .050$, and a low R^2 value of 17.9%, suggesting that only a small portion of the variation in firearm confiscations can be explained by total passenger volume. The corresponding residual plots reveal non-constant variance and potential outliers, especially in the later years, indicating that the regression assumptions may not be fully met across the entire period (see Figure 4).

Figure 3

Correlation Analysis – TSA Data (2002-2023)

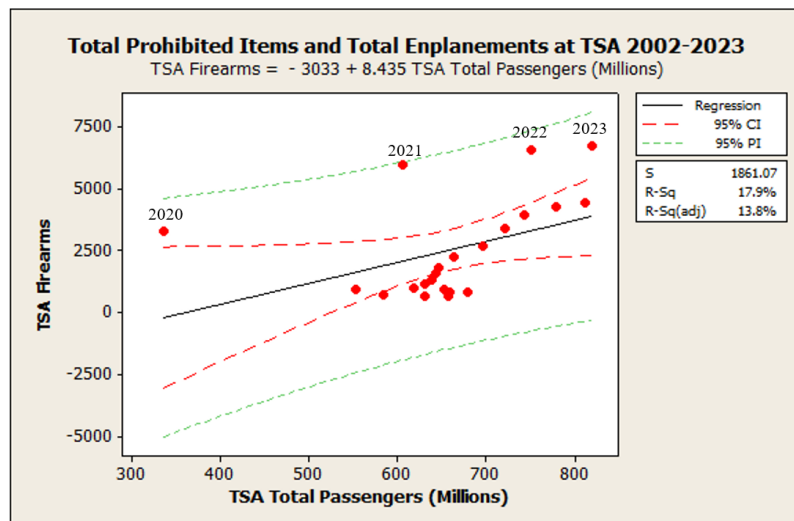
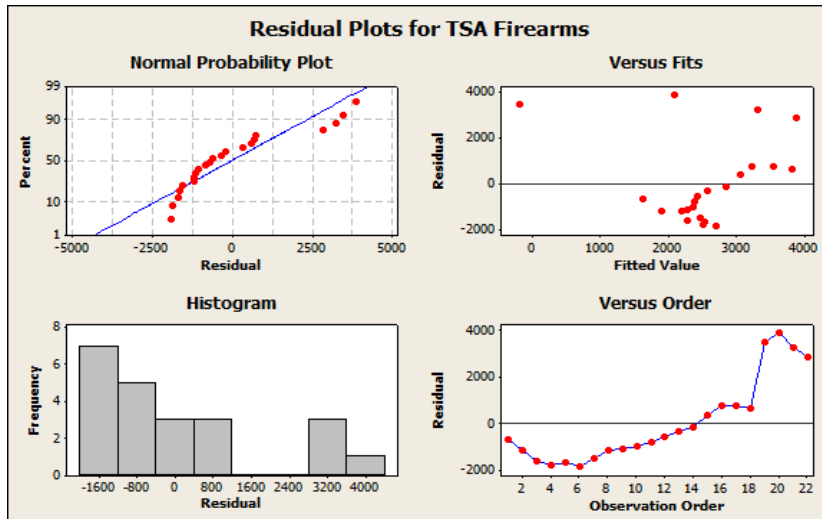
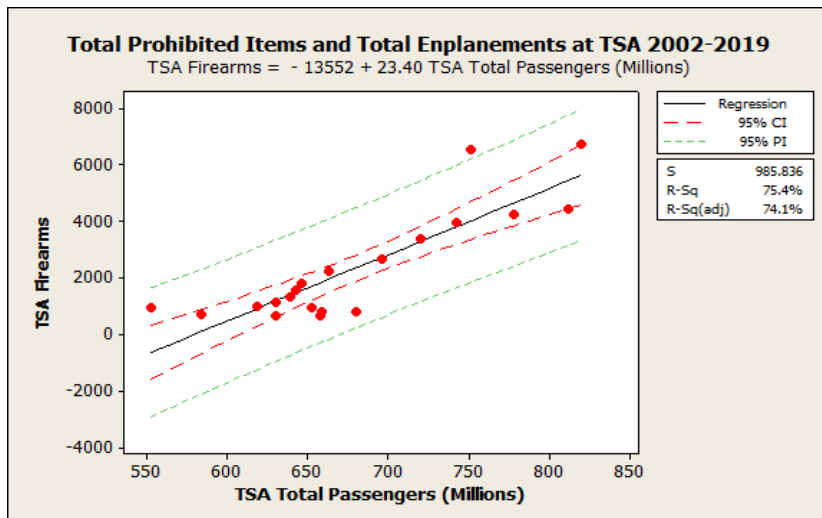


Figure 4*Residual analysis chart – TSA Data (2002-2023)***Figure 5***Correlation Analysis – TSA Data (Excluding 2020-2023)*

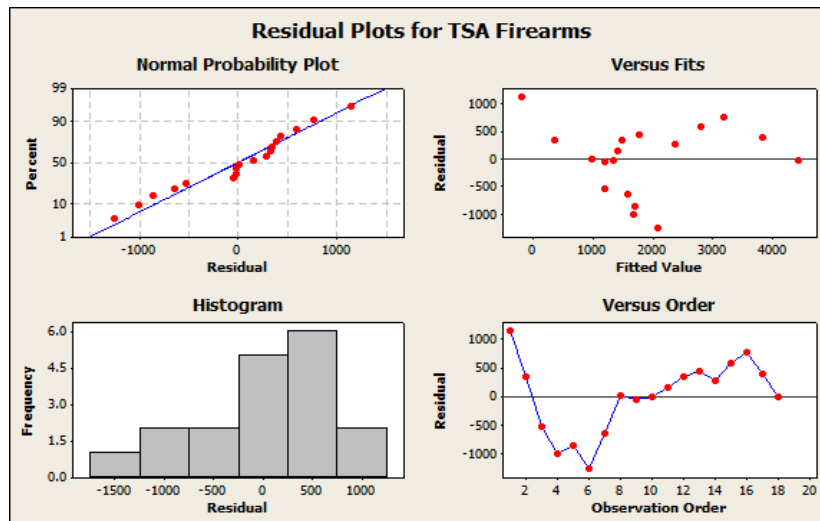
While the ICN dataset showed no noticeable distortion, the TSA data demonstrated unusually high firearm detection rates during the COVID-19 pandemic. This anomaly was likely due to a combination of unknown factors and significantly reduced passenger volumes, both of which substantially affected the correlation analysis. To ensure methodological rigor and mitigate these effects, two additional analyses were conducted alongside the full dataset evaluation:

- Excluding the years 2020–2023 (post-COVID impact)
- Excluding only 2020–2021 (peak pandemic years)

In the filtered analysis excluding 2020-2023 (Figure 5), the Pearson correlation coefficient improves substantially to $r = .868$ with $p < .001$, indicating a strong and statistically significant positive correlation between domestic passenger volume and firearm interceptions. This suggests a more stable relationship in normal travel conditions.

Figure 6

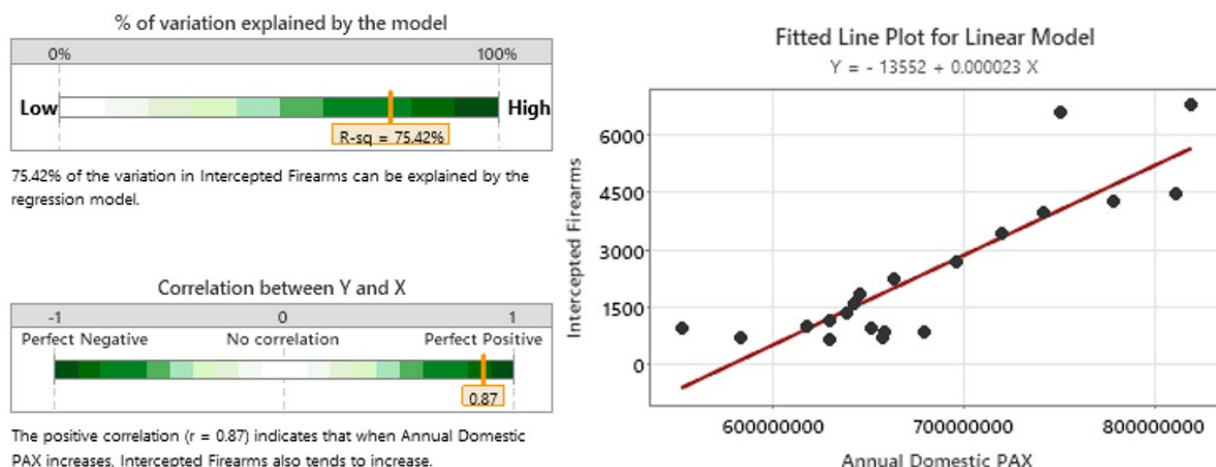
Residual analysis chart – TSA Data (Excluding 2020-2023)



To further validate the robustness of this trend, another analysis was conducted, excluding only 2020 and 2021. This analysis yielded a similar result ($r=.87$). This consistency suggests that passenger volume may have a stable relationship with the number of intercepted firearms, irrespective of the COVID-19 pandemic (see Figure 7).

Figure 7

Correlation Analysis – TSA Data (Excluding 2020-2021)



Economic Loss Estimation

The next step is to examine the second research question: *What are the estimated economic losses from routine security operations, excluding those resulting from security incidents?* To estimate the economic impact of confiscated items on sustainable airport security operation, this study identifies five potential contributors to financial loss. These include:

- 1) Time lost due to additional screening procedures for both passengers and security personnel.
- 2) Costs incurred for discarding or disposing of confiscated items.
- 3) Expenses related to informing the public about prohibited items and upgrading or installing relevant screening facilities.
- 4) Replacement costs for intercepted items, as passengers may need to repurchase confiscated belongings.
- 5) Administrative and miscellaneous costs related to the processing and handling of confiscated items by security authorities.

While all five factors are relevant, the current analysis focuses solely on the first factor, time loss, due to the availability of measurable data. Specifically, the study estimates the economic cost of time spent on manual bag searches involving prohibited items by calculating wage-based opportunity costs for both passengers and security personnel. The other factors are discussed as areas for future research. This approach provides a conservative estimate of the economic burden imposed by routine security operations involving prohibited items. The calculation was performed by multiplying the average search time (converted to hours) by the standard hourly wages of both Transportation Security Officers (TSOs) and passengers. As presented in Table 4, the estimated economic loss per manual bag search is \$1.58. This figure assumes: (1) both security personnel and passengers incur time-related costs during the screening process, and (2) on average, each searched bag containing a prohibited item results in the confiscation of one item.

Table 4

Estimated Economic Loss per Manual Bag Search of the U.S. Airport

	Average hourly wage (A)	Manual bag search time ^c (B)	Labor cost per manual bag search (A × B)
Passengers ^a	\$35.93	92 seconds = 0.02556 hours	\$0.92
TSOs ^b	\$25.91		\$0.66
Total economic loss per search		\$1.58	

Note. ^a Estimated hourly wage of passengers: Estimated based on data from the U.S. Bureau of Labor Statistics (U.S. Bureau of Labor Statistics, 2025).

^b Estimated hourly wage of TSOs: Derived from recent TSA job postings across 33 states (U.S. TSA, n.d.-a).

^c Time for a manual bag search: Averaged at 92 seconds (0.0256 hours), based on prior research (Van Boekhold et al., 2013).

It is important to note that this estimate excludes additional costs such as manual bag searches that do not result in confiscation, pat-down searches, and random searches conducted in compliance with regulatory requirements, all of which also contribute to economic loss. In addition to time lost due to screening, extra costs are associated with the disposal and management of confiscated items, public awareness campaigns, infrastructure investments, administrative expenses, and more. Furthermore, passengers who surrender their belongings at security checkpoints may need to repurchase similar or the same items, and therefore, they incur personal financial losses. Therefore, given that U.S. passenger traffic reached 1.58 billion in 2023 (Airports Council International-North America, 2024), along with other factors, the actual economic loss would be significantly higher.

Results

The methodology of this study addresses two primary research questions: (1) What is the relationship between passenger traffic volume and the number of confiscated items? and (2) What are the estimated economic losses resulting from routine security screening procedures, excluding those related to actual security incidents? To answer these questions, data were collected from publicly available sources: (1) statistics published by the United States Bureau of Transportation Statistics and (2) published articles referencing data from Incheon International Airport authorities in the Republic of Korea. The analysis revealed statistically significant correlations of passenger volume and confiscated item volume at the 0.05 alpha level for both Incheon International Airport (ICN) and U.S. TSA checkpoints. Specifically, the Pearson correlation coefficient indicated a strong positive relationship between passenger volume and the number of intercepted items at ICN ($r = .94$), as well as between passenger volume and firearm confiscations at TSA checkpoints ($r = .87$). These findings suggest that higher passenger traffic is associated with an increased number of prohibited items being intercepted. To address the second research question, the study estimated economic losses based on average search times and hourly wage data for both Transportation Security Officers (TSOs) and passengers. The resulting calculation estimated the economic loss per manual bag search to be approximately \$1.58, applicable only to instances in which a prohibited item was found and confiscated from the bag.

Discussion

This study explored the relationship between passenger traffic and the number of confiscated items at airport screening checkpoints, and examined the economic implications of these items. The results revealed a statistically significant and strong positive correlation at both Incheon International Airport (ICN) and U.S. TSA checkpoints for passenger volume correlating to the volume of confiscated items. These findings suggest that as passenger volume increases, the likelihood of prohibited items being intercepted also rises. In other words, despite ongoing public awareness campaigns, signage, and regulatory enforcement, passengers continue to bring restricted items to security checkpoints. This trend may point to gaps in communication strategies, limited passenger understanding of current security regulations, changing nature of security regulations and screening techniques, passenger inadvertent non-compliance, or a lack of willingness to comply, among other gaps.

From an economic perspective, this study also demonstrates how confiscated items contribute to measurable financial losses. By converting screening time into economic value—based on the duration of manual bag searches and average hourly wages—the analysis provides a conservative yet compelling estimate of costs, calculated at approximately \$1.58 per manual search involving a confirmed prohibited item. For example, at Incheon International Airport (ICN) in 2019, the estimated financial loss exceeded \$5.5 million ($3,527,883 \text{ Confiscated Items/Year} \times \$ 1.58/\text{search} = \$5,574,055/\text{year}$), based solely on the time expended addressing prohibited items relative to passenger volume. Importantly, this estimate excludes additional costs such as pat-down procedures, administrative processing, random searches, and searches that do not result in confiscation, suggesting that the true economic burden is likely substantially higher.

These findings underscore the necessity of pursuing more efficient and sustainable strategies for managing prohibited items. The handling and disposal of prohibited items, particularly liquids, aerosols, and gels (LAGs), raises environmental concerns given their substantial proportion among intercepted items. Disposal often results in landfill accumulation or the need for hazardous materials processing, both of which contribute to the ecological footprint of airport operations. Moreover, the logistical and administrative demands associated with donation, resale, or specialized disposal may further strain security operations. Although sustainability has become an increasingly important consideration in the aviation industry, efforts have mainly focused on alternative fuels and emissions reduction. However, airport operations, including security procedures, also significantly contribute to waste generation and energy consumption. Therefore, it is crucial to incorporate sustainability principles into aviation security policies and practices. By broadening passenger awareness beyond mere regulatory compliance to encompass sustainability and operational efficiency, airport authorities may reduce the volume of intercepted items and support more effective, environmentally responsible security practices.

A key limitation of this study is the lack of up-to-date and comprehensive data on confiscated items at airports. Many security authorities either do not systematically collect such data or choose not to disclose it publicly due to operational or security-related concerns. Additionally, the available datasets often lack detailed item classifications, which constrains the depth and accuracy of analysis. Future research is recommended to investigate additional factors contributing to the economic impact of airport security operations, conduct a more comprehensive study on sustainability and assessment of the environmental effects from confiscated items, and explore strategies to enhance public awareness and compliance with security regulations. By expanding the scope of passenger awareness to include sustainability considerations, airport authorities can contribute to both reduced item confiscation and more sustainable aviation security practices.

Conclusion

This paper is the first to examine the relationship between passenger traffic and the number of confiscated items at airport screening checkpoints. Using data from the United States and the Republic of Korea, the findings revealed a strong positive correlation between passenger volume and the number of confiscated items, particularly at Incheon International Airport (ICN), where the correlation coefficient reached 0.937. A similar pattern was observed in U.S. TSA

firearm data, with a correlation of 0.868 (excluding COVID-affected years), reinforcing the robustness of this trend. The results suggest a need to strengthen existing policies or develop new strategies aimed at reducing the number of prohibited items brought to airport security checkpoints.

Beyond the correlation analysis, the study also quantified part of the economic losses associated with additional screening procedures required to detect prohibited items. The estimated cost of \$1.58 per manual bag search, based on the time spent by both security personnel and passengers, translates to an economic loss exceeding \$5.5 million at ICN in 2019 alone. This figure does not include further costs such as pat-downs, administrative processing, or waste management. These findings underscore the operational and financial burdens that prohibited items impose on airport security systems, an issue often overlooked in discussions of aviation sustainability.

This research suggests the necessity of adopting new approaches to reduce the presence of prohibited items at airports. As global air traffic continues to grow, integrating sustainability principles into aviation security policies will be essential to ensure safe, efficient, and sustainable operations. By broadening airport security strategies to include sustainability considerations, the aviation industry can better manage long-term resource use, reduce environmental impact, and support future-ready security operations, and this ultimately increasing the overall security.

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Lessons from the 2023 IEEE Autonomous Drone Chase Challenge

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The IEEE Drone Chase Challenge was held in 2022 and 2023 to foster development in Unmanned Aerial Systems and to provide a venue for collegiate students developing integrated UAS solutions in which to compete. The challenge is comprised of two stages: an online simulator-based stage and a physical in-person final. The development of each competitor's unique solutions and difficulties faced by each finalist team are described herein. Improvements for other future competitions are suggested based on the experiences of the competitors and hosts from the 2023 IEEE Drone Chase Challenge. First, software integration and documentation must be complete and easy to follow for competitors, allowing them to focus on solution development, rather than troubleshooting errors. Second, scoring metrics must be designed to test for robustness to mitigate the effect of luck and other external conditions on the evaluation of a solution. Despite the current limitations realized during the competition, competitors, hosts, and the research community benefit from developing soft and technical skills through competition participation.

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Introduction

Unmanned aerial systems (UAS) have seen widespread adoption across new and established markets in the past decade. The use of UAS in applications such as search and rescue, package delivery, farming, and mapping continues to increase as rapid advances in battery technology, computational capabilities, artificial intelligence, and communications improve. The projected market growth of UAS is expected to increase to \$115 billion in 2035 due to the growth of unmanned aerial mobility and the potential delivery market (Federal Aviation Administration, n.d.). The continued advancement of UAS will continue to affect multiple industries across the globe. However, current limitations and challenges for UAS growth are focused on the limitations and restrictions on UAS artificial intelligence, automation, and operation. UAS systems require significant training investment for general operation to ensure safe and legal operation, as well as additional training on manufacturer-specific platforms. Despite training, UAS operators face limitations in commanding remote aircraft. In addition, operators may only operate one aircraft at a time, constrained by human perception and reaction limitations. Thus, increased automation, enabled by computational and energy capabilities advances, defines the frontier of UAS development (Yasin et al., 2020). Developing advanced algorithms and techniques for Unmanned Aerial Systems (UAS) to perform everyday tasks is vital in developing the technology.

Academic and research competitions have been shown to nurture these new algorithms and technologies. By hosting competitions, teams of students and researchers are given challenges and venues to competitively design, develop, and test real solutions to current and future applications. Thus, to foster the development of computer vision use in UAS applications, the 2023 Institute of Electrical and Electronics Engineers (IEEE) Drone Chase Challenge was hosted by Purdue University at its UAS Research and Test Facility. The competition was held successfully, with solutions from three finalists evaluated for the grand prize. Issues arose during the competition due to the design and software environments that distracted teams from optimizing their solutions. Instead, teams had to focus on achieving system stability after transitioning from the simulator environment. This paper offers details regarding the competition, highlighting lessons learned in hosting a UAS-focused competition based on the input and experiences of competitors. This article was written by some members of the hosting and participating teams to help other competition hosts learn from the successes and failures of the 2023 IEEE Drone Chase Challenge. The inclusion of the names participants and their picture were made at the request of the competing teams.

Computer Vision

Computer vision used in UAS has expanded to provide additional features to improve flight characteristics, obstacle avoidance, and supplement external navigational aids (McEnroe, 2022). Although prevalent on the major manufacturer's flagship models, challenges remain with the weight and power requirements of UAS and computing devices, limiting in-flight performance. Improving lightweight edge computing methods and techniques will expand the potential usage of UAS in existing industries (Wang, 2020). Focused improvements in computational capacity with proportional decreases in power consumption will be foundational

for autonomous flight path planning, obstacle detection, and object tracking. Current solutions for computer vision focus on maintaining an internet or telemetry link with a ground station, with the UAS offboarding heavy computational requirements to a computer with little to no limitations.

Purdue UAS Research and Test Facility

The Purdue University UAS Research and Test (PURT) facility is a large indoor motion capture-equipped facility for developing and testing control algorithms and UAS platforms. The facility is equipped with sixty motion capture cameras that provide millimeter precision real-time position information with six degrees of freedom to UAS, or research objects operating in the facility. A Robot Operating System (ROS) node network is present to serve as communications between the cameras, flight vehicles, rovers, or additional devices that require information. The motion capture cameras provide ground truth information to the entire facility and can emulate positioning systems such as GPS. This facility served as the host venue for the UAS competition described below.

Competition

Academic-focused competitions have fostered the development of advancing technologies and ideas across different fields, including computer vision. Building on successful competitions, such as the annual IEEE Low-power Computer Vision Challenge (LPCVC) (Alyamkin et al., 2019), the IEEE Drone Chase Challenge (DCC) has been hosted since 2022 to encourage the integrated development of computer vision applications in UAS. Rather than focusing on computer vision solutions' power consumption and accuracy, the IEEE DCC takes it further, requiring the integration of computer vision solutions with UAS path planning and command and control algorithms. The tasks needed to be completed by competitors' solutions can be seen in Fig. 1.

The Competition

Overview

The 2023 IEEE DCC was an international competition where any team could submit their solutions for following a rover (ground vehicle) around a mock city landscape of buildings represented by solid blocks. Evaluation of the solutions was based on the distance between the UAV and the rover as it navigated around buildings. The competitors were not provided with the location of the rover and had to identify and track the rover using computer vision. The scoring algorithm used was shown in equation 1:

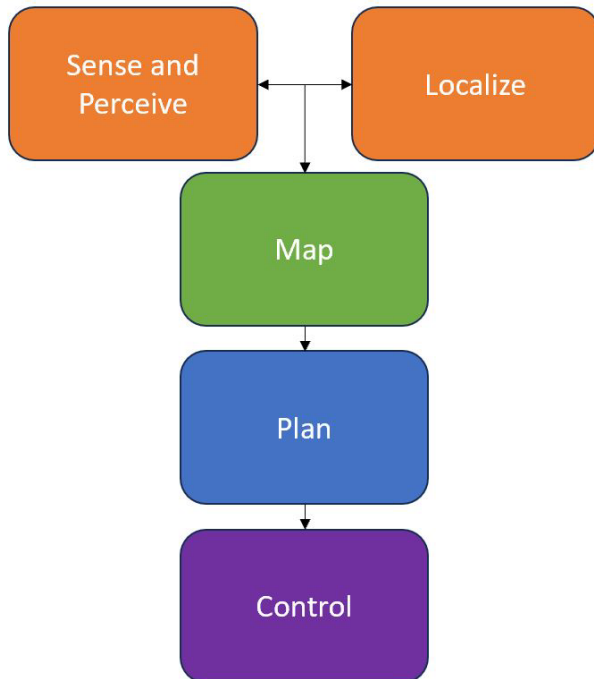
$$S_i = 1 - (|d - 1|/4) \quad (1)$$

S_i was the instantaneous score measured every second and d was the distance between the drone and the rover. The final score for a given trial was the average of all instantaneous scores. Instantaneous scores were only calculated between a start and end flag and while d was under five meters. All values above five meters for d were recorded as a 0. Competitors were allowed

to modify the core elements of object detection, path planning, and control solutions into one system to accomplish the objective.

Figure 1

Tasks required from each team's solution



The competition incorporated two stages. The first stage was an online digital twin (hardware, software, and layout) Gazebo simulator, where participants upload their solutions. A screenshot of the simulation environment is shown in Figure 2. The top-performing teams in the first stage were invited to the second stage, an in-person competition hosted at the PURT facility.

Figure 2

Drone Following Rover in the Simulator

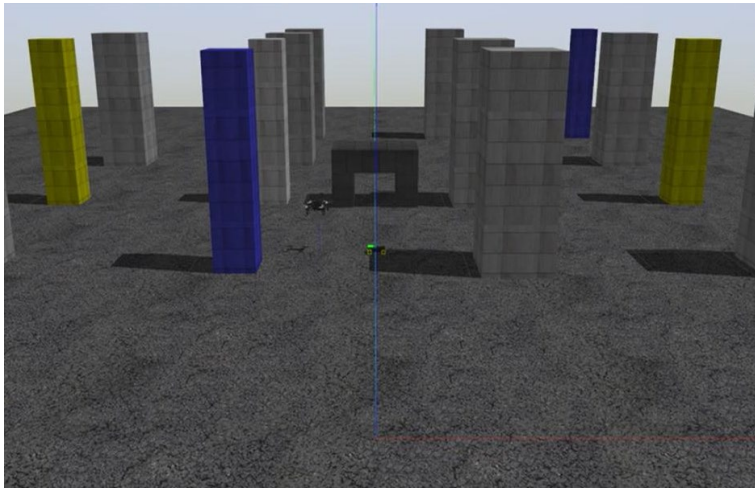


Figure 3

Drone Following Rover at PURT



A sample solution for the simulator was available to all competitors as a baseline and reference solution for implementing path-finding navigation and identifying and tracking the rover. Each solution component was packaged as ROS nodes to improve system performance and communication. The solution used the obstacle detection and avoidance vision algorithms created by PX4. Rover identification and tracking were trained using Openvino. Finally, the implementation of quadcopter planning used Rapidly Exploring Random Trees Star (RRT*). The entire sample solution was provided inside a Docker container to reduce installation overhead.

Due to restrictions during the COVID-19 pandemic, the 2022 competition was held remotely by participants, who provided solutions and were supervised in person by facility staff. Due to the remote nature, all solutions were flown on a Holybro PX4 Vision V1 with an Intel

Neural Compute Stick 2 and an Intel RealSense D435i camera. The 2023 competition's second stage was held in person, with competitors invited to bring and use any system with a wheelbase less than 500 mm. A PX4 Vision, with the same configuration as the 2022 competition, was available for competitors who did not travel with a drone.

Challenges/Trials

The simulator and in-person stages each contained four identical trials. The scores from the most challenging and complicated trial, the fourth, were used to judge winners during the simulator phase. However, for the in-person stage, weighted scores across all trials were used to calculate the final score. Scores from trials 1 and 2 were worth 15% of the final score, while trials 3 and 4 were each worth 35%. The sum of the weighted scores was the final score used to determine the winners. Additionally, the score from Trial 3 could replace a lower or missing score from Trial 1, while a score from Trial 4 could replace the score for all other trials.

In the second stage of the 2023 competition, time slots were allotted for teams to fly their solutions in PURT. Two one-hour periods per day across two days were scheduled for each team. Within their respective time slots, teams had unlimited attempts at trials. The highest score achieved in any attempt for a given trial was recorded as the respective score. For all the trials the rover's path and location after the starting position was unknown to the competitors.

Trial 1

For the first trial, the competitors were required to follow the rover with a red ball attached. The color of the ball was unique in the environment and provided simple identification of the UAV's target. The rover completed one lap of a figure-eight pattern around the competition course. During the duration of the trial, the motion capture system of PURT was used to calculate the distance between the UAV and the rover.

Trial 2

For the second trial, the solution required tracking the rover as it completed the same path as in the first trial. However, a tunnel structure in the rover's path was added to disrupt the vision of the UAV and the rover. The tunnel structure tested the solution's capability of finding and reidentifying the rover.

Trial 3

The third trial was identical to the first trial in regard to the rover's path, speed, and location, except that the red ball was removed from the vehicle. This trial required more complex and sophisticated object detection models to identify and follow the rover.

Trial 4

The fourth trial again utilized a rover with no distinguishing red ball attached. The same course and tunnel as Trial 2 were used. Figure 4 shows the drone following the rover and the tunnel used for Trial 4 in the simulated environment, while Figure 5 shows the same scenario

during the real-world-trial from the same perspective. Figure 6 shows how the drone appeared while following the rover in the real-world trials from a third person perspective.

Figure 4

Computer Vision Example from Simulator Trial

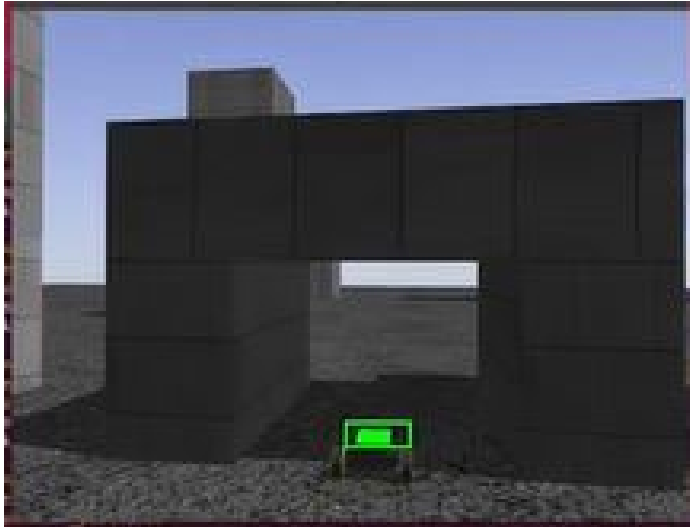


Figure 5

Computer Vision Example from Real-world Trial

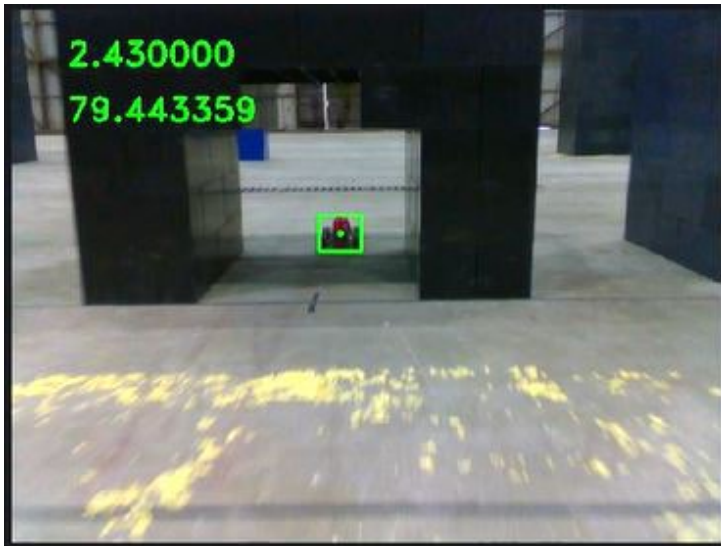
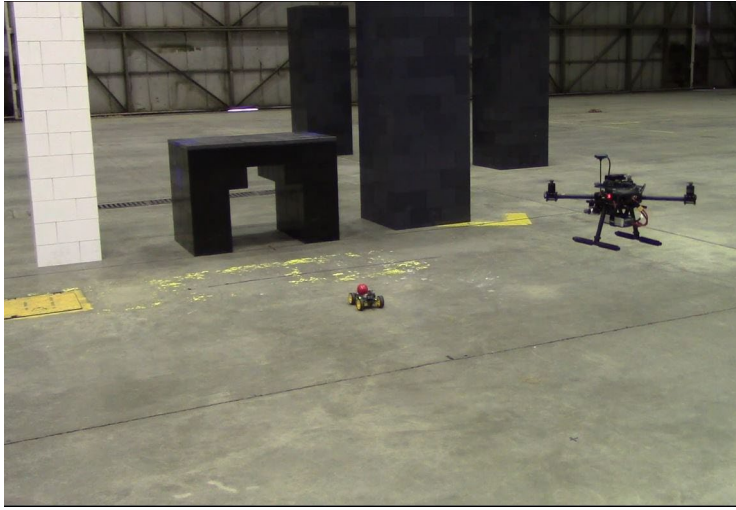


Figure 6*Drone Following Rover as it Approaches Tunnel (Real-world)*

Competitors' Performance and Solutions

While 13 teams registered for the 2023 IEEE DCC, only four teams submitted solutions for the initial simulation stage before the deadline. However, one of the four solutions did not successfully track the rover or navigate the obstacle course. Hence, the top three finalists were selected from the remaining working solutions. Scores from the top three teams in the first stage are presented in Table 1. Due to software issues, some submissions could not be verified (indicated by N/A). Trial 4 for all submissions was valid and was used for the simulator stage results.

The top three finalists then participated in the competition's second and final stage. Due to travel restrictions, team Edrone could not participate in person and thus participated remotely with assistance from staff at the facility. During the finals, BioRobotics finished first, followed by Edrone, then HighFlyers, the same ranking as in the first stage. The best trial scores and final weighted scores of each team are presented in Table 2. All teams competed on the same courses. However, methods to accomplish these tasks differed. Descriptions regarding each team's composition, difficulties, and approach are described in the following section.

Table 1*Results from First Stage*

Team	Trial Scores			
	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Trial 4</i>
BioRobotics	N/A	0.9311	0.9186	0.9388
Edrone	N/A	0.9319	N/A	0.9288
HighFlyers	0.9567	0.9137	0.9363	0.9202

Table 2*Results from Second/Final Stage*

Team	Best Trial Scores (Weight)				Final Weighted Score
	<i>Trial 1 (0.15)</i>	<i>Trial 2 (0.15)</i>	<i>Trial 3 (0.35)</i>	<i>Trial 4 (0.35)</i>	
BioRobotics	0.870 ^b	0.552 ^a	0.870	0.552	0.711
Edrone	0.790 ^b	0.600 ^a	0.790	0.600	0.695
HighFlyers	0.392 ^b	0.244	0.392	0	0.233

^aScores were carried over from Trial 4; ^bScores were carried over from Trial 3**BioRobotics**

Team BioRobotics from the Scuola Superiore Sant’Anna was a team of two researchers and eight undergraduate students from Italy. The team finished first overall in the 2023 IEEE DCC, scoring the highest in Trial 1 and 3 and the second highest in Trial 4. After preparing two workstations by installing all the software necessary for the simulation phase, BioRobotics adopted a “divide-and-conquer” strategy for the tasks described earlier in section B, allowing for parallel development of the solution.

These sub-tasks were identified:

- Drone navigation, common to all trials,
- Drone vision, differentiating it between trials 1 & 2 and 3 & 4
- Obstacle avoidance, trials 1 & 3 and 2 & 4.

The most challenging task was undoubtedly obstacle avoidance. During the simulation phase, a SLAM algorithm based on the Rtabmap library was developed, but it was found after simulation testing to be computationally expensive. The solution's computational cost was evaluated by deploying the entire software stack on an UPcore board with an Intel atom x5-z8350 CPU. The drone's behavior in the simulation was inadequate for tracking the rover, so given that development times were limited by the submission deadline, the team's approach to the problem changed. Instead of calculating the trajectory and then controlling the drone by position, a reactive system was implemented by controlling the drone "with speed". This consisted of calculating speed along x, y, z, and angular speed of yaw based on visual stimuli. Then to avoid unwanted side-effects such as overshooting and dampening, they implemented a proportional-integral-derivative (PID) system to mediate and filter the instantaneous speeds, also considering the past and the future states to make the drone's flight smoother.

Assuming the rover's path would be required to be free of obstacles, and the only "suspended" obstacles would have been the tunnels, the task was divided into two sub-problems: one for obstacle avoidance during the rover's pursuit and one for avoiding tunnels. This new

strategy reduced the drone's reaction times to obstacles to a few hundredths of a second, eliminating the bottleneck in the trajectory calculation and limiting the reaction time to the camera's acquisition rate of 30fps (1 frame every 0.0333s).

The team's positive experience with the simulation phase was enhanced by the opportunity to travel to Purdue University and test the algorithms in a real scenario. Unfortunately, the transition from simulator to reality was difficult, and the only test day was primarily used to readjust indoor flight codes. Simultaneously, the vision group calibrated the color threshold and retrained the neural network to recognize the rover, while the navigation and obstacle avoidance groups tried their best to calibrate the various PID parameters to control the speeds in the various flight phases. Unfortunately, this approach required an accurate calibration phase, and the simulation parameters were unsuitable for the real drone. During the few hours made available for testing, the team made the flight stable enough to follow the rover correctly but were far from the performance obtained in the simulation phase.

Edrone

Team Edrone was composed of ten individuals from Beihang University and SenseTime. The team was composed of graduate students, researchers, and working professionals. The team finished second overall and had the highest score for Trial 4.

The team took a conventional approach focused on optimizing and robust solutions. Initially using only the red, green, and blue (RGB) input from the RealSense camera, the team decided to use depth information to estimate the distance of the rover from the drone, as utilizing RGB information alone was difficult for the later challenges. However, utilizing RGB and depth information led to a computational bottleneck that the team addressed. The reconciliation process between RGB and depth images was sped up by matching only the corners of the images rather than the entire image.

Despite these steps, the team found that the drone was too slow to process visual information and consistently track and follow the drone at a close distance. Additionally, the loss of rover identification led to problems in reidentifying and continued tracking. Thus, the team implemented a PID algorithm to provide control feedback. The PID implementation further improved drone tracking and control while being a relatively robust solution. However, the continuation of tracking after the loss of the rover in many circumstances still occurred. Hence, another improvement to their solution was made by adding a prediction algorithm that anticipated the general direction of the rover's movement rather than anticipating the next point of the rover's travel.

HighFlyers

Team HighFlyers came in third in the competition's first and second/final stages. The team comprised five undergraduate and graduate students from the Silesian University of Technology.

The team had implemented the A* algorithm for path planning (Hart et al., 1968). As for the mapping, the team used the Octomap server available from ROS, similar to team BioRobotics.

During the in-person finals, the team could not field a consistent solution that tracked the rover through the course. Furthermore, without an error-correcting system, the team's solution could never correct its path after a false object detection. Following the competition, the team mentioned that their most significant difficulty was integrating their solutions from the simulator to the real-world system, calling it "integration hell". Cited differences between the simulator stage and the in-person stage include a different camera (RealSense instead of Depth Core Depth Camera), imprecision and errors in the camera, and object detection algorithms not encountered in the simulator. It led to a similar lack of robust real-world camera error-catching. In addition, the team also had problems integrating the open-source software needed, encountering dependency problems, even in the Docker environment provided. Finally, the team mentioned that finding the appropriate documentation and sufficient examples for some of the libraries needed in ROS and for the autopilot was difficult. The limited documentation made the team unable to test some functions before arriving on-site for the finals.

Discussion

Improving Integration and Software

The competition aimed to challenge teams to develop and optimize computer vision, localization and mapping, and control solutions for UAS. Much of the work performed to accomplish the tasks demanded by the competition focused on successfully implementing algorithms and software. While competitors were provided two days to conduct competition flights, they occurred only on the second day. The limited flights indicated that the transfer of solutions from the simulated environment to the real-world environment was not as simple as expected. All teams encountered software implementation and integration issues throughout the competition, including a mismatch in coordinate frames between simulated and actual environments. BioRobotics and HighFlyers cited the solution transfer from the simulator to the in-person system and the software documentation as their most significant problems. While not explicitly mentioned by team Edrone, integrating the software into the real-world drone was also an apparent problem, evidenced by the time the team spent working with the facility's staff to upload their team's solution to the drone.

The challenges faced by the competitors demonstrated to the organizers that improvements to the documentation, sample solution, and facility software are required for future competitions. While the organizers cannot know or provide information for all packages that competitors may use, information regarding the sample solution packages should be refined and provided. Clear instructions to transfer the simulator to a drone should be available in the future to reduce integration difficulties and shift more focus to the solutions. Some participants have suggested that presentation videos explaining underlying concepts, rather than just example code, may be helpful and allow a broader range of competitors to participate. Additionally, a review of the simulator needs to be performed so that it represents real-world conditions more

accurately. Issues such as a different camera used in the simulation compared to the in-person final could be easily fixed by ensuring settings before deploying the software. The simulator should also incorporate processing limitations due to the drone's limited capabilities. Furthermore, ensuring the smooth transition between simulator and in-person stages will reduce the time per team for preparing and running their solutions, increasing efficiency and reducing the cost of hosting the competition. In addition to these individual lessons, the authors recommend that competition hosts test the distributed software, their instructions, and workflow on various computer setups to verify that they are understandable, complete, and functional. Having beta testers sample competition material can mitigate some of the difficulties faced by competitors even before the first iteration of such a competition.

Improving Scoring and Challenges

Improvements to the scoring system and challenges are required to ensure that the competition evaluates competitors fairly and in line with objectives. A simple scoring system based on the approximate distance of the drone from the rover was used. The system led to penalties searching for the rover at different parts of the competition area led to different penalties, with advantages for drones that stop in the middle of the competition area rather than a corner. This results from the maximum distance a rover can get from a drone being higher in non-central locations. A solution to this problem would be to apply penalties on the score based on the distance traveled by the rover since the last time the drone tracked the rover.

Additionally, during the competition, less robust solutions outperformed better solutions in the static environment. BioRobotics' control algorithms worked well because of the information gathered during the test phase. Increased complexity and unique yet equivalent trials can force competitors to develop more robust solutions by adding additional unknowns to the competition task. Examples include varying the height and shape of the tunnel, changing the location of the buildings, and changing the rover's paths from practice runs to score runs, which can be used to test for robustness in solutions.

Submission Rate

Another issue encountered during the competition was the low submission rate from registered teams. While 13 teams registered, only four teams provided solutions, with only three of those solutions being viable. This was an issue that the authors suppose could have been caused primarily by two issues.

First, the tasks demanded by the competition were difficult. Not only were teams expected to use computer vision to identify and track a moving rover, they were also expected to control a flying drone based on the vision input alone. While some students may be expected to accomplish these tasks, many may not be able to without significant study. Second, while teams were able to compete with their own drones, the qualifying simulator stage was built in Gazebo and configured to run with specific software. Hence, not only were teams expected to be able to perform the already difficult competition task, but they were also expected to perform these tasks in a very specific software environment which they may not have been familiar with. Constant delays in the production of the simulator environment exacerbated this issue as teams

were left with only two months to learn, use, and qualify for the competition using the simulator. Several software bugs and compatibility issues compounded this problem.

While related to the high attrition among registered teams, the authors felt that the organizers could have promoted the competition better by posting information about the competition on additional channels and distributing this information through the institutions of potential competitors, and at relevant conferences. Increased promotion may have improved the turnout and output of the competition.

From these experiences, the authors suggest that competitions, especially those targeted towards undergraduate students, be limited in scope such that barriers to entry be reasonable for students who may not be able to dedicate significant amounts of time to the competition or who may not have the combination of skills required to participate. For example, this competition could have focused solely on the control of the drone based on input from a predeveloped computer vision system. Additionally, having a more flexible and open competition where participants did not need to use the simulator and software provided by the hosts could have allowed participants who were capable but not familiar with the competition's preferred software to compete. However, doing so introduces other variables that can imbalance the competition. In summary, the competition's submission rate likely could have benefited from narrowing the scope of the competition or increasing the flexibility of entries.

Value of the Competition

While the 2023 IEEE DCC may not have generated novel developments in path planning, object detection, or command and control algorithms, the competition resulted in learning experiences for the participating competitors and the opportunity to use some of the unique equipment available at PURT. Competitors mentioned that they had learned new technical skills due to participating in learning different software and algorithms commonly used in robotics and UASs. In addition, soft skills were also developed as team members from each team worked in sub-teams specializing in specific tasks required of the entire solution and collaborating to integrate all their work into the final solution. In the case of all three finalist teams, individuals from different backgrounds, majors, and stages in their studies or careers were involved, promoting collaboration and cooperative learning. Participants mentioned how the competition provided them with a venue and means to learn more about the challenges related to UAS and provided motivation to learn more about the subject.

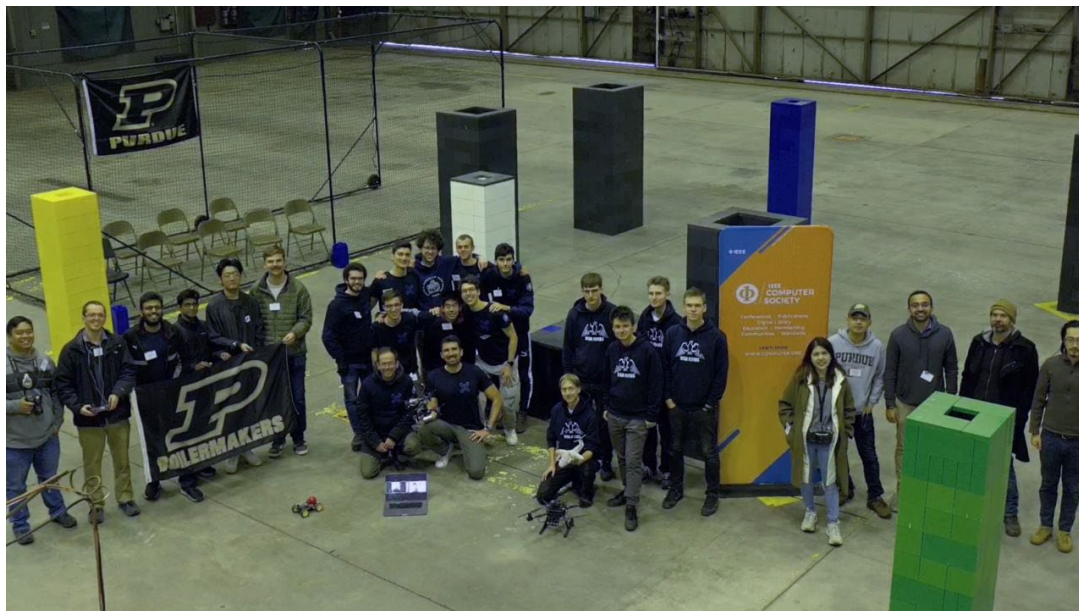
From the host's perspective, the competition, which was primarily organized and run by students, provided practical experience in developing, organizing, and executing an international event. The educational value of hosting such events should not be overlooked by educators and institutions. Students at the host institution learned to coordinate with international participants, develop schedules, answer questions, and coordinate between stakeholders such as the university's risk management team, airport management, safety officials, and legal offices.

Based on these experiences, the authors believe that additional competitions should be hosted to foster not only the engagement of students and researchers in UAS issues, but in other

aviation topics, as well. Competitions allow teams from various schools and organizations to participate in environments and contexts they may not otherwise be exposed to at their home institutions. Bringing together people from various backgrounds fosters additional learning and the potential for collaboration, while allowing institutions and students to compare their knowledge and output with others. This competition provided a unique experience for all its participants and the hosts to learn from, providing a tangible learning experience for all the students involved.

Figure 7

Competitors and Organizers of the 2023 IEEE Drone Chase Challenge at PURT



Conclusion

As autonomous UAS are introduced for various applications, additional development and research in computer vision, localization and mapping, and command and control will be necessary. Through competitions, progress in these fields will be fostered. Using the capabilities available at PURT, the IEEE DCC, held since 2022, aims to provide an opportunity for researchers, students, and industry professionals to compete against others worldwide in developing integrated UAS solutions. In trying to achieve this, the competition organizers have found through the 2023 competition that software integration from simulator to real-world needs to be improved together with software documentation to improve the competition environment and focus on what matters most: developing better UAS algorithms and solutions. Furthermore, changes to the competition rules and scoring metrics are required to ensure that better, more robust solutions are rewarded over luck-based factors. Despite the issues faced, the 2023 IEEE DCC offered a learning experience for the competitors and hosts alike that will hopefully translate to further developments for the field in the future.

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Fostering Mental Wellness in the Early Stages of Professional Pilots' Careers: A Collegiate Curriculum for Aviators

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Mental health challenges remain a pressing concern in aviation, affecting both professional pilots and collegiate aviation students. Contributing factors include irregular schedules, extended time away from family, academic and operational pressures, and high-performance expectations. Part 141 collegiate flight students face these stressors early in their careers, compounded by the need to maintain Federal Aviation Administration (FAA) medical certification. Stigma and fear of career repercussions discourage many from seeking care, creating hidden safety risks. This ongoing study explores the development of a Mental Wellness Curriculum (MWC) tailored to collegiate flight students, with the goal of embedding proactive wellness education into training. Using a mixed-methods approach, the study draws from existing literature, stakeholder collaboration, and evidence-based practices to design curriculum modules focusing on stress management, resilience-building, stigma reduction, and healthy lifestyle practices. Importantly, the curriculum incorporates Safety Management System principles, positioning mental wellness as a core component of operational safety. Preliminary findings highlight the urgent need for structured mental wellness education to build resilience among future aviators and strengthen the safety culture of the aviation industry.

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Introduction

Aviation is a high-stakes environment where safety depends not only on technical proficiency but also on the psychological health of pilots (Federal Aviation Administration [FAA], 2024; Hoffman et al., 2024). Mental health has increasingly emerged as a critical issue, highlighted by recent high-profile cases such as the Alaska Airlines Flight 2059 incident, in which the pilot reported severe depression, grief, and sleep deprivation (Cleave & Earl, 2025). This event underscored how untreated mental health conditions can escalate into direct safety risks, even among experienced and medically certified aviators (Miller & Assad, 2024). A wide range of operational and lifestyle factors contribute to mental health challenges in aviation. Pilots are frequently subjected to extended time away from home and family, erratic schedules that disrupt circadian rhythms, fatigue from long duty days, and a constant burden of safety responsibility. Many also experience isolation during layovers or extended trips and face disruptions to healthy lifestyle habits, including proper diet, exercise, sleep quality, and access to social support. These stressors, when combined, can degrade cognitive performance, slow reaction times, impair decision-making, and ultimately increase risk within the aviation system (Minoreti & Piercarlo, 2023; Walden & Thomas, 2025).

These challenges are not limited to airline pilots. Collegiate aviation students, particularly those enrolled in FAA Part 141 programs, encounter remarkably similar pressures early in their training. Their workload combines demanding science, technology, engineering, and mathematics (STEM) coursework with intensive flight training (Mendonca et al., 2023). The structured nature of collegiate aviation programs creates irregular schedules, late-night study periods, and reduced sleep quality, producing fatigue and stress patterns that closely mirror those of professional operations (Jacobs et al., 2020). Students, like professional aviators, must sustain performance under conditions of high workload and constant evaluation while simultaneously meeting medical certification requirements that create additional stress (Pitts & Faulconer, 2023).

One of the greatest barriers to addressing these issues is the stigma surrounding mental health in aviation. Many aviators (Hoffman et al., 2023), including students (Pitts & Faulconer, 2023), are reluctant to seek support out of fear that disclosure could jeopardize their FAA medical certification and future career opportunities. Financial costs and distrust of the medical review system compound this reluctance. As a result, nondisclosure or “firewalling”, withholding medical information to protect flying privileges, has become common. While this may protect short-term aspirations, it conceals long-term risks and perpetuates hidden safety threats within the system (FAA, 2024).

By recognizing the parallels between collegiate aviation students and professional pilots, it becomes clear that early, proactive mental wellness education is essential. If students are equipped with the tools to manage stress, build resilience, and openly address mental health challenges during their training, they will be better prepared to manage these demands throughout their professional careers (Mendonca et al., 2024). Collegiate aviators represent the primary pipeline for airline, corporate, and military operations, which means the attitudes and habits they develop now will directly shape the future of the industry (Keller et al., 2020). Promoting resilience and wellness from the outset leads to healthier student pilots progressing into healthy professional pilots, ultimately strengthening the overall safety culture within the aviation industry.

Methods

This ongoing study adopts a mixed-methods approach. The first phase involves a comprehensive literature review examining mental health in aviation and identifying gaps in existing programs. The review includes both scholarly studies and recommendations from aviation regulators and industry stakeholders. The second phase emphasizes collaboration with mental health professionals from the Embry-Riddle Aeronautical University Counseling Center and curriculum specialists from the Center for Teaching and Learning Excellence. Their input ensures that the curriculum is both evidence-based and pedagogically sound. Additional perspectives are drawn from aviation professionals working in airline, military, and corporate sectors, who provide insights into the real-world stressors and mental health challenges encountered across professional practice.

Based on these inputs, the project is developing a curriculum that incorporates mental health education (e.g., Jorm, 2012; Golightly et al., 2017), stress management techniques such as mindfulness and relaxation strategies (Rogerson et al., 2024), resilience-building practices, and healthy lifestyle promotion, including sleep hygiene, physical fitness, and social connection (Mahindru et al., 2023; Prakash et al., 2021). Crucially, the curriculum integrates Safety Management System (SMS) principles by framing mental health as a safety hazard that can be identified, assessed, and mitigated through education and training (DeFusco et al., 2015). The final phase of the study involves stakeholder feedback and preliminary evaluation. The curriculum will then be reviewed and refined with input from students, counselors, faculty, and aviation professionals, with the aim of ensuring its relevance, effectiveness, and adaptability across collegiate aviation contexts.

Expected Findings and Conclusions

Mental health in aviation continues to be an area that requires stronger engagement and leadership from academia (Boyd & Bliss, 2024; Cross et al., 2024; Mendonca et al., 2024; Wilson et al., 2023), the FAA (2024), and the wider aviation community (International Civil Aviation Organization, 2022; Royal Aeronautical Society, 2024). While much attention has been given to regulatory barriers and crisis management, less progress has been made in developing proactive strategies that prepare aviators to manage their psychological well-being before problems escalate. One promising approach to fill this gap is education (DeFusco et al., 2015; FAA, 2024; Shin et al., 2022). By embedding structured training on mental wellness into collegiate flight programs, institutions can better equip future pilots to manage stress, build resilience, and openly address mental health challenges without fear of stigma (Bowyer et al., 2024).

The current study is developing a Mental Wellness Curriculum designed specifically for Part 141 collegiate flight students. Unlike prior research that has focused on one-time interventions, this project seeks to establish a sustainable and evidence-based framework that can be integrated into existing aviation training (Mendonca et al., 2024). Drawing on mental health best practices (e.g., National Institute of Mental Health, 2024), input from counseling professionals, and aviation-specific safety considerations (e.g., FAA, 2024), the curriculum emphasizes stress management, resilience-building (e.g., Lacomba-Trejo et al., 2022), healthy

lifestyle practices (University of California San Francisco, n.d.), and the integration of SMS concepts (DeFusco et al., 2015). The expectation is that such a curriculum will not only increase mental health literacy among collegiate flight students but also foster a culture in which psychological well-being is recognized as essential to operational safety.

Preliminary insights indicate that collegiate pilots already face many of the same stressors as professional aviators, including irregular schedules, heavy performance pressure, and fatigue (Boyd & Bliss, 2024; Pan & Mendonca, in press). Yet, despite these challenges, many students hesitate to seek professional help. The stigma surrounding mental health in aviation, combined with fears that disclosure could jeopardize their FAA medical certification and career prospects, creates powerful disincentives for open discussion (FAA, 2024; Pitts & Faulconer, 2023). This reluctance perpetuates hidden risks and underscores the need for early education that normalizes help-seeking behavior and reframes wellness as a safety-critical issue rather than a personal liability.

Although the study is ongoing and outcome data are not yet available, the curriculum development process has highlighted the value of proactive education. Integrating mental wellness into collegiate aviation training is expected to reduce misinformation, encourage healthier coping strategies, and strengthen resilience before students enter professional practice. By addressing stigma and disclosure concerns directly, the program aims to reshape attitudes toward mental health, preparing students to manage these issues throughout their careers.

Significance of this Study

The importance of this study lies in its potential to address one of the most pressing and under-discussed safety challenges in aviation: mental health (FAA, 2024). Collegiate pilots, much like their professional counterparts, face demanding schedules, high performance expectations, and the constant pressure of maintaining medical certification (Mendonca et al., 2024). Yet many lack the tools to manage these stressors effectively, often constrained by the same stigma and fear of disclosure that discourage professional pilots from seeking support (Pan, 2025; Pitts & Faulconer, 2023). By developing and integrating a Mental Wellness Curriculum, this initiative seeks to correct misinformation, narrow knowledge gaps, and improve overall mental health literacy among pilots, while fostering resilience and encouraging early help-seeking behaviors. The long-term impact of this work may extend well beyond the university setting, as students who are trained to value and practice mental wellness carry these skills into their professional careers. In this way, early education creates a trickle-down effect: healthier student pilots evolve into healthier professional pilots, strengthening safety culture across the aviation industry and helping to transform mental health practices throughout the broader aviation ecosystem.

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Data-Driven Analysis of Engine-Related Wildlife Strikes in Multi-Engine Jet Aircraft (2009–2023)

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Wildlife strikes remain a persistent hazard to aviation safety, with engine ingestions representing a particularly serious threat to aircraft performance and operational integrity. This study analyzes 13,467 wildlife strikes involving aircraft engines reported in the FAA National Wildlife Strike Database (2009-2023) to identify patterns and operational factors influencing the frequency and severity of engine strikes in multi-engine civil jet aircraft. Building upon Dolbeer's (2017) findings, preliminary results indicate a modest left-side predominance, with 4,112 strikes (52.9%) recorded on left-side engines and 3,659 strikes (47.1%) on right-side engines. A total of 2,266 strikes (16.8%) resulted in engine damage, most frequently during the takeoff, climb, and approach phases of flight. Nearly 47% of all engine strikes occurred below 1,000 feet AGL, underscoring the near-ground nature of these events. Although small-bodied species accounted for most engine strikes ($N = 8,757$; 64.1%), large-bodied species, representing only 7.1% of events, produced the highest proportion of damaging engine strikes (61.6%). These results demonstrate a clear relationship between animal size, impact energy, and engine vulnerability. Collectively, the findings confirm that engine strikes remain predominantly a low-altitude, airport-environment hazard, reinforcing the need for species-specific mitigation strategies, enhanced habitat management, and data-driven Safety Management System initiatives to improve wildlife-hazard risk assessment and operational resilience across the aviation industry.

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Introduction

Wildlife strikes remain a persistent hazard to aviation safety worldwide. In the United States alone, more than 313,000 wildlife strikes to civil aircraft were reported between 1990 and 2024, resulting in at least 126 aircraft destroyed and 82 fatalities (Dolbeer et al., 2025). Despite major advances in airport-based mitigation and habitat management (Cleary & Dolbeer, 2005), the frequency of reported strikes continues to rise, largely due to increasing aircraft movements, expanding populations of large bird species protected under the Migratory Bird Treaty Act, and improved awareness and reporting practices. While many strikes occur near airports, events beyond the airfield perimeter, particularly those involving turbofan-powered, multi-engine aircraft remain an operational safety and economic concern. Engine ingestions account for a significant proportion of damaging strikes and can result in power loss, precautionary landings, or catastrophic failure (FAA, 2025a). The Federal Aviation Administration's (FAA) National Wildlife Strike Database (NWSD) provides an extensive dataset to analyze these occurrences and guide hazard-mitigation strategies across flight phases and aircraft types (FAA, 2025b).

Dolbeer (2017) analyzed NWSD records from 1990 to 2015 for commercial transport and business jets equipped with two underwing-or fuselage-mounted turbine engines to determine whether bird strikes occurred more frequently on one side of the aircraft. The study found a statistically significant bias toward strikes on the left (red-lighted) side, suggesting that avian visual sensitivity to longer wavelengths may reduce birds' ability to detect and avoid aircraft from that direction. Building upon this foundation, the current investigation revisits the phenomenon using an expanded dataset (2009-2023) to evaluate whether the left-side bias identified by Dolbeer (2017) persists in modern fleets. Specifically, the study compares the frequency of bird strikes between left and right engines, as well as the proportion of damaging strikes affecting each side. In addition, descriptive analyses are conducted to examine operational variables associated with these events, including phase of flight, time of day, and altitude of strikes.

Understanding the distribution and characteristics of engine-specific wildlife strikes is vital for improving hazard identification, risk assessment, and mitigation within the aviation system. Studies of this nature play a critical role in advancing aviation safety by transforming operational data into actionable insights that guide technology development, regulatory policy, and Safety Management System (SMS) initiatives (Ayres et al., 2009). The findings contribute to ongoing efforts to enhance wildlife-hazard management through evidence-based safety strategies and data-driven decision-making.

Methods

Data for this study were obtained from the FAA NWSD, which documents voluntarily and mandatorily reported wildlife strikes involving civil aircraft in the United States (FAA, 2005b). The dataset for this ongoing study includes strike reports submitted by pilots, maintenance personnel, airport operators, and other aviation stakeholders from 2009 through 2023. To ensure consistency and comparability, only turbine-powered, multi-engine civil jet aircraft were included in the analysis. The dataset was first filtered to include strikes involving aircraft equipped with two, three, or four jet engines. Records missing information about engine number and time of day were excluded to maintain analytical accuracy.

Engine position was standardized to allow comparison of left- and right-side strikes across different aircraft configurations. For two-engine aircraft, left-engine strikes corresponded to *engine #1*, and right-engine strikes to *engine #2*. For three-engine aircraft, left-side strikes included those involving *engine #1* and *engines #1 and #2*, while right-side strikes included those involving *engine #3* and *engines #2 and #3*. For four-engine aircraft, left-side strikes included *engine #1*, *engine #2*, and *engines #1 and #2* combined, while right-side strikes included *engine #3*, *engine #4*, and *engines #3 and #4* combined. This categorization provided a consistent framework for comparing strike frequency and severity between the left and right sides of multi-engine civil aircraft.

Descriptive analyses were then conducted to examine the total number of strikes and the proportion of damaging strikes reported for each side. Additional variables extracted from the NWSD included phase of flight (e.g., takeoff, approach, and landing), time of day (day, night, dawn, dusk), and altitude of strike occurrence. These variables were organized to identify patterns and operational conditions most frequently associated with engine strikes. A more robust statistical analysis will be conducted to further investigate potential differences between left- and right-engine strikes; however, this paper presents preliminary descriptive findings to highlight emerging trends and guide subsequent inferential work.

Preliminary Findings and Discussions

The wildlife hazard problem must first be understood before it can be effectively mitigated. As Cleary and Dolbeer (2005) noted, “a vital first step toward understanding and solving the multidimensional wildlife hazard problem is the collection and analysis of data from actual wildlife strike events” (p. 5). In this context, the present analysis examines wildlife strikes involving multi-engine civil jet aircraft to identify patterns, trends, and operational factors specifically associated with engine strikes. This study focuses exclusively on engine-related wildlife strikes, excluding all events involving other aircraft components such as wings, fuselage, landing gear, and or windshield. Between 2009 and 2023, a total of 13,467 wildlife strikes involving aircraft engines were reported in the FAA NWSD, of which 2,266 (16.8%) resulted in damage to one or more engines. The majority of reported engine strikes involved two-engine civil jet aircraft ($n = 13,059$), although three- and four-engine configurations ($n = 408$) were also represented.

When combining all aircraft configurations, left-side engines accounted for 4,112 strikes (52.9%) of all recorded engine events, while right-side engines accounted for 3,659 strikes (47.1%), indicating a modest but consistent left-side predominance consistent with Dolbeer’s (2017) findings. In terms of damaging events, 803 strikes were reported to left-side engines and 775 to right-side engines, a distribution similar to that observed for total strikes. These results suggest that while left engines experience a slightly higher overall exposure to bird strikes, the proportion of damaging events relative to total strikes is comparable between sides. Analysis by time of day showed that engine strikes were most frequent between 6:01 a.m. and 6:00 p.m., accounting for 6,342 events (47.1%) of all reported cases. The largest number occurred during the morning period (6:01 a.m. to noon; $n = 3,686$; 27.4%), followed by the afternoon period (12:01 p.m. to 6:00 p.m.; $n = 2,656$; 19.7%). The highest proportion of damaging events (20.7%) was observed during the afternoon hours, when both bird activity and air traffic density

tend to peak. Strikes occurring during nighttime hours (6:01 p.m. 6:00 a.m.) represented 3,762 events (27.9%), of which 665 (17.7%) resulted in damage. These findings suggest that while the majority of engine strikes occur during daylight, the risk of damage remains appreciable across all time periods, likely reflecting variations in both avian behavior and operational lighting environments.

Phase-of-flight data revealed that total engine strikes were most frequent during the approach ($n = 3,970$; 29.5%), climb ($n = 1,493$; 11.1%), and takeoff ($n = 1,332$; 9.9%) phases, reflecting increased bird activity and aircraft proximity to ground-level habitats. In contrast, damaging engine strikes were proportionally more common during the climb ($N = 631$; 42.3%), takeoff ($n = 413$; 31.0%), and cruise ($n = 16$; 26.7%) phases, when higher airspeeds and engine thrust could increase the severity of impact (Eschenfelder; 2005; Mendonca et al., 2024). Altitude data confirmed that the vast majority of engine strikes occurred below 1,000 feet AGL, within the airport environment or its immediate vicinity. A total of 6,379 strikes (47.4%) were recorded below this altitude band, including 5,787 strikes (43.0%) between 0–500 feet and 592 strikes (4.4%) between 501-1,000 feet. Of these, 1,233 (19.3%) resulted in damage to one or more engines, underscoring that most hazardous wildlife interactions occur during takeoff, landing, or low-altitude maneuvering. These findings reaffirm that engine strikes are overwhelmingly a near-ground hazard, emphasizing the continued importance of airport-area wildlife management, habitat modification, and low-altitude operational awareness as suggested by Dolbeer et al. (2025).

Analysis by size of animal revealed a strong association between species body mass and the severity of engine strike outcomes (Dolbeer, 2020). Of the 13,647 engine strikes analyzed, the majority involved small-bodied species ($n = 8,757$; 64.1%), but these accounted for a comparatively low proportion of damaging engine strikes ($n = 659$; 7.5%). Medium-sized species ($n = 2,538$; 18.6%) were responsible for 829 damaging engine strikes (32.7%), while large-bodied species ($n = 975$; 7.1%) produced the highest proportion of damaging engine strikes ($n = 601$; 61.6%). This pattern demonstrates a direct positive relationship between animal size and the severity of engine impact, aligning with prior findings that larger birds and mammals transfer greater kinetic energy to turbine components upon collision (DeVault et al., 2011). These results underscore the critical importance of species- and size-specific risk management strategies in reducing the probability of damaging engine strikes within the airport environment.

Conclusions

This study provides a focused examination of engine-specific wildlife strikes involving multi-engine civil jet aircraft between 2009 and 2023, expanding upon earlier research by Dolbeer (2017). The descriptive findings reveal that the vast majority of strikes occur below 1,000 feet AGL, predominantly during takeoff, climb, and approach, and that left-side engines experience slightly greater exposure than right-side engines. Although most events involve small-bodied species, the likelihood of damage increases substantially with animal size. Collectively, these findings reinforce that engine strikes are primarily a low-altitude, airport-environment hazard that warrants continued emphasis on habitat management, avian-activity monitoring, and risk-based mitigation strategies. The significance of this study lies in its ability to inform evidence-based safety practices and support the development of predictive models for

engine-strike risk assessment, contributing to more effective SMS integration and enhanced operational resilience across the aviation industry.

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12-05-2025

Impact of Mentoring on College Mentors: A Student Perspective in an Aviation-Focused Program

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Serving as a mentor can offer numerous benefits, including the development of interpersonal and leadership skills, increased confidence, and a sense of purpose. However, mentors may also face challenges related to time management, emotional commitment, and balancing academic and personal responsibilities. Despite the growing popularity of mentoring programs, limited research has examined the specific impacts that mentoring has on the mentors themselves—particularly in terms of academic performance, emotional well-being, and career aspirations. This mixed-methods research project investigates the experiences of college-level female students who mentor female high school students pursuing aviation or aerospace-related education. Participants are members of STEM-focused student organizations and serve as mentors to students enrolled in high school programs such as Embry-Riddle Aeronautical University's Aerospace Career Academies (ACA) and/or Jr. ROTC programs. The study aims to explore how mentoring experience affects college students' academic progression, leadership development, and emotional resilience. Data collection includes a pre-survey and post-survey administered via Qualtrics, as well as a 45-minute recorded focus group conducted via Zoom. All identifying information will be kept confidential, and pseudonyms will be assigned after initial data collection to protect participants' identities. By better understanding the effects of mentoring on mentors, this research seeks to inform the development of future programs that foster mutual growth and support, enhancing the mentoring experience and encouraging more individuals to serve in such a role, formally or informally. Additionally, the study aims to explore how serving as a mentor helps students develop transferable skills and professional competencies that positively impact their transition into the workforce and future career paths.

Recommended Citation:

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Literature Review Summary

Emerging research shows that mentoring can be a powerful and meaningful experience for mentors, supporting both emotional and psychological growth. Prummer et al. (2024) found that mentoring helps develop emotional intelligence by increasing empathy, self-awareness, and emotional control. Serving as a mentor gives students structured opportunities to reflect on their experiences and improve how they relate to others. Through this process, student mentors strengthen their ability to manage emotions and build supportive relationships within academic and social settings. These findings suggest that mentoring helps mentors grow personally and interpersonally, not just professionally.

Pölczman et al. (2025) also found that student mentors in a near-peer mentoring program reported higher levels of resilience and confidence. Their study showed that helping and guiding peers builds coping skills, adaptability, and self-belief. These results highlight that mentoring is a two-way learning process; mentors benefit emotionally and mentally as they support others.

Further recent studies by Higson (2025) and McCleary-Harris (2025) reinforce that mentoring has influences in both directions, demonstrating continued scholarly interest in understanding how mentoring impacts those who serve as mentors. Higson (2025) observed that mentoring encourages students to build emotional intelligence and resilience by learning to handle challenges and adapt to change. Likewise, McCleary-Harris (2025) found that mentoring enhances communication, flexibility, and relationship-building skills, while also fostering a stronger sense of belonging in academic communities. Together, these recent contributions add evidence that mentoring benefits both mentors and mentees across multiple areas of development.

Despite the growing body of evidence, more research is needed to understand how mentoring specifically affects student mentors across different academic contexts. Exploring how mentoring supports mentors' emotional intelligence, resilience, and sense of belonging is important for designing programs that provide lasting benefits to both participants. The present study aims to address this gap by focusing on the mentor's experience as a key part of effective mentoring practices in higher education.

Program Overview

The mentorship program originated within the Women in Aviation (WAI) Chapter at Embry-Riddle Aeronautical University (ERAU) and was initially designed to connect college mentors from the WAI Chapter with high school students enrolled in the Gaetz Aerospace Institute's Aerospace Career Academies.

Recruitment focused on volunteer mentors, which achieved 23 student mentors who signed up. However, 15 high school mentees participated in the first cohort, which meant some mentors were never paired or were paired in partnership with another mentor, giving two mentors to one mentee.

The program's objectives were rooted in the belief that mentorship promotes leadership development and self-awareness through real-world engagement; enhances emotional intelligence, empathy, and resilience through interpersonal connection; strengthens communication and adaptability; and fosters belonging and purpose within academic and professional aviation communities.

Research Purpose and Design

The purpose of this study is to examine the developmental outcomes experienced by college-level female mentors who support high school students in aviation and aerospace education pathways. While mentoring programs are often evaluated based on the benefits to mentees, comparatively little is known about the effects of mentoring on the mentors themselves. This study seeks to address that gap by investigating how mentoring shapes mentors' academic engagement, leadership development, resilience, and career aspirations within the context of a gender-imbalanced field.

Specifically, this research aims to understand how the mentoring relationship functions as a reciprocal learning process for college women in aviation-related programs. Serving as mentors may foster a sense of belonging and self-efficacy in a field where women remain underrepresented. Through semi-structured mentoring activities, reflection, and relationship-building, mentors may develop enhanced communication skills, empathy, adaptability, and confidence in professional settings. In addition, mentoring can offer meaningful opportunities for personal growth, including encouraging self-reflection, purpose development, and an expanded understanding of leadership and community contribution.

By focusing on mentors' experiences, this study contributes to a broader understanding of how peer-based outreach initiatives can serve as transformative learning opportunities for emerging professionals. The findings aim to inform the design of mentoring programs that intentionally support both mentor and mentee development, with particular attention to fostering persistence and leadership among women in STEM and aviation disciplines.

The study employs a mixed methods design to capture both quantitative and qualitative dimensions of the mentoring experience. Pre- and post-surveys assess shifts in mentors' academic engagement, confidence, and self-perceived leadership competencies, while focus group interviews explore the emotional and interpersonal aspects of mentoring relationships. Together, these data sources provide a holistic view of how serving as a mentor contributes to students' academic and personal development, ultimately supporting their transition from higher education to professional practice in aviation and aerospace careers.

Research Questions:

1. How does participating as a mentor impact academic progression and growth?
2. How does mentoring influence interpersonal and leadership skills?
3. What challenges do mentors encounter?
4. How do these challenges shape the mentoring experience overall?

Data were collected through initial applications, monthly reflection forms, and planned but unexecuted post-event focus groups. While reflection submissions were limited (16 total, from 7 unique mentors), qualitative insights revealed that mentors often discussed topics such as college life, work, and resume preparation. Mentors expressed varying levels of success and engagement, from highly productive sessions to frustration with mentee participation.

Findings and Challenges

Preliminary findings indicate that mentors experienced increased confidence and empathy, though they also struggled with time constraints and mentee engagement. While mentors claimed they had sufficient resources, informal conversations revealed a desire for more support materials and guidance. Challenges included inconsistent data collection, rolling pairings that limited longitudinal tracking, and variable mentor commitment. Despite these obstacles, enthusiasm for continued involvement remained high, suggesting that increased participation may occur with minor adjustments.

Program Evolution and Future Directions

The program has since expanded beyond its original cohort. It is not limited by gender for both mentor and mentee participation, and reaches dozens of dual-enrollment high schools across Florida. Program management tools such as Monday.com and improved Canvas design have increased efficiency and mentor accountability. Recruitment efforts remain ongoing and continue to evolve to reach a broader demographic of potential mentors and mentees.

Intentional Growth: Considering Middle School Involvement

As the program matures, organizers are exploring the inclusion of middle school students through early exposure initiatives. However, this expansion will be approached intentionally to ensure developmental appropriateness, mentor readiness, and resource sustainability. Engaging middle school students presents unique opportunities: fostering interest in STEM and aviation earlier, nurturing long-term academic pathways, and building continuity across educational stages. Yet, it also introduces challenges—such as the need for age-appropriate mentorship strategies and additional mentor training.

Conclusion

Mentorship provides dual benefits: empowering mentees while cultivating leadership, communication, and emotional intelligence among mentors. Findings from this study suggest that even limited engagement as a mentor can yield meaningful personal and professional growth for college students. Participants reported increased confidence, empathy, and self-awareness, as well as a greater sense of purpose and belonging within the aviation community. These outcomes align with prior research highlighting mentoring as a transformative, reciprocal process that promotes emotional resilience and leadership development among participants.

However, the study also illuminated several challenges, including inconsistent participation, limited time availability, and the need for clearer program structure and ongoing

mentor support. These findings underscore the importance of intentional program design. This is more emphasized given that this is a volunteer-based initiative where academic and personal responsibilities compete for participants' attention, both mentors and mentees. Strengthening mentor training, providing structured reflection opportunities, and incorporating feedback mechanisms can enhance both mentor satisfaction and developmental outcomes.

From an institutional perspective, mentoring programs such as this can serve as powerful tools for retention, engagement, and leadership cultivation among underrepresented groups in aviation and aerospace. By fostering supportive relationships and opportunities for meaningful contributions, universities can help mentors translate their mentoring experience into tangible career readiness and self-efficacy. Moreover, programs that explicitly acknowledge and assess mentor development are better positioned to sustain participation and achieve long-term impact.

As the ERAU mentorship initiative expands to include a wider variety of participants and potentially middle school partnerships, the lessons learned from this research will guide evidence-based growth. Continued data collection and longitudinal tracking will be critical to understanding how mentoring influences academic persistence, professional identity formation, and leadership trajectories over time. Future research should also explore the intersection of gender, discipline, and mentorship dynamics to further refine strategies for fostering inclusive pathways into aviation and STEM careers.

Ultimately, this study reinforces that mentoring is not a one-sided endeavor. Mentoring is a collaborative, evolving process that benefits both mentors and mentees. By centering mentor experiences, educators and program designers can create sustainable frameworks that empower students to grow as leaders, advocates, and future professionals in the aviation and aerospace industries.

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Assessment of Mental Health and Help-Seeking Barriers Among Collegiate Aviation Students

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Mental health concerns among collegiate aviation students have become increasingly significant as the demands of flight training and academic performance intersect with regulatory pressures unique to the aviation industry. This study examined levels of anxiety, depression, and self-stigma related to help-seeking among students enrolled in aviation-related programs across five U.S. institutions. Using a non-experimental, quantitative survey design, data were collected from 231 participants using the Generalized Anxiety Disorder-7 (GAD-7), Patient Health Questionnaire-9 (PHQ-9), and custom items assessing stigma and attitudes toward seeking mental health support. Results revealed that 43.7% of respondents met criteria for at least mild anxiety and 39.8% for at least mild depressive symptoms. Notably, over half of the respondents expressed reluctance to seek counseling due to concerns about Federal Aviation Administration (FAA) medical certification implications. Findings highlight the prevalence of mental health challenges among aviation students and underscore the need for institutional interventions to reduce stigma and align support services with aviation-specific career considerations.

Recommended Citation:

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Introduction

Collegiate aviation students, including those pursuing programs in flight training, air traffic control management (ATC), and aircraft maintenance (A&P), face unique high psychological and academic demands. Managing academic coursework, practical coursework, and Federal Aviation Administration (FAA) certification requirements often contributes to elevated levels of stress, anxiety, and reduced well-being among these students (Mendonca et al., 2023; Pitts & Faulconer, 2023). Broader research indicates that nearly one in three young adults experience depression or anxiety, with 30.6% of those aged 18–25 reporting depressive symptoms in 2020 (Goodwin et al., 2022). Aviation-specific stressors, however, extend beyond academics. The FAA medical certification process introduces an additional psychological burden. More than half of collegiate aviation students perceive FAA mental health regulations as overly restrictive, and nearly half report reduced willingness to seek professional help as a result (Stein, 2023). Such perceptions mirror trends among professional aviators, where disclosure fears often deter care-seeking (Cross et al., 2024). Research on professional pilots and air traffic controllers indicates elevated rates of anxiety, depression, and fatigue linked to high workload, performance evaluation, and regulatory scrutiny (Wu et al., 2016; Rutledge et al., 2024). However, limited studies have explored these issues among collegiate aviation students, a critical population preparing to enter the industry. To address this research gap, this study aimed to evaluate collegiate aviation students' mental health, perceptions surrounding help-seeking behavior, and FAA medical disclosure.

Methodology

Research Design and Participants

A non-experimental, quantitative survey design was utilized to measure mental health indicators and attitudes among collegiate aviation students. Participants were recruited from five U.S. institutions offering aviation training programs. Eligible participants were 18 years or older and actively enrolled in an aviation-related major, including flight, air traffic control management (ATC), aviation maintenance (A&P), or unmanned aircraft systems (UAS).

Data Collection and Analysis Procedures

A 35-question online survey was distributed via Google Forms and consisted of three components: (1) demographic and academic background; (2) standardized mental health instruments; and (3) custom items addressing self-stigma and regulatory attitudes. The Generalized Anxiety Disorder-7 (GAD-7) and Patient Health Questionnaire-9 (PHQ-9) provided quantitative assessments of anxiety and depression severity, respectively. Both instruments are validated for screening in non-clinical populations and use cutoff thresholds to categorize symptom levels as minimal, mild, moderate, or severe. The final section comprised ten custom statements rated on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree), assessing stigma, willingness to seek counseling, and perceived FAA medical certification repercussions. These items were developed based on existing literature in aviation psychology and pilot stigma research. Data were analyzed using IBM SPSS to calculate descriptive statistics,

correlations between variables, and non-parametric Kruskal-Wallis H-tests to explore group differences by program type and gender.

Results

A total of 231 valid responses were included in the analysis. The majority of participants were male (71%), aged 18–24 (84%), and pursuing flight training or air traffic management programs (68%). Figure 1 illustrates the distribution of GAD-7 anxiety levels, while Figure 2 displays PHQ-9 depression scores across participants.

Figure 1
GAD-7 Anxiety Score Distribution

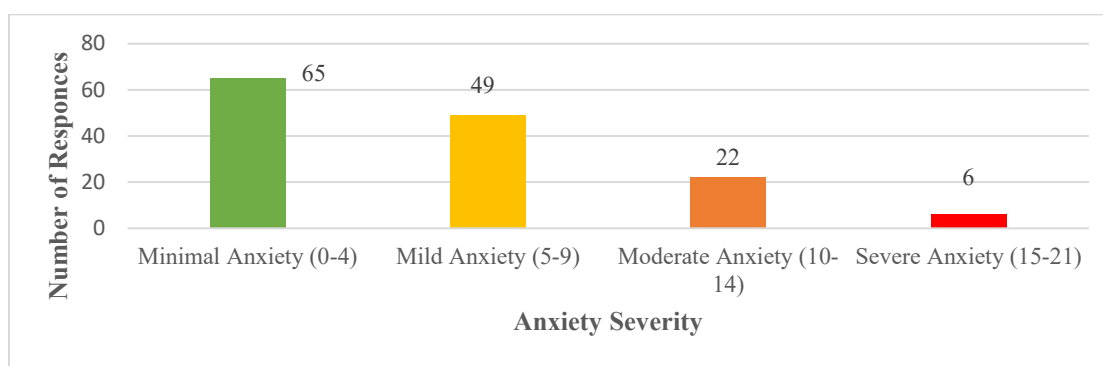
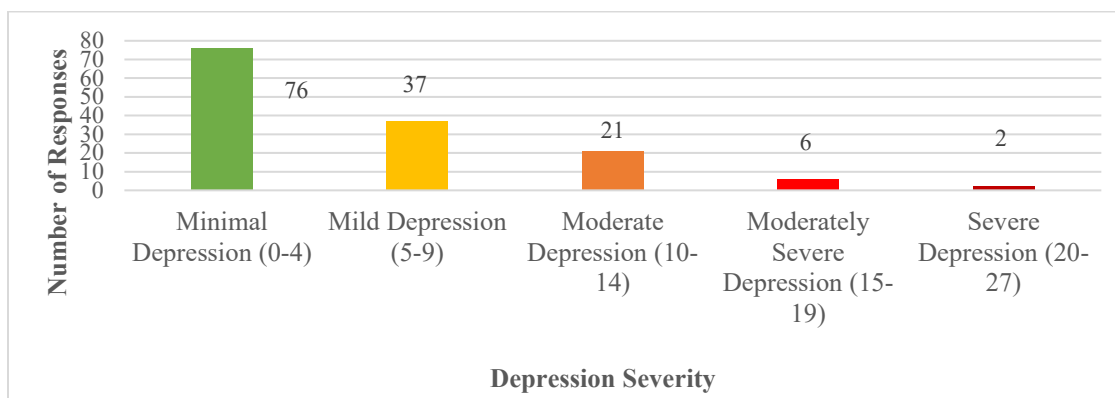


Figure 2
PHQ-9 Depression Score Distribution



Analysis revealed that 43.7% of participants met criteria for at least mild anxiety (GAD-7 ≥ 5), with 18.1% reporting moderate to severe symptoms (GAD-7 ≥ 10). Similarly, 39.8% exhibited at least mild depressive symptoms (PHQ-9 ≥ 5), and 15.3% fell within the moderate to severe range (PHQ-9 ≥ 10).

A significant proportion of respondents (56%) agreed or strongly agreed that they would hesitate to seek counseling due to FAA medical certification concerns. Approximately 48% agreed that pilots who disclose mental health issues are perceived as less competent, reflecting

internalized stigma within the aviation community. Gender-based comparisons using Kruskal–Wallis tests indicated no significant differences in anxiety ($p = .432$) or depression scores ($p = .379$). However, female participants reported slightly higher perceived stigma levels and greater concern about regulatory repercussions.

Discussion

The results highlight a substantial prevalence of anxiety and depression symptoms among collegiate aviation students, consistent with broader trends in university populations but complicated by aviation-specific stressors (Abrams, 2022; Goodwin et al., 2022; Mendonca et al., 2023). Prior research has shown that collegiate aviators experience higher levels of psychological distress due to the combined demands of academic performance, financial pressure, and the technical rigor of flight training (Clarke et al., 2024; Pitts & Faulconer, 2023). The intersection of mental health and aviation regulation introduces unique barriers, as fear of FAA medical review may deter individuals from seeking timely support (Stein, 2023; FAA, 2024). This finding underscores the systemic nature of stigma in aviation, where mental health is often equated with diminished performance or safety risk (Cross et al., 2024; Corrigan & Rao, 2012).

The high percentage of students reluctant to seek counseling potentially reflects perceived incompatibility between self-care and aviation professionalism. Many participants viewed mental health disclosure as a potential career threat, mirroring concerns observed in professional pilot populations (Wu et al., 2016; Minoretti et al., 2023; Rutledge et al., 2024). Similar trends have been documented among airline pilots and air traffic controllers, where fear of certificate suspension or career disruption discourages open discussion of psychological concerns (DeHoff & Cusick, 2018; Cross et al., 2024). These findings suggest that education surrounding FAA medical policies is insufficient and that misconceptions about disqualification remain widespread (FAA, 2024).

From an institutional perspective, aviation programs should consider integrating proactive wellness initiatives, including confidential counseling access, peer mentorship, and faculty training to identify at-risk students. Such approaches align with prior research emphasizing the role of early intervention and resilience training in collegiate pilot programs (Mendonca et al., 2024; Key et al., 2023). Embedding mental health resources into existing Safety Management System (SMS) frameworks may also normalize psychological well-being as a component of aviation safety culture. Rather than focusing solely on compliance, SMS implementation could incorporate mental health indicators into hazard identification and risk assessment processes (Ahad et al., 2023; Ahmed et al., 2021; Flight Safety Foundation, 2024).

Additionally, outreach from the FAA to clarify mental health reporting procedures could alleviate unnecessary fears among student pilots. Improved communication and transparency regarding the medical review process have been recommended by both academic researchers and aviation safety organizations (Shepardson, 2023; FAA, 2024). Collaborations between regulators, universities, and flight departments are needed to modernize the perception of mental fitness, ensuring that students can seek help without jeopardizing aviation career aspirations (Boyd & Bliss, 2024; Minoretti, 2025).

Conclusion and Future Work

This study highlights that mental health challenges, particularly anxiety, depression, and stigma, are prevalent among collegiate aviation students. The results indicate that regulatory perceptions significantly influence help-seeking behavior, with more than half of participants citing FAA medical concerns as a deterrent to accessing support. Institutions should prioritize targeted mental health education and integrate well-being strategies within training curricula to promote a sustainable, safety-oriented aviation workforce. Future research should explore trends or changes in student mental health as they progress through training, examine intervention effectiveness, and compare aviation-specific populations with general university cohorts.

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12-05-2025

Investigating Health-Promoting Lifestyle Factors and Demographic Impacts Among Collegiate Flight Students

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Collegiate flight students face unique physiological and psychological challenges in maintaining a balanced and health-promoting lifestyle due to the simultaneous pressures of academic coursework and intensive flight training. This study investigated the interrelationships among six dimensions of a health-promoting lifestyle, health responsibility, physical activity, nutrition, spiritual growth, interpersonal relationships, and stress management. A quantitative, non-experimental survey design was utilized with the validated Health-Promoting Lifestyle Profile II (HPLP II) instrument. Data was collected from 191 collegiate flight students enrolled in Federal Aviation Administration (FAA) Part 141 programs across the United States. Findings indicated a moderately healthy overall lifestyle score ($M = 2.64$, $SD = 0.39$), with significant positive correlations among all six lifestyle categories. No statistically significant differences were found between genders or among different flight certification levels. Results suggest that health behaviors among collegiate flight students are interdependent, with stress management, interpersonal relationships, and spiritual growth demonstrating the strongest associations with overall wellness. These findings provide actionable implications for aviation training programs and policymakers to enhance collegiate flight student well-being, optimize performance, and promote a stronger safety culture in flight training operations.

Recommended Citation:

Pan, B. D. & Mendonca, F. A.C. (2025). Investigating health-promoting lifestyle factors and demographic impacts among collegiate flight students. *Collegiate Aviation Review International*, 43(2), 444-451. Retrieved from <http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/10447/9195>

Introduction and Background

Collegiate flight students experience distinctive challenges in sustaining healthy lifestyle practices as they manage the concurrent demands of rigorous academic coursework and intensive flight training schedules. The result is a population that is particularly vulnerable to fatigue, nutritional imbalance, stress, and limited sleep quality. These challenges mirror many of those experienced by professional airline pilots, who often report higher incidences of fatigue, sedentary behavior, and poor diet due to irregular schedules and operational demands (Minoretti & Emanuele, 2023; Venus & Holtforth, 2022). While considerable literature exists on the general health behaviors of college students (e.g., American College Health Association [ACHA], 2022; Huang & Liu, 2020) and on occupational health risks faced by commercial pilots (Wilson et al., 2023), there remains a research gap in understanding how collegiate flight students manage their wellness. The collegiate flight student population represents a transition phase between higher education and the professional aviation industry, and their lifestyle patterns may have long-term implications for safety and performance in future airline careers.

A health-promoting lifestyle is defined as a multidimensional approach to personal well-being encompassing six domains: health responsibility, physical activity, nutrition, spiritual growth, interpersonal relationships, and stress management (Walker et al., 1995). Prior studies have shown that maintaining positive behaviors in one domain often enhances outcomes in others (Phulkerd et al., 2021; Al-Qahtani, 2019). For example, regular exercise contributes to stress reduction and improved interpersonal relationships, while spiritual growth and social support enhance resilience under pressure (Amiri et al., 2019). Conversely, neglecting these dimensions can have cascading effects, leading to fatigue, reduced concentration, and psychological strain, critical factors that impair pilot performance and decision-making (Clarke et al., 2024).

Given the aviation industry's sustained emphasis on safety, performance, and human factors, understanding the lifestyle behaviors of collegiate flight students is essential for both educational and operational contexts. The health and well-being of student pilots directly influence their cognitive performance, stress management, and overall readiness to meet the physical and psychological demands of flight operations. Identifying patterns in lifestyle choices can help educators, training institutions, and regulators develop evidence-based interventions that foster safer and more sustainable professional practices. Accordingly, this research investigates two key areas: (a) the relationships among the six dimensions of a health-promoting lifestyle and (b) the extent to which demographic factors, specifically gender and flight experience, may influence these behaviors within the collegiate aviation population.

Methodology

Research Design

This study utilized a quantitative, non-experimental survey design using the Health-Promoting Lifestyle Profile II (HPLP II) developed by Walker et al. (1995). The survey instrument consisted of 52 items on a 4-point Likert scale (1 = Never, 2 = Rarely, 3 = Sometimes, 4 = Often), measuring the frequency of engagement in health-promoting behaviors across the six

lifestyle dimensions. The HPLP II has demonstrated high internal consistency and construct validity in multiple populations (Cronbach's $\alpha = .78-.84$; Tanjani et al., 2016). The survey also collected demographic data, including gender, age, academic level, and flight certification. Flight experience was measured ordinally by the highest certification attained (e.g., Student, Private, Instrument, Commercial Single-Engine, Commercial Multi-Engine, and CFI/CFI-I).

Participants and Data Collection Procedures

Participants in this study consisted of 191 collegiate flight students enrolled in FAA Part 141 flight training programs at six universities across the U.S. Eligibility criteria required participants to be at least 18 years of age and actively involved in flight training within the preceding six months. Following Institutional Review Board (IRB) approval, the survey was distributed online via Microsoft Forms®. Faculty and department chairs at participating institutions were invited to encourage participation in the study and share the survey link among their students. A non-random convenience sampling approach was utilized to recruit participants and collect data.

Statistical Analysis

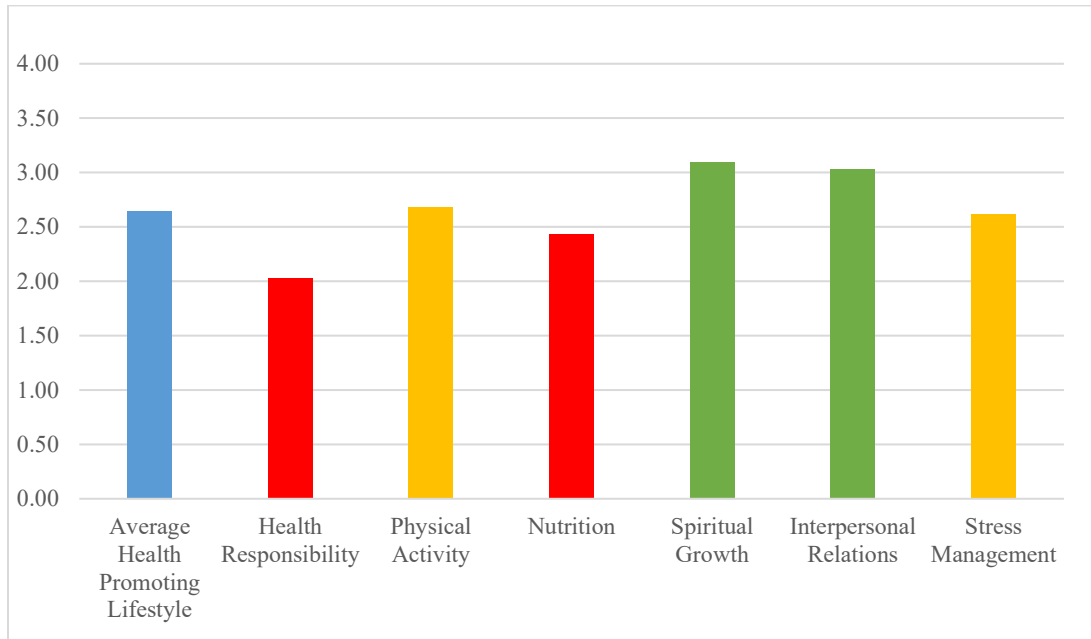
Descriptive statistics were computed to summarize demographic distributions and mean HPLP II scores. To test relationships among lifestyle domains, two-tailed Pearson correlation analyses were conducted. One-way ANOVA tested for differences by flight certification, and independent-samples t-tests evaluated gender-based differences. Statistical significance was set at $p < .05$. Analyses were conducted using IBM Statistical Package for Social Sciences (SPSS).

Results

Descriptive Statistics

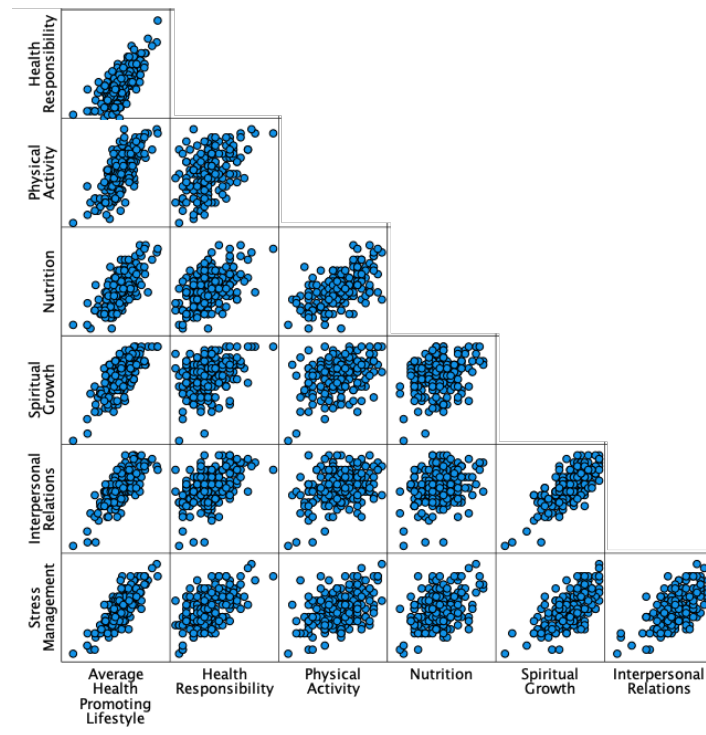
Of the 198 responses received, 191 were valid and included in the analysis (Male: $n = 137$; Female: $n = 52$; Prefer not to say: $n = 2$). The majority of participants were aged 18–21 (82%), with most students enrolled as sophomores (31%) or juniors (27%). Flight experience ranged from student pilot to certified flight instructor (CFI/CFII). The overall mean HPLP II score was 2.64 ($SD = 0.39$), indicating a moderately healthy lifestyle. Among the six categories, health responsibility ($M = 2.03$) and nutrition ($M = 2.42$) scored below the moderate threshold (between 2.5 and 3), while spiritual growth ($M = 3.09$), interpersonal relationships ($M = 3.03$), and physical activity ($M = 2.68$) showed healthier patterns. Figure 1 presents the mean scores across categories.

Figure 1
Mean Health-Promoting Lifestyle Scores by Category



Correlations Among Lifestyle Categories

Pearson's correlations indicated significant positive relationships among all six lifestyle categories and the overall HPLP II score ($p < .001$). Large-effect correlations were observed between stress management and overall lifestyle ($r = .808$), spiritual growth and overall lifestyle ($r = .751$), and interpersonal relationships and overall lifestyle ($r = .759$). These findings suggest that students who engage more frequently in one health-promoting behavior similarly tend to engage more frequently in others. The scatterplot matrix (Figure 2) illustrates these interrelationships.

Figure 2*Scatterplot Matrix of Relationships Between Lifestyle Categories*

Demographic Analyses

A one-way ANOVA revealed no significant differences in overall lifestyle scores among students with varying flight certifications, $F(6, 191) = 0.50, p = .775$. Likewise, an independent-samples t-test indicated no gender differences in overall HPLP II scores (male: $M = 2.65$, female: $M = 2.65$; $t(187) = -0.05, p = .964$). These results suggest that gender and flight experience exert limited influence on the extent to which flight students engage in health-promoting behaviors.

Discussion

Interconnected Lifestyle Behaviors

The significant correlations among all health-promoting lifestyle categories reinforce the idea that wellness behaviors function as a system rather than as isolated actions. Improvements in one area can positively influence others, consistent with prior findings from Amiri et al. (2019) and Phulkerd et al. (2021). The particularly strong association between stress management and overall lifestyle implies that coping strategies and emotional regulation play a central role in maintaining well-being during flight training. Effective stress management may enable students to make healthier nutritional choices, engage in physical activity, and foster stronger interpersonal relationships.

Role of Health Responsibility and Nutrition

Health responsibility and nutrition were the lowest-scoring domains, which aligns with previous findings among college populations (ACHA, 2022; Huang & Liu, 2020). Flight students may prioritize operational training and academic performance over personal health maintenance due to time constraints, financial pressures, or lack of institutional support. This behavior could have long-term safety implications, as neglecting nutrition, rest, or exercise may compromise cognitive performance and reaction time in aviation settings. Structured health-education programs integrated into flight curricula could enhance awareness and self-management among students.

Gender and Experience Effects

Although previous studies have found gender differences in health behaviors, often with females reporting higher wellness engagement (Baum et al., 2021; Pop et al., 2021), this study found no significant gender effect. One explanation may be the highly standardized and regimented nature of flight training, which imposes similar routines, schedules, and behavioral expectations across all participants regardless of gender. Similarly, no significant differences emerged by flight certification level, suggesting that as students progress in training, they may not substantially alter their lifestyle behaviors. Instead, wellness habits may develop early in training, indicating a potential for early intervention in freshman or sophomore years.

Implications for Aviation Education and Safety

The findings have practical implications for aviation safety management systems (SMS) and collegiate flight program design. Institutions can enhance training outcomes by promoting wellness initiatives that target nutrition, stress management, and physical activity. Faculty and administrators might incorporate regular health check-ins, fatigue management modules, and mentorship programs emphasizing lifestyle balance. A stronger focus on mental and physical well-being can directly influence flight performance, reduce attrition rates, and foster safer future professionals.

Conclusion and Future Research

This study provides empirical evidence of significant interrelationships among the six domains of a health-promoting lifestyle in collegiate flight students. Although overall lifestyle scores were moderately healthy, deficits in nutrition and health responsibility highlight areas for institutional intervention. Future research should expand the sample to include international flight students, examine longitudinal lifestyle changes across training phases, and explore the influence of environmental and institutional factors. Integrating quantitative and qualitative approaches could yield deeper insight into behavioral motivations and barriers to healthy lifestyle habits in aviation education.

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Military Veterans to Collegiate Aviation and Beyond: Lessons Learned Supporting Collegiate Aviation Student Veterans

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Military veterans bring leadership, discipline, and experience to collegiate aviation. Yet, their transition from military service to academic and professional flight careers often presents distinct challenges, even when compared to other non-traditional students. This article presents three effective strategies for supporting and enabling student veteran success in aviation programs. The first example highlights the Charlie and Hazel Daniels Veterans and Military Family Center. This on-campus, public-private partnership provides mentorship, community reintegration, and transition services for veterans and their families. The next initiative, Vets2Wings, is an FAA-funded initiative that offers targeted funding to assist current student veterans in achieving their professional pilot career goals. Finally, the last section addresses the unique challenges and complications that veterans may face when seeking FAA medical certification, along with recommendations on methods to ease the process. Collectively, these examples highlight strategies that can strengthen institutional support systems and promote smoother transitions for student veterans from military service to successful aviation professionals.

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Introduction and Background

Military veterans bring leadership, discipline, and valuable experience to college aviation, but they often encounter complex transitions as they shift from military life into an academic and professional environment. As non-traditional students, they must navigate a form of social reintegration while dealing with unique financial and medical certification challenges when compared to their more traditional counterparts. This article examines three key areas to demonstrate how these challenges can be addressed, enabling veteran students to succeed in collegiate aviation programs. The first section discusses the Charlie and Hazel Daniels Veterans and Military Family Center, an on-campus public-private resource to help veterans transition into civilian life. Next, the Vets2Wings initiative highlights the value of targeted funding, career mentorship, and industry engagement to help veterans transition into an aviation career by offering flight training assistance. Finally, the last section examines the unique challenges that prior-service military members may face when applying for their FAA Medical certification and offers suggestions to ease the process. Together, these three examples provide integrated approaches to help veterans successfully transition from military service to collegiate aviation programs and onto successful aviation careers.

The Charlie and Hazel Daniels Veterans and Military Family Center

MTSU Veterans Programs

A non-traditional student is referred to as someone who does not follow the typical academic path by attending college directly after high school. The difference between military veterans and other non-traditional students lies in the environment they are coming from. Veterans are accustomed to the rigors of military structure. Many veteran students have active combat experiences that are vastly different from those of everyday citizens, let alone younger traditional college students. These differences can lead to a form of culture shock that presents challenges to the transition from active-duty military service to veteran student status. Middle Tennessee State University (MTSU) has developed a comprehensive program to help veteran students navigate the path into the college environment. In addition, an internal support structure has been developed specifically for Aerospace veterans, which emphasizes outreach designed to encourage social interaction. The Aerospace program expands the university's goal to maintain active involvement opportunities for veterans, along with direct mentoring as needed for individuals who so desire.

Mission

Musician Charlie Daniels had strong ties to Tennessee and held his very first Volunteer Jam concerts at MTSU during the 1970s, establishing a close relationship with the university. Mr. Daniels has been quoted as saying, "I learned at an early age that only two things protect America, the grace of Almighty God and the United States military." Charlie Daniels saw an opportunity to give back to veterans and worked with MTSU to open The Charlie and Hazel Daniels Veterans and Military Family Center, where he remained actively involved until his death in 2020. The center was established in April of 2015, and a 3,200-square-foot facility was completed and staffed by November of that year. The Daniels Center's mission is to provide

transition services to veterans and their families as they return to civilian life after military service. To accomplish this mission, the center has developed the “E” mission, which consists of five tenets: *Enroll* military-connected students; *Encourage* those students while they attend MTSU; assist with *Employment* opportunities; *Educate* the MTSU community at large about military-connected student involvement; and *Expand* the veteran-educated knowledge base. As of Fall 2025, 1,252 veterans and their dependents are served at MTSU, accounting for 6% of the university's student base.

Goals of the “E” mission are accomplished through the dedicated work of twelve full-time employees funded by the university, the state of Tennessee, and the federal government. Additional full-time employee funding comes from the Daniels Center’s self-directed fundraising efforts. The senior advisor for the program is a retired 3-star Army general with 38 years of active-duty experience, including 14 years as a general officer and 5 1/2 years of combat experience. A full-time director and assistant director lead the day-to-day operations of the center. The staff consists of a full-time veterans’ health advocate who provides mental health counseling and a veterans’ benefits advocate for vocational rehab counseling. The center is fortunate to have two on-site, full-time veteran service officers to help veterans process their Veterans Administration (VA) claims. Additionally, the Daniels Center employs a veteran job placement specialist, a university school certifying official, and a VA school certifying official.

Veteran Personal Outreach

The Daniels Center offers numerous and varied services to veterans. What makes them truly unique is that they offer these services to any veteran, from anywhere, not just the MTSU community. Aside from providing ample office and lounge areas dedicated to veteran usage, Daniels Center personnel will also travel to a veteran if needed. They have helped veterans and their families financially through rent and mortgage payments and raised over \$150,000 to assist veterans in financial need during the COVID pandemic. They have participated in off-campus community and business outreach programs through benefits fairs with major companies such as Alabama Power and Nissan. The Daniels Center strives not only to help develop a veteran’s educational path but also to provide veterans and their families with professional development opportunities. Through specific training sessions, the center helps develop resumes, obtain job interviews, and develop entrepreneurial knowledge.

In addition to assisting with personal, governmental, and VA issues, the Daniels Center works tirelessly to welcome and accept military veterans and their families into the MTSU community. Organized newcomer in-briefings and social mixers are a large part of the introductory process. Overall information about the center, including program updates, individual veteran successes, and coverage of their program, is provided in an outreach publication. Journey magazine, available both online and in print, helps veterans keep up with all the center does. It is a way to get information out to anyone, including the public, in a widely accessible manner. Although recognized by the university president en masse at each main university graduation ceremony, the Daniels Center also holds separate veteran graduation stole ceremonies for prior service members and their families in a more private and personal setting. These ceremonies emphasize the sacrifices veteran families have made prior to attending college, in addition to celebrating the great successes of each veteran who has achieved

graduation. These ceremonies elicit high emotions, great pride, and have proven to be a key recognition focal point.

Veteran Social Interaction

The Daniels Center places equal emphasis on the social aspect of the university community, offering veterans many opportunities to enjoy the Nashville area and its entertainment venues. The university, through the Daniels Center, has established relationships with numerous organizations that offer veterans and their families complimentary admission to various events. They have partnered with the Nashville Predators hockey team, Nashville Sounds baseball, and the Nashville Soccer Club, not only for game tickets, but also for special military and MTSU-centered events that recognize veterans directly. There have also been tickets provided for the Nashville Symphony, Grand Ole Opry, and the Nashville Ballet. NASCAR and Formula 1 races have been attended by MTSU veterans free of charge. The social and entertainment opportunities are truly amazing, and all made possible through the hard work of Daniels Center employees. The Daniels Center is the main reason that MTSU remains one of the nation's most military-focused universities.

Aerospace Veterans Group

Aerospace faculty members, many of whom are veterans themselves, noticed that student veterans were searching for assistance with their transition into the department, in addition to the university. An initial interest meeting for veterans was organized, consisting of 10 veteran students and two faculty members. The discussion primarily focused on what the veterans needed and what they were experiencing in their college classes, as compared to what they had expected. Feedback indicated that veterans were accustomed to receiving straightforward answers and wanted people they could trust to provide them with information that would help navigate department-specific details. Course selection, the flight lab process, VA funding for flight training, VA issues with FAA physicals, and the general process needed for success in the Aerospace department were discussed. What the veterans divulged during this meeting was that they wanted a point of contact who was trustworthy and understood where they were coming from as active-duty military personnel. Although they wanted no special treatment, they did feel different from the traditional student base. "These kids don't get it," was a common sentiment initially as the veterans, understandably, differentiated themselves from the average college student. Another key point emphasized was that they wanted social interaction with other veterans within the department. Although the Daniels Center does an excellent job connecting veterans to the university community, Aerospace veterans wanted a similar situation on a more personal level with their Aerospace peers.

The MTSU Aerospace Veterans Group was established during the spring semester of 2022. As of 2025, the number of veterans in the department stands at 212, which equates to 15.5% of the Aerospace student population. Eight faculty and staff personnel are also former military. Three professors in the professional pilot concentration, the largest concentration in the department, are former military pilots. The two UAV faculty and staff members are veterans, along with senior faculty in the maintenance management concentration. Additionally, the flight operations program manager and one of the three flight training managers are also former

military. As the advisory function of the Group is well covered, in addition to the support received from each other, veteran Aerospace students start out with a full grasp of who to see and what to do from day one. To date, this network has greatly eased the transition into the department.

An equally important function of the Aerospace Veterans Group is the social aspect within the department. One might say that this aspect is most important, since a great deal of advice occurs during social functions. Gatherings are held at least monthly. Restaurants, sports bars, pool and dart halls, and firearms ranges have all been frequented by the MTSU Aerospace Veterans Group. Gathering numbers average between 25 and 50, with as many as 60 veterans attending some activities.

The combination of services offered by the Charlie and Hazel Daniels Veterans and Family Center and the Aerospace Veterans Group continues to provide MTSU Aerospace veterans with the camaraderie and mentorship that they are used to from their military time. The programs provide valuable insight and opportunities within the university environment to veteran students and have been instrumental in aiding veteran student success.

Vets2Wings

Background

The Veterans Pilot Training Pilot Program, branded Vets2Wings (V2W), at the University of North Dakota (UND) is a new initiative designed to help U.S. military veterans transition into aviation careers by offering funding for flight training. The program, officially launched on 4 October 2022, is funded through a \$2.5 million cooperative agreement with the FAA and is designed to assist veterans who already hold a private pilot's license in completing FAA instrument, commercial multi-engine, and certified flight instructor certifications and ratings. The program recruited current veteran students at all levels of the Commercial Aviation degree program to participate through four separate application sessions. The V2W program is also part of a broader effort to address the national pilot shortage, which has significantly impacted regional airlines and airports across the U.S.

Students are selected to participate in the program through an online application that gathers their demographic and eligibility status. Additionally, it elicits short essay responses concerning the students' willingness to participate in the program and measures their career aspirations to become commercial aviation pilots.

Veteran Student Benefits

Each veteran student who joined the program is unique in their program status, and the amount of Veterans Affairs (VA) or National Guard benefits they receive. The administrative team's finance and accounting professionals analyze each student's needs and update them on a monthly basis to ensure funds are expended in a timely manner. On average, each of the current participants will receive approximately \$24,500 of flight training benefits, with the range extending from \$17,500 to \$71,500.

In addition to the flight course cost benefits, veterans also participate in mentorship and career advice sessions led by industry professionals. These sessions increase their opportunity to successfully transition to Restricted ATP hours, building and commercial airline positions post-graduation. Some of the mentorship involves information and application advice for major airline pathways programs. Currently, 75% of V2W students either belong to a pathway program or plan to apply to one within the next year.

Since many veteran participants are non-traditional students who bring prior life and professional experience to college, this program also provides excellent mentorship and camaraderie opportunities for the students.

Industry Interaction

The Vets2Wings (V2W) program hosted several key industry engagement events throughout the 2022-2025 academic years, providing valuable insights and career guidance to veteran students pursuing aviation careers. The industry events ranged from focused small group discussions and presentations to roundtable networking sessions. To date, the program has hosted ten events where students interacted with representatives from more than twenty different airlines and aviation companies. These events fostered an environment of mentorship, career development, and industry connections, ensuring V2W students are well-prepared for their future careers.

Measures of Success

From November 2022 to October 2025, the following metrics illustrate participants' dedication to the program as well as their overall success.

- 30 veteran students have graduated and begun building hours towards their R-ATP
- Overall average GPA for V2W members stands at 3.5, with numerous students making the Dean's List each semester (perfect 4.0 average)
- 100% of V2W students have passed the FAA-required written examination for each certificate on the first attempt (program goal is 90%)
- 170 FAA certificates and ratings have been earned by V2W students

Post Graduation

Through the Summer Semester of 2025, the V2W program has produced 30 graduates. Upon graduation, participants will seek employment to begin building flight hours towards their Restricted Airline Transport Pilot (R-ATP) FAA certification. One of the benefits of graduating from the University of North Dakota's aviation program is that students will only require 1,000 hours of flight time to qualify for this certificate. This allows them to reach airline pilot positions much sooner.

Each semester, a V2W representative from UND flight operations shares valuable insights into the hiring process for students interested in flight instructor positions, with advice that can be applied to any aviation career. To date, 53% of our V2W graduates have been hired

as flight instructors at UND, which exceeds the 20% average hiring rate for all graduates and is yet another testament to their aptitude, maturity, and success within the program.

Student Feedback

The administrative team continually seeks student feedback within the program to improve and tailor it to student needs. Additionally, the students share their opinions on the overarching benefits of the program. The top five themes are presented below:

1. Allows students to focus on studies and flying without stressing about paying the bills
2. Enables more camaraderie amongst participants; they learn from and mentor each other
3. Gives students a support group; provides a common bond
4. Students can see how the dream of flying professionally can become a reality
5. Industry visits have connected students to industry partners, resulting in enhanced mentorship and pathway opportunities to the major airlines

Lessons Learned

Based on three years of implementation, several key lessons have emerged regarding program impact and best practices. This program has been highly successful in providing veteran aviation students with additional funds to cover the flight course costs not already covered by other veterans' assistance sources. More importantly, this program demonstrated that our veteran students are very professional and dedicated to achieving their goals of becoming commercial airline pilots, helping to alleviate the current and projected shortage of commercial pilots in the United States.

The additional benefits provided to veterans in this program increase their chances of success in the program and post-graduation. The peer-to-peer mentorship opportunities that arise during the program are invaluable, and many veterans seek the same type of camaraderie they enjoyed during their military service. Potential employers also recognize the benefits of prioritizing veteran hiring and have been eager to engage with the V2W students in small group settings, which also increases our veterans' chances of success.

Future of Funding Veteran Flight Training

It is hoped that additional funding will be available in the future to expand this pilot program to other institutions, so that many other veterans can achieve their dream careers in commercial aviation. UND Aerospace is eager and ready to share the lessons learned from this program with other aviation universities that desire to establish a similar program.

Overcoming Veteran Medical Certification Challenges

As previously mentioned, veterans can make exceptional students. Beyond the typical non-traditional student, they tend to be more purpose-driven and have experience being responsible for themselves and others, resulting in an increased level of maturity. This can not only provide for their own success, but it can also serve as an example for other students. Yet,

this advanced maturity often stems from unique experiences gained as a result of their military service, and these experiences can make FAA medical certification more complicated than that of more traditional collegiate aviation students. This includes more extensive and documented medical histories, possible Veterans Administration (VA) disability ratings, and distrust of governmental medical systems that is equal to or greater than that found in civilian aviation (Hoffman et al., 2023).

This section outlines some of the unique FAA medical complications that veterans can experience, their impacts, and some methods that may be used by both veterans and collegiate aviation programs to ease the process of receiving their FAA medical certificate.

Common Veteran FAA Medical Complications

Given the combat and combat-like experiences encountered by many veterans, it is not uncommon for them to leave the military service with medical diagnoses and VA disability ratings that can complicate receiving a Federal Aviation Administration (FAA) Medical Certificate. A few of the common issues veterans can face when applying for their medical include mental health, traumatic brain injury (TBI), and Obstructive Sleep Apnea (OSA) diagnoses or ratings. Additionally, there are a few lesser-known and often unexpected issues that can cause delays and difficulties for aviation personnel with prior military experience. This includes prior military medical waivers that may not directly transfer to the FAA system, non-compensatory (0%) and ‘surprise’ disability ratings, off-label prescriptions, and other non-medical issues, such as military non-judicial punishment.

When evaluating individuals with mental health, TBI, and OSA ratings or diagnoses, the Aviation Medical Examiner (AME) and FAA must consider several factors for each case, including the severity of symptoms, types of treatment, and the recency of symptoms, treatments, and any changes in treatment (U.S. Federal Aviation Administration [FAA], 2025a). Even with these factors, an AME is often able to issue a medical certificate upon completion of the examination. The FAA provides mental health, head and brain injury, and OSA decision tools to help AMEs determine what they can approve at their level and what conditions may require deferral for further evaluation (FAA, 2025b).

Lesser-Known Complications

Besides these more common conditions, several lesser-known issues can complicate the FAA medical process for veterans. One often surprising item is that prior military aviation medical waivers are not automatically approved by the FAA. In fact, if the waiver does not match one of the Conditions AMEs Can Issue (CACI) or meet the criteria listed in other decision worksheets, a special issuance will likely be necessary (FAA, 2024). Additionally, the military grants aviation waivers for certain conditions and medications that currently do not have an approved pathway from the FAA.

Other factors that can cause confusion include 0% and ‘surprise’ ratings. A non-compensatory (0%) disability rating occurs when the VA recognizes a service-connected condition but determines it is not severe enough to warrant compensation (U.S. Department of

Veterans Affairs [VA], 2023). Even though service members do not receive compensation for these conditions, the FAA still recognizes them as disabilities, and, as such, they must be disclosed when applying for an aviation medical. ‘Surprise ratings’ are not an official rating category, but refer to situations where a veteran’s assigned rating has a different title than the one they requested. For example, a service member might request ratings for adjustment disorder, but the VA may assign a rating for PTSD, anxiety, or depression instead. If the veteran does not carefully review their decision letter, they might miss these different conditions. This could affect their ability to obtain an FAA medical, and in certain scenarios, may also lead to the suspension or revocation of their certificate if they fail to include these conditions in their application. (FAA, 2023b, 2025c)

Off-label medication use may pose another challenge for FAA medical applicants. Many drugs on the FAA’s Do Not Fly medication list may be prescribed off-label for conditions that typically do not lead to grounding (FAA, 2023a). As an example, some well-known telehealth services currently prescribe SSRIs that are not approved by the FAA as a treatment for sexual health concerns. It is essential for veterans, like all aviation professionals, to understand the impact of any medication they may be taking, regardless of the reason it was prescribed.

Finally, certain military non-judicial punishment actions, commonly known as Article 15s or Captain’s Masts, may affect the FAA medical process. MedXPress questions 18W and V ask about arrests, convictions, and administrative actions, including non-traffic-related convictions (FAA, 2025a). Since non-judicial punishments can be used as an administrative action in lieu of a Court Martial, some believe they meet the criteria of administrative actions and should be included when completing an FAA Medical.

Recommendations for Applicants

To help overcome many of these challenges, we recommend encouraging veterans to prepare for their medical just as they would for a final exam, checkride, or promotion board: *Select, Study, Prepare, Complete Your Homework, and Plan Ahead*. The first step is to *select* the right AME. It is important to find an AME who is both up-to-date with the FAA’s latest standards and has experience working with aviators who have VA disability ratings. Additionally, if the service member has mental health or addiction concerns, it is essential that they find a well-qualified Human Intervention Motivation Study (HIMS) AME. Reaching out to other veterans for recommendations can be helpful in identifying AMEs with the appropriate veteran experience.

The next step is to *study* the FAA Guide for Aviation Medical Examiners. The guide offers detailed instructions on all aspects of the application process, including the criteria AMEs use to evaluate each item. After studying, it’s time to *prepare* by gathering their VA Decision Letter, relevant military medical records, and completing the online MedXPress questionnaire. If the veteran has questions about their specific situation, they should request a separate consultation from an AME or an external medical consultation service (e.g., AOPA PPS, Wingman Med, Aviation Medical Advisory Service). *Completing Homework* is always important, and in this case, that includes reviewing and filling out any CACIs or decision worksheets for their specific medical conditions. Having these completed can not only speed up

the medical examination by ensuring the proper paperwork is available, but it can also help prompt an AME who is unfamiliar with the latest guidance for a particular issue.

Finally, it is important for the student veteran to *Plan Ahead*. In addition to allocating enough time to schedule their FAA Medical, it is also important to be prepared for a possible deferral. Waiting until days or weeks before the semester or flight training begins does not allow enough time to address any missteps or unplanned complications.

College Support

At the college level, three main areas can help support veteran students: a detailed aviation medical provider list, encouraging a ‘veteran aviators organization’, and advising service members impacted by a Deferred Medical. Providing a detailed list of aviation medical providers goes beyond simply providing the contact information for local AMEs. Veterans can be best served by AMEs with experience evaluating VA disability ratings and with an understanding of military medical records. For schools with in-house AMEs, consider allowing prospective or accepted student aviators to use the organization’s medical examiner, as they are likely to be one of the most experienced and up-to-date in the area. Outside of standard AMEs, a list of FAA and military-familiar HIMS and mental health providers can assist veterans with questions and aviation-appropriate treatment for any mental health concerns.

If the institution is uncomfortable developing and providing a detailed list themselves, one alternative is to encourage the formation of a veteran aviators student organization to curate and distribute the aviation medical provider list. Similar to Middle Tennessee State University’s Aerospace Veterans Group, this type of organization could go well beyond helping construct a provider information sheet by supporting veteran students with professional development opportunities, networking, and offering mentorship for fellow veterans enrolled in aviation degree programs.

Finally, providing specially trained academic advisors for veteran students with deferred medicals can help them complete their degree programs and ratings while maximizing the efficient use of their veterans' benefits. Unlike other scholarships that offer a specific dollar amount, most VA-related education benefits cover a set number of months (VA, 2025). Because of this, a student veteran who is unable to complete flight training for multiple semesters due to a deferred medical might miss out on the funds needed to complete their training. Advisors who understand the specific limitations of the Post-9/11 GI Bill, Veteran Readiness and Employment, and the Montgomery GI Bill Selected Reserve will be best equipped to give accurate and timely advice to veterans, helping them decide how to best use their benefits to achieve their goals while waiting for medical clearance. Such actions can help improve retention of prior service members, while supporting recruitment by fostering a veteran-friendly environment.

Benefits of Proactive Preparation and Institutional Support

While veterans bring experience, discipline, and leadership skills to collegiate aviation programs, their transition into the civilian aviation community can be affected by FAA medical certification challenges that are unique to their military backgrounds. Complex medical histories,

VA disability ratings, and differences between military and FAA medical waiver systems can cause uncertainty and delays. However, by encouraging student veterans to prepare proactively and offering institutional support, these challenges can be alleviated. Creating a veteran-friendly environment and providing tailored guidance can help student veterans successfully navigate the FAA medical process and achieve their goal of becoming aviation professionals.

Conclusion

Supporting veterans in collegiate aviation programs requires coordinated strategies that address social, financial, and medical certification challenges. The Daniels Center offers a method for helping service members transition back into civilian life, and Vets2Wings provides financial assistance for veterans interested in a career in aviation, while informed guidance, proactive preparations, and support can help former military members obtain their aviation medical certifications. Together, these efforts show that aligning emotional, academic, and administrative support helps universities and aviation professionals turn barriers into opportunities, ensuring veterans continue to strengthen the aviation industry.

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Implementing an Enrollment Cap in a Southeastern Collegiate Flight Program

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A southeastern land-grant university decided to impose an enrollment cap on its Part 141 collegiate flight program due to increased enrollment pressures and limited availability of training resources. This article presents a case study of the planning and implementation of an integrated two-stage admission program that focused on selecting students based on academic rigor, preparedness, and aviation readiness. A diverse selection committee of both military and civilian flight training experts reviewed 493 applicants using a rubric-based examination of aviation experience and essay responses, while excluding standardized test scores and high school grade point averages (GPAs). In the process, student motivation, ability to perform well on the FAA written exam, and any prior aviation experience were highlighted while avoiding placing a competitive disadvantage on non-pilot applicants. The quality of the essays and the degree to which the candidate demonstrated dedication to aviation made more difference in a person's selection than licensure alone. The study concludes with recommendations for incorporating personality and grit assessments in future iterations to enhance predictive validity and reduce reviewer workload.

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Introduction

Managing rapid enrollment growth is a significant challenge for many collegiate aviation flight programs. The rising popularity of collegiate flight training can be attributed to several factors. In recent years, careers as pilots have become as lucrative as those in law, medicine, or business, with commercial pilot salaries for regional carriers doubling from 2015 to 2017 (Tulis, 2017). Additionally, graduates from most collegiate aviation programs are eligible for up to a 500-hour reduction in flight time required to obtain an Airline Transport Pilot certificate. A recent study of 33 collegiate aviation flight programs found that the schools surveyed were operating at 97% of their maximum capacity, with 14 out of 33 schools exceeding 100% capacity in enrollment (Thomas & O'Toole, 2020). Furthermore, 82% of schools reported a lack of Certified Flight Instructors (CFIs), and 42% cited aircraft availability as a limitation to flight training (Thomas & O'Toole, 2020). Collectively, many collegiate aviation flight programs are struggling to keep up with the increased demand for pilots.

Due to growing demand and limited resources, enrollment caps have become a necessary tool to implement in many collegiate flight programs. At public land-grant institutions, implementing such caps requires careful consideration of their mission to provide accessible education to the working class. Land-Grant institutions were established by the Morrill Acts of 1862 and 1890. These institutions were designed to support national development in essential fields like agriculture and engineering (National Association of State Universities and Land-Grant Colleges, 2008). In light of the pilot shortage, flight training at a land-grant university aligns well with this mission. This case illustrates how enrollment policies in high-demand majors must balance resource constraints with institutional values and national workforce needs.

Selection Committee Formation and Purpose

The School of Aviation formed a committee consisting of faculty and flight instructors, with backgrounds in military, corporate, airline, and general aviation. The committee's primary objective was to develop a comprehensive applicant screening process tailored to the collegiate Part 141 flight program.

In establishing the screening process, the committee's main goal was to uphold high academic standards while also supporting the land-grant institution's core mission. This mission emphasizes making educational opportunities accessible to people without an aviation background rather than favoring those with airline-pilot family backgrounds. The selection of committee members was intentional to ensure representation from both military and civilian flight training backgrounds. This diversity helped foster a balanced admissions approach by ensuring a wide range of skills and perspectives in the aviation industry. Guided by a unified purpose, the committee engaged in thorough discussion and review of the current literature on student selection criteria for collegiate aviation programs.

Candidate Selection Considerations in Collegiate Aviation

Selecting collegiate aviation students is challenging because there is no agreed-upon set of metrics that identifies the perfect candidate. Unlike many professional fields, the Federal

Aviation Administration (FAA) does not require a college degree for individuals pursuing a career as a commercial or airline transport pilot, and this is also true for many airlines (FAA, 2024). This situation invites discussion on which criteria should be prioritized in the selection process. Specifically, there is ongoing debate regarding whether academic achievements or proven flying aptitude should be emphasized, and whether personal qualities such as determination and resilience, often referred to as "grit," should play a significant role in selection.

Selection Methods in Practice

Upon reviewing the student selection processes at various colleges, it is evident that approaches vary. Some institutions use a first-come, first-served method to admit flight students, granting entry solely on the timing of a student's application after university admission. In contrast, other programs employ a more comprehensive secondary application process. This additional screening often involves evaluating specific academic characteristics, such as high school grade point average (GPA) and standardized test scores, to estimate a student's likelihood of successfully completing the aviation program (Broach et al., 2019; Osman et al., 2022).

However, it is important to note that standardized tests, such as the ACT and SAT, have limited predictive validity for academic performance beyond the freshman year of college (Pennsylvania State University, 2010; Sanchez, 2024; Snyder & Dillion, 2011). Accordingly, these scores offer only a narrow view of a student's academic preparedness for flight training. Recognizing these limitations, the committee favored a holistic approach to evaluating applicants, rather than relying heavily on high school GPA and standardized test scores.

Aptitude and Personality Predictors

In addition to traditional academic metrics, some organizations, both within and outside collegiate settings, use psychomotor and cognitive aptitude tests to assess candidates. These assessments measure hand-eye coordination and intellectual abilities. Two popular examples include the PILAPT (Pilot Aptitude Test) and the Cut-e Pilot Assessment. While these tests are relatively affordable (costing less than \$100 per individual), their effectiveness as screening tools varies. Research has shown that psychomotor tests can predict initial success in pilot training, whereas cognitive and psychometric exams are better indicators of performance in ground school and simulator environments (Carretta & Ree, 2003; McFarland, 2017; Vidulich & Tsang, 2001). Nevertheless, additional peer-reviewed studies are needed to fully understand their predictive value throughout all stages of flight training.

Other factors that correlate with success in collegiate aviation programs include high school GPA and grades in college-level aeronautics courses (McFarland, 2017). Studies suggest that these academic indicators are linked to successful progression from private to commercial pilot training and to reduced training time. Furthermore, research on personality traits has identified that students who score high in conscientiousness and agreeableness—traits from the Big Five personality model—tend to complete aviation programs more efficiently, requiring fewer training hours (Billingslea, 2025).

Implementation Strategy

After careful deliberation, the committee adopted a straightforward approach to determine a student's likelihood of success in the four-year collegiate professional flight training program. Recognizing that some applicants will have a private pilot's license, which could confer a significant advantage. In contrast, others may not have had the financial means or opportunity to obtain one, the committee established a predetermined percentage of seats specifically for non-pilot applicants. This measure was intended to ensure qualified candidates without prior flight experience would not be overlooked in favor of those with existing licensure.

Two primary objectives guided the committee: (1) avoiding an overly complex application process that could discourage prospective students and (2) preventing additional financial burdens, such as requiring third-party testing. At the same time, the process needed to identify applicants who demonstrated both academic potential and a strong motivation to complete flight training. To achieve these goals, a two-step application process was employed. The first step was for students to gain early admission to the university, thereby confirming their academic preparedness. The second step involved submitting a secondary application. This step initially screened students to prove possession of an FAA first-class medical certificate, a local requirement for the flight school. The application then evaluated candidates' potential for success in flight training based on their aviation background.

Data such as names and demographic information were removed by college-level admissions staff before reviewers saw their assigned essay question. Applicants were given an identification number, and only the requested information was reviewed. Because cognitive ability was assessed at the university level through the Early Action program, reviewers were not provided with applicant test scores or GPA information. Applicants were awarded points for various achievements and experiences, such as completing and passing the FAA private pilot written exam or Part 107 drone certification exam, participating in a discovery flight, completing a solo flight, holding a private pilot's license, and responding to four essay questions. These essays were designed to assess each candidate's motivation, preparation for flight training, and leadership qualities. For the essay component, each response was evaluated by at least two raters. To support interrater reliability and consistent scoring, the reviewers received training on the grading rubric using sample essays of varying quality. Additionally, general criteria were agreed upon by the reviewers (e.g., content versus writing quality). Each applicant received a numerical score and was ranked accordingly from highest to lowest.

Selection Results

The selection committee reviewed 493 applicants, of whom 20% were female and 15% were minorities. After a thorough review that lasted approximately six weeks, during which each committee member read 493 essays, 182 offers were made (17% female and 14% minority).

Notably, the demographics of the students receiving offers were similar to those of students enrolled in the program over the previous five years. In the application pool, 60 students already possessed their private pilot license (16 from Part 141 flight schools and 44 from Part 61 flight schools). Of that group, 49 were offered admission, with all applicants from

Part 141 flight schools receiving a slot, and only 33 of the 44 from Part 61 schools receiving one. However, a review of the essays and FAA written test scores showed that those 11 were not as competitive as other students.

In reviewing the characteristics of the bottom 20% of those offered an admission slot (36 students), all were non-pilots, and none took the FAA written exam. Many of them have soloed, and nearly all have had a discovery flight. What ~~really~~ set them apart from the non-selects was the quality of their essays, which painted a clear picture of their desire and readiness for a rigorous Part 141 flight school.

In reviewing the characteristics of the top 20% of the non-selects (36 students), all of them took the FAA written. Although they passed, they generally scored low. Nine of them held a private pilot license, and 24 of them soloed. However, in general, their applications were not as strong as others' because of a combination of low essay scores.

Discussion

Overall, the selection committee felt that those offered admission demonstrated a propensity for success in a rigorous Part 141 collegiate flight school. Although not used as a screening tool in the secondary application (e.g., standardized test scores such as the ACT/SAT), the average ACT score was 29. Having a private pilot license did not guarantee acceptance; rather, it was performing well on FAA written exams (either the private pilot written or the part 107 drone license exam) and having substantive, well-written essays. Likewise, a lack of attention to the application (sloppiness and incomplete sections), as well as low FAA test scores, hurt students' chances of acceptance.

Conclusion

The selection process took six weeks, during which each committee member read nearly 500 essays. This did put a strain on the team and created a desire for an alternative evaluation tool, besides essays, to reduce the team's burden. Going forward, the current students who selected their slot performance will be tracked, along with additional research, to obtain their Big Five Personality traits and Grit score. Grit is the passion and perseverance for long-term goals, and research supports the idea that a person's "grit" can be measured (Duckworth, 2016). Along with current data from their application, we will identify the factors that lead to students' success over the four years of the program. This data will be used to update our application process.

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Enhancing Private Pilot Training Readiness through Virtual Reality: Utah Valley University's Experience Integrating VR Simulation into the Private Pilot Ground Course

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Flight training programs across the aviation industry continue to face high attrition rates, with FAA and industry estimates indicating that as many as 40 to 60 percent of student pilots leave training before earning their Private Pilot Certificate. To help address this challenge, Utah Valley University (UVU) introduced a Virtual Reality (VR) flight simulation program for students enrolled in the Private Pilot Ground Course who had not yet begun their flight training. The program was designed to give students early, hands-on exposure to flight concepts and cockpit procedures in an immersive environment. This study explores how VR-based pre-flight training influences student preparedness, confidence, and later success in flight training. Early findings from student feedback and performance data show clear advantages—students reported stronger understanding of key concepts, greater procedural familiarity, and higher overall confidence entering flight training.

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Purpose of the Study

The goal of this study is to explore whether introducing flight concepts early through virtual reality (VR) simulations in the Private Pilot Ground Course at Utah Valley University can help students feel more prepared, confident, and ready for actual flight training. Specifically, this research asks: Does learning through VR improve the success and performance of UVU Private Pilot Ground students compared to traditional instruction alone? This research is ongoing and will provide an overview of current findings and future expectations.

Introduction

The aviation industry continues to face challenges with student retention, training efficiency, and overall success in flight programs. According to the Aircraft Owners and Pilots Association (AOPA, 2010), roughly 40–50% of student pilots in the United States do not complete their training or earn a Private Pilot Certificate, meaning many drop out while still at the student pilot level. At the same time, the Federal Aviation Administration (FAA, 2023) highlights the growing demand for professional pilots, making it clear that the industry must find ways to train more pilots efficiently while managing high attrition rates and rising costs. These challenges underline the need for new, cost-effective approaches that are proven to support student success and satisfaction in pilot training programs.

At Utah Valley University (UVU), the School of Aviation Sciences is addressing this issue by incorporating VR simulation into the Private Pilot Ground Knowledge Course. UVU recently revised its flight training approach, now requiring students to successfully complete the FAA-approved ground course and pass the FAA written exam before entering the Part 141 flight course. As a result, many students start flight training with little or no cockpit experience, making it difficult to connect classroom theory with the practical skills needed in the air. Implementing this new standard has some positive and some negative consequences for students. Some positives include a semester before flight courses to dedicate to ground study and knowledge, and time to focus solely on ground understanding and the FAA written exam. Also, once they complete the semester focused on ground instruction, they begin their flight training and will review all required ground subject areas once more. Some negatives include a lack of hands-on experience, resulting in a disconnect between ground knowledge areas and understanding.

To bridge this gap, UVU introduced a VR-based flight simulator curriculum that aligns with requirements for private pilot training. This approach gives students early, hands-on experience in a realistic cockpit environment, giving them experience they otherwise wouldn't receive until later in their training. The idea emerged after teaching a semester of students who lacked this opportunity and noticing how much their understanding of ground knowledge suffered without prior exposure to the cockpit.

Background and Rationale

Traditional pilot training typically follows a concurrent model, where students complete ground school coursework while simultaneously gaining hands-on flight experience. UVU's

recent curriculum changes, which require students to finish the ground course before being accepted into the flight course, have highlighted a gap between ground knowledge and understanding real-world flight concepts. While this model has clear advantages, it can sometimes leave new pilots unprepared for the mental and technical demands of actual flight lessons. According to recent research, VR and AR technologies help learners better understand spatial relationships, remember maneuvers more effectively, and become comfortable with complicated technical tasks, with aviation being one notable example (Guthridge, 2022; Hight, Fussell, Kurkchubasche, & Hummell, 2022).

By introducing VR simulation earlier, even before formal flight training begins, students gain valuable hands-on experience and familiarity with cockpit procedures without being in a real airplane. By involving students in hands-on, immersive activities, this approach embodies the principles of experiential learning theory (McLeod, 2017), which identifies active participation as critical for learning and skill acquisition.

Through this program and research, UVU aims to determine whether integrating VR modules into the ground course can enhance student readiness, build confidence, and lead to better long-term outcomes in flight training.

Participants and VR Training Design

This study focused on students enrolled in Utah Valley University's Private Pilot Ground Course during the academic year. To explore the impact of VR-based training, students were divided into two groups. One group completed all seven VR simulation modules, while the other followed the traditional ground course without VR exposure. Each semester, roughly 40 students take the course, and for this study, 18 students were able to participate in the VR program. This number reflected the availability of simulators, instructors, and student schedules. Participation was voluntary and approved through UVU's internal research oversight process. Data collection includes post-course feedback emails, instructor observations, and performance outcomes measured through stage checks and exam results.

The VR program was designed in collaboration with a commercial company, using advanced flight simulation software and hardware to create a realistic cockpit experience. The curriculum includes seven modules that follow the FAA's Private Pilot Airman Certification Standards (ACS). Students practice everything from aircraft preflight and cockpit familiarization to taxiing, basic flight controls, straight-and-level flight, climbs, descents, and turns. They also complete modules on takeoffs and landings, slow flight and stalls, emergency procedures and decision-making, and traffic patterns with radio communications.

For students, the experience is immersive and hands-on. They gain the chance to familiarize themselves with cockpit procedures, practice maneuvers, and make decisions in real-time, all before ever stepping into an actual airplane. This early exposure helps bridge the gap between classroom theory and practical flight skills, giving students a stronger foundation, boosting their confidence, and preparing them for success as they move into live flight training.

Assessment Metrics and Expected Outcomes

Based on ground and simulated flight instruction provided, and the opportunity for students to apply some ground knowledge areas to flight, we expect the following outcomes for participating students.

- Improved stage check and check ride pass rates
- Better FAA written exam scores (less beginner confusion on procedures)
- Higher rate of course completion — fewer students dropping out
- Reduced cost in terms of less time spent in remedial instruction or repeating lessons
- Smoother transition to solo flight & reduced anxiety in early flight training

Student performance and engagement will be evaluated using a variety of measures. These include stage check performance during flight training, end-of-course flight evaluations, check ride pass rates, FAA written exam scores, and overall course completion and retention rates. Beyond these quantitative metrics, student testimonials and instructor feedback provide valuable insight into students' experiences, offering a more complete picture of how VR training influences learning, confidence, and preparedness for real-world flight.

Findings at UVU

Enhanced Preparedness and Confidence

Many students reported feeling significantly more confident before their first real flight lessons thanks to the VR training. One student shared:

“With or without extra credit for me, I thank you for making this program. I feel more prepared for the upcoming flight lesson next semester.”

(Student Participant, Private Pilot Ground Course, Fall 2024)

Another student highlighted how the VR experience helped reduce anxiety and reinforced learning:

“I enjoyed the Sim training and felt that it helped to take concepts and put them into action. I would recommend it to everyone.”

The VR modules also helped students connect classroom theory with practical flight applications. One participant explained:

“This simulator helped me a lot, especially in applying what we learn in class to this or vice versa. Sometimes it was hard to sit there for two hours with it on your head, though. Overall, I’m really glad that I did it and I feel more prepared for actual flying.”

Several students even suggested that the VR component become a permanent part of the course:

“I think it should be a part of the private ground class, to help understand more about what's being taught.”

These testimonials highlight how the VR program not only boosts confidence but also strengthens the connection between theoretical learning and practical skills, giving students a head start before entering the cockpit.

Skill Transfer to Real Flight Training

Students who later began actual flight training reported a clear connection between their VR experience and real cockpit proficiency. One participant explained: “My first flight ever happened to be in a Cessna 172, where everything was familiar. I am a first-hand witness that the simulator was extremely helpful and will significantly limit the amount of actual flight time I will need to be successful in my check-ride.”

Quantitative Observations

Although this research is still ongoing, early course data suggest improved student retention and higher engagement in the ground course sections that included VR simulation. Instructors noted reduced “first-flight anxiety” and faster procedural recall during students’ initial flight lessons. While long-term tracking continues, these preliminary results indicate that early VR exposure can enhance both readiness and retention.

Discussion

UVU’s VR program illustrates that immersive, hands-on learning can improve efficiency and reduce initial difficulties for students in aviation training (Hight, 2022; Hight, Fussell, Kurkchubasche, & Hummell, 2022). While VR does not fully mimic the real experience of flying, it provides a controlled, repeatable setting where learners can practice procedures, making it a valuable addition to conventional ground training.

According to student feedback, VR experiences boosted confidence and helped translate classroom knowledge into practical skills. This supports principles from McLeod's (2017) experiential learning theory and Mayer’s (2014) cognitive theory of multimedia learning, which highlights the importance of active, hands-on, and visually rich learning to enhance skill development.

Benefits to UVU and Students

For UVU, integrating VR into the Private Pilot Ground Course offers several advantages: it strengthens the university’s reputation for innovation and student-centered instruction in aviation education, provides an opportunity to reduce course failures and training costs by better preparing students before they enter flight labs, and generates data-driven evidence that can guide curriculum development and attract future funding or research partnerships.

For students, the benefits are equally clear. Early VR exposure increases confidence and procedural familiarity before the first flight, improves the connection between theory and hands-on application, reduces anxiety during initial lessons, and can potentially shorten the time needed to reach proficiency. Students also experience higher engagement in the ground course and greater motivation to continue in flight training, which can translate into lower training costs and fewer course failures.

Implications for Aviation Education and National Relevance

This study contributes to the broader national conversation on integrating technology into flight education as a way to address pilot shortages and improve training efficiency. UVU's findings align with FAA-supported efforts exploring VR as a viable and effective training supplement. As aviation programs across the country face rising costs and instructor shortages, VR simulation represents a promising, evidence-backed pathway toward innovation and student success in pilot training.

Conclusion and Future Work

Incorporating virtual reality flight simulation into UVU's Private Pilot Ground Course shows strong potential to improve student preparedness, confidence, satisfaction, and success. Participant feedback suggests that VR can effectively bridge the gap between classroom learning and real-world flight experiences. Early evidence indicates that VR exposure can enhance retention and readiness, ultimately supporting greater success in flight training programs.

Future research will focus on long-term outcomes, comparing check ride pass rates, flight-hour efficiency, and written exam results for VR-trained versus non-VR-trained students. Completion of this research program could establish best practices for UVU's aviation department and provide a model for aviation programs nationwide seeking to improve training efficiency and reduce student attrition through technology-enhanced learning.

Disclosure: Chat-GPT: Used to check grammar, section breaks, and flow, and was used to enhance some sentences.

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Sustainable Retention Strategies in Aviation Education: Coaching Leadership, Instructor Behavior, and Career Decidedness

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Attrition in collegiate aviation training remains high, with only about 20 percent of students completing flight programs. This study investigates how flight instructor leadership behaviors influence student persistence in aviation education. Grounded in Tinto's Model of Institutional Departure and Attribution Theory, the research examines how Coaching Leadership Style (CLS) and Attribution of Instructor Behavior (AoIB) affect Career Decidedness (CD) and Intention to Persist (ITP). Survey data from 223 students at five University Aviation Association programs were analyzed using structural equation modeling (SEM). CLS significantly predicted CD, which in turn predicted ITP, while AoIB directly predicted ITP. Post hoc analyses revealed that CLS statistically suppressed AoIB, indicating that students often interpret coaching behaviors as altruistic. These findings highlight the importance of instructor leadership training and introduce the SEGAS framework—Set expectations, Encourage perspectives, Give feedback, Ask for feedback, and Supply resources—as a practical tool to strengthen student persistence in flight education.

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Introduction

Attrition in collegiate flight training continues to threaten the aviation workforce pipeline. Only about two in ten students complete flight training (Beckett, 2016), creating a persistent gap between pilot supply and demand. For institutions that invest heavily in-flight education infrastructure, each student lost represents a significant financial and operational cost. More importantly, high attrition delays the production of qualified pilots during a time when the aviation industry continues to face workforce shortages and mounting operational demands.

Although cost, time, and training difficulty are frequently cited reasons for withdrawal, these explanations alone do not account for why some students persist while others leave. Prior research has emphasized academic performance, financial factors, and program structure, but has paid little attention to the relational dynamics that occur between instructors and students. The instructor–student relationship in flight training represents a unique blend of teaching, evaluation, and mentorship. This dynamic parallels the employee–supervisor relationship in organizations, where leadership behaviors strongly influence job satisfaction and retention (Bean, 1982; Bers & Smith, 1991).

This study examines whether leadership behaviors demonstrated by flight instructors influence students' intention to persist in aviation education. Specifically, it explores how Coaching Leadership Style (CLS) and Attribution of Instructor Behavior (AoIB)—students' perceptions of an instructor's motives—affect Career Decidedness (CD) and Intention to Persist (ITP). The research seeks to identify leadership behaviors that strengthen student commitment and inform instructor-training strategies designed to improve retention outcomes in collegiate aviation programs. Guided by these issues, the study addressed three primary research questions:

- How does Coaching Leadership Style (CLS) affect student persistence in collegiate aviation programs?
- How does Attribution of Instructor Behavior (AoIB) influence persistence?
- Does Career Decidedness (CD) mediate the relationships among CLS, AoIB, and Intention to Persist (ITP)?

These questions frame the investigation of instructor leadership behaviors as a factor in student retention and provide the foundation for testing the proposed structural model.

Theoretical Framework

Understanding why students persist in collegiate aviation training requires connecting educational theory with leadership and motivational behavior. Persistence is not solely a product of academic ability or resources; it reflects how students experience their environment and relationships within it. Two established theories—Tinto's Model of Institutional Departure and Attribution Theory—provide a foundation for examining how instructor behaviors influence student commitment and persistence. When combined with the concept of Coaching Leadership

Style (CLS), these frameworks offer an integrated perspective on how leadership behaviors translate into motivational and retention outcomes in aviation education.

Tinto's (1975) Model of Institutional Departure explains persistence through academic and social integration. For flight students, the instructor–student relationship is a central element of social integration (Pascarella & Terenzini, 1980). Attribution Theory (Heider, 1958; Kelley & Michela, 1980) explains how students interpret instructor motives—as altruistic or self-serving—and how those perceptions influence engagement.

Coaching Leadership Style aligns with both frameworks. Coaching leaders emphasize feedback, development, and individualized support (Ellinger et al., 2011; Berg & Karlsen, 2016). When instructors use coaching behaviors, students may attribute altruistic motives (Barbuto & Wheeler, 2006), strengthening their commitment to training.

Methodology

To examine how instructor leadership behaviors influence student persistence, this study employed a quantitative design grounded in structural equation modeling (SEM). The approach allowed for simultaneous testing of multiple relationships among key constructs—Coaching Leadership Style (CLS), Attribution of Instructor Behavior (AoIB), Career Decidedness (CD), and Intention to Persist (ITP)—and for evaluating mediation effects that reflect the complex psychological and behavioral factors influencing persistence in aviation education.

Design and Sample

A quantitative, non-experimental SEM design examined relationships among CLS, AoIB, CD, and ITP. Participants were 223 flight students (ages 18–25) enrolled at five UAA institutions, Angelo State University, Delta State University, Southeast Missouri State, Purdue University, and University of North Dakota between October 2023 and March 2024.

Instruments

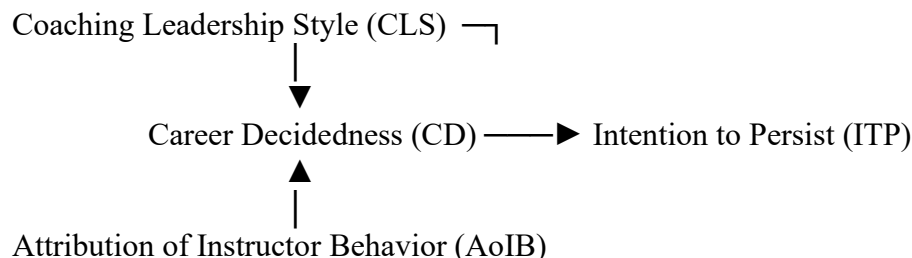
Four validated scales were administered with their original response formats: CLS was measured with five items on a seven-point Likert scale (1 = strongly disagree to 7 = strongly agree); AoIB was measured with four items on a four-point Likert scale (1 = strongly disagree to 4 = strongly agree); CD was measured with six items on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree); and ITP was measured with six items on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Internal consistency (Cronbach's α) in the present sample was $\alpha = .88$ (CLS), $\alpha = .86$ (AoIB), $\alpha = .68$ (CD), and $\alpha = .65$ (ITP).

Analysis

Structural equation modeling (AMOS 29) indicated good model fit (CFI = .968; RMSEA = .049). Bootstrapped CIs confirmed all significant paths. Figure 1 illustrates the hypothesized model tested in this study.

Figure 1.

Conceptual model of relationships among study variables (CLS and AoIB → CD → ITP).



Results

After removing incomplete or invalid responses, 223 valid survey cases were retained for analysis. Confirmatory factor analysis (CFA) supported a four-factor structure (CLS, AoIB, CD, ITP) with acceptable fit indices ($\chi^2(84)=128.9$, CFI=.97, RMSEA=.049, SRMR=.054). Structural model fit was good ($\chi^2(85)=129.7$, CFI=.97, RMSEA=.049, SRMR=.054). CLS significantly predicted CD ($b=.27$, $p=.02$); AoIB→CD was nonsignificant ($b=-.23$, $p=.33$). CD predicted ITP ($b=.11$, $p=.04$). AoIB directly predicted ITP ($b=.28$, $p<.001$). Career Decidedness mediated the CLS→ITP path (indirect $b=.03$, $p=.04$) but not AoIB→ITP ($b=-.02$, $p=.17$).

Post Hoc Analysis

The high correlation between Coaching Leadership Style (CLS) and Attribution of Instructor Behavior (AoIB) ($r = .71$, $p < .001$) suggested potential multicollinearity within the overall structural model. Examination of standardized loadings indicated that CLS may have acted as a suppressor variable, reducing the explanatory power of AoIB in predicting Career Decidedness (CD) and Intention to Persist (ITP). Suppression occurs when one variable accounts for variance shared with another predictor but unrelated to the outcome, which can lead to an underestimation of the suppressed variable's true effect (Oh, 2023).

To clarify these effects, two additional SEM models were tested. Model 5 (M5) included CLS as the sole independent variable, while Model 6 (M6) included only AoIB. In M5, CLS demonstrated significant direct effects on both CD ($b = .18$, $SE = .06$, $p < .001$) and ITP ($b = .11$, $SE = .04$, $p = .002$), but the indirect effect of CLS on ITP through CD was not significant ($b = .012$, $SE = .015$, $p = .12$). In M6, AoIB exhibited significant direct effects on CD ($b = .27$, $SE = .13$, $p = .02$) and on ITP ($b = .27$, $SE = .09$, $p = .002$), as well as a significant indirect effect of AoIB on ITP mediated by CD ($b = .027$, $SE = .023$, $p = .025$).

Together, these findings indicate that CLS and AoIB are distinct but highly related constructs. Their overlap in the full model concealed each variable's independent contribution: CLS suppressed AoIB, resulting in an underestimation of AoIB's effect on CD and, subsequently, on ITP. When analyzed separately, both variables significantly influenced students' intention to persist, with CD mediating the indirect relationship between AoIB and

persistence. These results reinforce that students interpret coaching leadership behaviors as altruistic instructor intent and that both constructs are essential components of effective retention strategies in aviation education.

Discussion

The findings confirm that instructor leadership behaviors play a meaningful role in student persistence within collegiate aviation training. When instructors demonstrate a coaching leadership style, students interpret those behaviors as authentic concern for their success, which increases career decidedness and, in turn, their intention to persist. This relationship reinforces Tinto's (1975) assertion that persistence is influenced by both academic and social integration and supports earlier leadership–motivation research indicating that developmental feedback and support strengthen individual commitment (Restubog et al., 2010). The significant direct effect of Attribution of Instructor Behavior (AoIB) on persistence suggests that perceived altruism alone can motivate students to continue training, while the indirect effect of Coaching Leadership Style (CLS) through career decidedness highlights the developmental pathway by which leadership behaviors foster long-term commitment to aviation education.

Practical Implications

The study's findings point to clear, actionable steps for improving student retention in flight training. Because coaching leadership behaviors are interpreted by students as genuine altruism, instructor-development programs can intentionally cultivate these behaviors to strengthen persistence and career commitment. To translate the results into practice, this study proposes the SEGAS framework, which operationalizes coaching behaviors for use in instructor training:

- S – Set expectations. Clearly define performance goals, responsibilities, and standards so students understand what success looks like in both the cockpit and the classroom.
- E – Encourage broader perspectives. Help students see challenges as opportunities for growth by connecting flight-training experiences to larger professional and personal goals.
- G – Give constructive feedback. Provide timely, specific, and actionable feedback that reinforces progress and guides improvement without discouragement.
- A – Ask for feedback. Invite students to share their perceptions of instruction and learning, promoting open communication and mutual accountability.
- S – Supply resources. Ensure students have access to the materials, mentoring, and institutional support they need to meet training and academic requirements.

When instructors apply the SEGAS framework when interacting with their students, the students interpret those behaviors as altruistic support, leading to stronger persistence. Integrating SEGAS into instructor-development programs can improve retention not only in aviation but in other high-attrition disciplines such as healthcare and technology.

Conclusion

Persistence in aviation education depends not only on cost or curriculum but on leadership within the instructor–student relationship. Coaching Leadership Style—perceived as altruistic instructor behavior—strengthens Career Decidedness and, ultimately, Intention to Persist. Implementing SEGAS as a leadership framework offers a sustainable strategy for reducing attrition and supporting the next generation of professional pilots.

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The Role of Stakeholder Engagement in Advancing Environmental Sustainability at U.S. Airports

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As the aviation industry faces intensifying environmental, regulatory, and societal pressures, airports are increasingly expected to implement sustainability initiatives aligned with national and international frameworks such as NEPA, VALE, and CORSIA. However, progress across U.S. airports remains uneven, often constrained not only by technical or financial limitations but also by the quality of stakeholder engagement. This study applies Stakeholder Theory and the Stakeholder Salience Model to examine how stakeholder power, legitimacy, and urgency influence sustainability implementation in diverse airport contexts. Using a qualitative multiple-case study design, the research investigates the roles of federal regulators, airport operators, airlines, and local communities in shaping environmental outcomes. Preliminary findings suggest that stakeholder alignment is a critical determinant of success, with implications for policy design, infrastructure planning, and participatory governance. The study contributes a stakeholder-centered framework to better understand and improve sustainability performance in the U.S. airport sector.

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Introduction

The aviation industry is under growing regulatory, economic, and social pressure to reduce its environmental footprint and demonstrate tangible progress toward sustainability. Despite the presence of frameworks such as the National Environmental Policy Act (NEPA), the FAA's Voluntary Airport Low Emissions (VALE) program, and the international Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), many U.S. airports continue to face challenges in implementation. These challenges stem from limited resources, uneven institutional capacities, and inconsistent stakeholder engagement (Dimitriou & Karagkouni, 2022). This study applies Stakeholder Theory (Freeman, 1984) to examine how variation in stakeholder power, legitimacy, and urgency influences sustainability outcomes across airport contexts.

U.S. airports operate under different conditions in terms of size, funding, infrastructure, governance, and local political and community expectations. These structural and institutional differences significantly shape how environmental policies are interpreted and implemented on the ground, often resulting in uneven sustainability outcomes (Marete & Johnson, 2021; Rawson, 2012). While large hub airports have implemented initiatives such as solar energy deployment, electrified ground-support equipment, and pilot projects involving Sustainable Aviation Fuel (SAF), (Mizrak et al., 2025), many smaller regional airports continue to struggle with basic compliance due to financial and technical limitations. Beyond these constraints, an underexplored contributor to these disparities is the structure and quality of stakeholder engagement, namely, how well key actors are included, aligned, and empowered

The ability of stakeholders to shape sustainability outcomes depends not only on their commitment to environmental goals, but also on their position within the airport system and broader policymaking environment. Stakeholders' capacity to influence outcomes is mediated by their power to act, the perceived legitimacy of their claims, and the urgency of the issues they raise. To conceptualize this dynamic, the study draws on Stakeholder Theory (Freeman, 1984) and the Stakeholder Salience Model (Mitchell et al., 1997), which highlights how these three attributes interact to determine which stakeholders command organizational attention. This framework is especially relevant in sustainability contexts, where decision-making requires balancing environmental imperatives with economic, operational, and political considerations (Amaeshi & Crane, 2006).

Background and Theoretical Framework

Airports occupy a critical position in advancing environmental sustainability within the aviation sector, operating at the intersection of regulatory compliance, infrastructure investment, and public accountability. In the United States, a layered governance system shapes airport sustainability policy. At the federal level, the National Environmental Policy Act (NEPA) provides the foundational framework, requiring Environmental Assessments (EA) and Environmental Impact Statements (EIS) for federally supported airport projects (FAA, 2015). Complementing this, the FAA's Voluntary Airport Low Emissions (VALE) program incentivizes the adoption of cleaner technologies, having funded over 140 projects at 58 airports and reduced ozone emissions by more than 1,700 tons annually as of 2023 (FAA, 2020).

State-level programs often reinforce or extend these mandates. California's Global Warming Solutions Act (AB 32 and SB 32), for instance, requires airports to report greenhouse gas emissions and implement low-emission strategies (CARB, 2022). Florida's Environmental Resource Permit (ERP) program mandates stormwater management and wetland protections for airport development (FDEP, 2023). These national and state efforts operate alongside international measures such as ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which establishes emission baselines and offset requirements for international air travel (ICAO, 2022). These overlapping policy layers heighten the importance of effective stakeholder coordination at multiple governance levels.

Despite this multi-level framework, sustainability implementation remains uneven across U.S. airports. Large hubs like San Francisco International and Dallas Fort Worth International have reached advanced levels of Airport Carbon Accreditation (ACA), while many smaller airports struggle to meet baseline compliance due to financial and technical constraints (ACI World, 2023; Rawson, 2012). These disparities suggest that formal policy structures, while necessary, are insufficient to ensure consistent progress. Increasingly, the ability to align and activate key stakeholders appears to influence whether sustainability initiatives move forward in practice.

To examine this dynamic, the study draws on Stakeholder Theory (Freeman, 1984), which holds that organizations succeed by managing relationships with those who can affect or are affected by their actions. In the airport context, this includes a diverse set of actors including airport authorities, regulators, airlines, environmental agencies, and local communities each with differing capacities, interests, and degrees of influence. Stakeholder engagement serves not only to build legitimacy and consensus but also to bridge technical, political, and procedural gaps in policy implementation (Amaeshi & Crane, 2006; Zizka et al., 2019).

Building on this foundation, the study incorporates the Stakeholder Salience Model developed by Mitchell, Agle, and Wood (1997), which categorizes stakeholders based on three key attributes: power (ability to influence), legitimacy (perceived appropriateness), and urgency (time-sensitivity of claims). Stakeholders who possess all three are likely to command attention and shape decisions, while others may need to rely on alliances, public pressure, or institutional leverage. This model is particularly suited to analyzing sustainability efforts in the airport sector, where decision-making authority is often fragmented and where environmental action depends on the alignment of multiple actors.

Stakeholder Salience and Influence in U.S Airport Sustainability

Building on the stakeholder salience framework introduced earlier, this section applies the model to the U.S. airport context by assessing the relative power, legitimacy, and urgency of key stakeholder groups involved in sustainability planning and implementation. These attributes are not fixed but vary by project type, regulatory context, and institutional arrangement.

Federal Regulators (FAA)

The Federal Aviation Administration (FAA) holds high power and legitimacy through its statutory authority under the National Environmental Policy Act (NEPA) and administration of programs like the Voluntary Airport Low Emissions (VALE) initiative. Urgency is often situational—for example, when environmental assessments delay critical infrastructure projects or when sustainability measures are tied to discretionary grants. The FAA's Community Involvement Plan (CIP) formalizes public engagement practices, enhancing legitimacy by integrating local concerns into decision-making (FAA, 2016).

Airport Operators

Airport operators serve as pivotal intermediaries between national policy and local implementation. They possess considerable power over infrastructure, procurement, and planning, and derive legitimacy from their public or quasi-public status. Their urgency tends to rise during capital project cycles, funding windows, or periods of community or political pressure. Operators often act as coordinating hubs convening airlines, regulators, and contractors to ensure project alignment.

Airlines and Fixed Base Operators (FBOs)

Airlines and FBOs hold significant operational power, particularly in areas such as fuel use, turnaround efficiency, and infrastructure access. Their urgency increases when sustainability initiatives affect operating costs or access to alternative fuels or electric charging infrastructure. However, their legitimacy in environmental or land-use decisions is often weaker, as they are typically perceived as commercial actors. They occupy the 'dominant' stakeholder category, able to influence outcomes, though often requiring alignment with other actors to lead effectively.

Communities and NGOs

Local communities and environmental organizations often bring high legitimacy and urgency, particularly when projects involve flight path changes, noise impacts, or equity concerns. Although these groups frequently lack formal power, their influence can be exerted through litigation, public advocacy, or political mobilization. FAA guidance now encourages early and transparent engagement with community actors, recognizing their ability to affect project timelines and regulatory outcomes (FAA, 2016; Amaeshi & Crane, 2006).

Table 1*Stakeholder Salience Attributes and Classification in U.S. Airport Sustainability*

Stakeholder Group	Power	Legitimacy	Urgency	Salience Category
Federal Aviation Administration	High	High	Variable	Definitive
Airport Operators	High	High	Variable	Definitive
Airlines / FBOs	High	Medium	High	Dominant
Communities / NGOs	Low	High	High	Dependent
Passengers (indirect)	Low	Medium	Low	Latent

Note. Salience categories are based on Mitchell et al.'s (1997) stakeholder attributes of power, legitimacy, and urgency.

Methodology

This study employs a qualitative multiple-case study design to explore how differences in stakeholder salience affect the implementation of environmental sustainability initiatives at U.S. airports. Given the institutional diversity across the airport sector, this design enables comparative analysis of stakeholder dynamics across varied airport contexts.

Case Selection Criteria

This study employs a qualitative multiple-case study design to explore how differences in stakeholder salience affect the implementation of environmental sustainability initiatives at U.S. airports. Given the institutional diversity across the airport sector, this approach allows for comparative analysis of stakeholder dynamics across varied operational and governance contexts.

Cases are selected using purposeful sampling to reflect variation across three dimensions:

1. Airport size and operational complexity (e.g., large hubs, medium-sized commercial airports, general aviation facilities);
2. Ownership and governance structure (e.g., city-owned, independent authority, or regional port-managed); and
3. Geographic and regulatory context, to capture variation in state-level environmental policy and political climate.

Proposed cases for initial analysis include large hubs such as San Francisco International Airport (SFO), Denver International Airport (DEN), and Dallas Fort Worth International Airport (DFW). These airports were selected based on the visibility of their sustainability programs and stakeholder engagement practices. Additional cases may include smaller or under-resourced airports to explore contrasting implementation pathways and stakeholder dynamics.

Data Collection

The study draws on three primary data sources:

- Semi-structured interviews with airport operators, regulatory officials, airline representatives, and community or environmental stakeholders;
- Document analysis, including sustainability master plans, Environmental Impact Statements (EIS), greenhouse gas inventories, and stakeholder engagement materials; and
- Public reports from relevant agencies (e.g., FAA, ICAO), industry groups (e.g., ACI-NA), and third-party programs (e.g., Airport Carbon Accreditation).

Interview protocols follow Seidman's (2019) three-phase interview three-phase interview model, which includes contextual background, focused event exploration, and participant reflection.

Analytical Strategy

Data will be analyzed using a reflexive thematic approach (Braun & Clarke, 2022), with coding informed by both the Stakeholder Salience Model (Mitchell et al., 1997) and inductive insights from interview and document data. Initial coding categories include stakeholder power, legitimacy, urgency, and perceived barriers to alignment. At this stage, analysis is exploratory. The goal is to identify patterns in how different actors influence policy implementation, and to examine how salience attributes shift across project types and governance contexts.

Discussion and Implications

This study offers a structured framework for examining how stakeholder relationships influence the adoption and implementation of sustainability initiatives at U.S. airports. By applying Stakeholder Theory and the Stakeholder Salience Model, the research reframes implementation challenges not only as technical or financial issues but as governance dynamics rooted in stakeholder influence, alignment, and institutional context. Through this approach, the study aims to contribute to a more stakeholder-centered understanding of environmental sustainability progress in the airport sector, one that accounts for varying degrees of power, legitimacy, and urgency across actors such as federal regulators, airport operators, airlines, and local communities. The proposed framework helps explain why similar policy tools such as NEPA, VALE, or CORSIA produce different outcomes depending on stakeholder groups and responsiveness.

Although findings are still in development, early insights suggest several implications for practice and future research:

- Airport operators and regulators may benefit from tools that assess stakeholder salience at the project planning stage, allowing for more anticipatory engagement and collaborative alignment;
- Sustainability policy frameworks could be designed to elevate dependent stakeholders, particularly communities and NGOs, whose legitimacy and urgency are high but whose institutional power remains limited;

- Leadership development in aviation should incorporate stakeholder management, environmental communication, and collaborative decision-making, especially for professionals tasked with implementing sustainability programs under regulatory and political constraints.

As data collection continues, the study seeks to refine its cross-case analysis and stakeholder typology, with the goal of producing both scholarly insights and applied guidance. Feedback from the conference community will be essential in improving the conceptual model, refining interview protocols, and identifying additional cases where salience-based dynamics are particularly visible. Overall, this research contributes to ongoing conversations in aviation policy, environmental governance, and public-sector implementation by positioning stakeholder alignment as a central driver of sustainability performance at U.S. airports.

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Enrollment and Engagement: How to Revitalize a Dying sUAS Program

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This study investigates the impact of pedagogical innovation on student engagement and enrollment within the Unmanned Aerial Systems (UAS) program at Metropolitan State University of Denver. Initial research revealed a consistent pattern of high enrollment in the introductory UAS course, contrasted by low participation in intermediate and advanced courses. Through a combination of qualitative and quantitative methods, including surveys, interviews, and historical data analysis, the study identified a lack of engaging instructional methods as a key barrier to student progression. In response, the introductory course was redesigned using a flipped classroom model, integrated FAA Part 107 certification preparation, hands-on drone activities such as Drone Soccer and FPV simulators, and promoted real-world flight missions in upper-level courses. Post-implementation data showed a dramatic increase in student engagement and a significant rise in enrollment across all course levels. These findings underscore the importance of dynamic, student-centered teaching strategies and suggest that thoughtful curriculum design can directly influence program success and student retention.

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Phinney, C. (2025). Enrollment and engagement: How to revitalize a dying sUAS program. *Collegiate Aviation Review International*, 43(2), 493-498. Retrieved from <http://ojs.library.okstate.edu/osu/index.php/CARI/article/view/10463/9201>

Introduction

When I was hired as a professor at Metropolitan State University of Denver, I was tasked with determining why our Unmanned Aerial System (UAS) program was struggling in student enrollment. To be fair, enrollment in the Introduction to UAS course was robust and often created a substantial waitlist; it was the intermediate and advanced courses that experienced low or non-existent enrollment numbers. My research showed this trend for the past five years but it's likely been the norm from the beginning of the program.

During my first year, I conducted both qualitative and quantitative research to answer the question, why was enrollment flatlining after students were successfully in completing the introduction to UAS course. Observations, surveys and historical research were the vehicles for my data accusation.

As professors, we excel in being experts within our industry, conducting research to be at the forefront of our fields. Most are successful in this endeavor but often come up short in teaching pedagogy. We often neglect to ask the question, am I a good teacher and reflect on better teaching practices.

The results of my research aligned with this exact notion, subject matter over teaching pedagogy was creating the enrollment deficit in our upper division UAS courses. Taking this data into account, I used my own pedagogy in program/curriculum development and findings from education experts to create a positive shift towards increasing enrollment in the upper division UAS courses.

As hypothesized, the changes made to these programs did have a direct positive impact on student engagement and ultimately student enrollment. The data also strengthens other research showing that classes shouldn't be focused on power point knowledge transfer, but on strong teaching pedagogy.

Literature Review

A flipped classroom involves students pre-loading information before they attend class. This allows for better use of time during class including scenario based learning, small groups and more one on one instruction from the instructor.

In a recent study by Masha Smallhorn, students were transitioned from a traditional classroom to a flipped classroom. She begins by saying, "an analysis of the weekly reflection responses found that, in the first two weeks of the semester, students reported neutrally about preparing for the flipped class by reading through the resources, watching the online videos and completing the quiz" (Smallhorn 2017). Overall, the students' response from the new flipped classroom model is to be expected. We have been trained for generations in what a traditional classroom should be. As educators, we tend to stay in our lanes. Smallhorn expands by saying, "As the semester progressed, students' attitudes towards the flipped classroom improved. In week nine, students were asked to reflect on the flipped classes they had attended and discuss how they had helped them to understand the material provided in the online resources"

(Smallhorn 2017). “An analysis of their responses (n=59) found that 95% of students who responded thought that overall, the flipped classroom had been a positive learning experience” (Smallhorn 2017). One of her students said, “They have allowed me to not just have knowledge passed on in a passive manner, like most other topics, but instead apply what we are learning in a practical sense, in an environment where there is help available (both from other students and teachers). They have also made me feel better prepared for the exam” (Smallhorn 2017). Her study went on to analyze student engagement. Smallhorn explains, “students were defined as highly engaged, moderately engaged or poorly engaged, based on the number of flipped classes attended over the semester. 88% of students who achieved a high distinction grade were highly engaged, compared to only 33% of students who achieved a passing grade. Of the students who failed the topic, 57% were poorly engaged, while 20% were moderately engaged. She goes on to say, “This suggests that attending flipped classes is strongly linked to learning outcomes and that students who are poorly engaged are more likely to fail the topic (Stronghorn 2017).

The flipped classroom model demonstrates positive outcomes in student engagement and success, grounded in the principle of student ownership of learning. To support this ownership, incorporating hands-on learning technologies can help create a dynamic and effective educational environment.

A study was done involving 68 students being immersed in Virtual Reality to create hands on learning. “The research results indicate that in the VR hands-on learning environment, participants engage in reflection through the provided feedback, effectively enhancing their engagement, cognitive levels, and hands-on task abilities. Simultaneously, it also successfully assists participants in developing problem-solving skills and critical thinking in higher-order thinking” (Huang) 2024). The results of the study showed, “Participants actively engaged in reflection on their own learning tasks and actions within the hands-on learning environment, enabling them to develop a deeper understanding of the learning material and enhance their real-world hands-on tasks abilities, we encourage the integration of reflection strategies in VR learning environments for hands-on learning, as they can yield positive benefits for learners” (Huang 2024). This study makes it clear that utilizing up to date technology not only enhances learning but also aligns with the current generation learning styles.

Methods

Does student engagement translate into student enrolment? Specifically, does changing the traditional classroom model presently used in our Introduction to UAS course help increase the low enrollment in the upper division UAS courses. For clarity, our UAS program is as follows:

- Introduction to Unmanned Aircraft Systems (Introduction)
- Unmanned Systems Flight and Controls (Intermediate)
- Unmanned Aircraft Data Collection and Analysis (Advanced)
- Aviation Weather
- Aviation Elective

Student enrollment numbers from the UAS program were compiled from the last five years to acquire quantitative data. Anonymous surveys were administered to 25 students who had previously taken the introductory UAS class. These students were selected randomly without prior knowledge of knowing who had continued to the upper division UAS courses or dropped out of the program. Short impersonal interviews were also conducted to provide qualitative data on their experiences in the program. After analyzing the information, we transitioned the class into a Flipped Classroom model that provided high student engagement. After a year, enrollment in the upper division UAS courses was re-evaluated with positive results.

Results

Table 1

Percentage of enrollment for all three courses prior to the class transition

Year	Introduction to UAS	Intermediate UAS	Advanced UAS
2020	90%	0%	31%
2021	93%	21%	12%
2022	92%	6%	0%
2023	92%	15%	0%
2024	94%	0%	0%

Table 2

Student survey results before the class transition

Did you feel prepared to take the FAA Part 107 written test after completing Introduction to UAS?	YES 1	NO 22	Not Sure 2
How often did you fly the drones while in the Introduction to UAS class?	Did not fly 25	1-10 Times	11-15 Times
Would you recommend this class to other students?	Yes 3	NO 22	
After completing Introduction to UAS, how likely were you to enroll in the intermediate or advanced UAS course?	Likely 1	Unlikely 21	Not Sure 3

Table 3

Percentage of enrollment for all three courses after class transition

Year	Introduction to UAS	Intermediate UAS	Advanced UAS
2025	100%	100%	82%

Table 4

Student survey results before the class transition

Did you feel prepared to take the FAA Part 107 written test after completing Introduction to UAS?	YES 22	NO 1	Not Sure 2
How often did you fly the drones while in the Introduction to UAS class?	Did not fly	1-10 Times	11-15 Times 25
Would you recommend this class to other students?	Yes 25	NO 0	
After completing Introduction to UAS, how likely were you to enroll in the intermediate or advanced UAS course?	Likely 23	Unlikely	Not Sure 2

Discussion

Based on survey results collected prior to any program changes, it was clear that students did not enjoy the Introduction to UAS course. To address this, I focused on increasing student engagement, operating under the hypothesis that this change could lead to higher enrollment in upper-division courses.

The first major change was integrating the flipped classroom model. It took the students a few weeks to adapt to the new learning style but quickly became popular. Integrating Part 107 into the curriculum was the next step. Part 107 is a widely sought out credential that was missing from our program. Additionally, we introduced Drone Soccer, a hands-on e-sport that enriched our program by providing students with hands on flying, a student lead organization and programming experience. Lastly, we introduced an FPV (first person view) drone simulator into the classroom. This created excitement and familiarity with current trends.

Lastly, we advertised the exciting flight missions that students would experience in the upper division UAS courses. These flights include, search and rescue, inspections, thermal, photogrammetry and geo-spatial missions utilizing our new Autel Evo-Max 4T drone.

Conclusion

The results of this research clearly show an increase in enrollment in upper division UAS courses after the changes were made to the Introduction to UAS course. The student surveys also strengthen this conclusion with 88% of the students feeling prepared to take the FAA written test. 100% of the students flew drones more than 11 times during the semester. 100% of the students would recommend taking the course. 92% of the students are considering taking both upper division courses after completing the intro UAS class. These results came from building a program based upon hands on learning, a flipped classroom model and current generation relevancy. In short, we made the program fun while maintaining a rigorous curriculum.

This study also serves as a reminder for educators to think creatively and broaden our teaching pedagogy. While we are experts in our academic disciplines, we must also strive to be experts in how we deliver knowledge. Maybe a flipped classroom doesn't work for your environment or current funding won't allow for new tech, but there are hundreds of ways to make a class more interesting, you just need to take that first step away from the PowerPoint lecture.

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An Examination of the Implications of Space Exploration Through the Lens of Five Ethical Philosophies

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In the early 21st century, the rapid advance of space exploration has resulted in both significant scientific and economic prospects and profound ethical challenges. This paper examines the ethics of modern space exploration through five relevant principal ethical philosophies: Utilitarianism, Deontological Ethics, Virtue Ethics, Environmental Ethics, and Feminist Ethics. Utilitarianism evaluates actions based on outcomes, advocating for those that maximize overall well-being, while Deontological Ethics emphasizes adherence to moral duties and principles. Virtue Ethics focuses on the character and virtues of individuals and organizations, while Environmental Ethics highlights the intrinsic value of non-human environments and advocates for their preservation. Feminist Ethics stresses inclusivity, equity, and social justice. The paper develops a comprehensive ethical framework to guide humanity's ventures into space by integrating these different perspectives.

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Introduction

The stakes of venturing into outer space—from satellite deployments and crewed lunar bases to interplanetary travel and asteroid mining—have never been higher, both in terms of potential scientific and economic benefits and inherent risks. As humanity extends its reach beyond Earth, we must ask: What ethical frameworks should guide our actions in space? How do we ensure that our pursuits reflect justice, sustainability, and inclusivity, not just technical or economic feasibility? The paper explores ethical frameworks through the evaluation of space exploration activities through five philosophical lenses. The primary research question addressed in this paper is: What ethical framework(s) best address the multifaceted dilemmas of space exploration in a way that promotes justice, sustainability, and inclusivity.

Space exploration represents a technical challenge and a profound ethical and philosophical problem (Jaehnichen, 2020). Our actions in exploring outer space could have long-lasting implications for future generations of both human and potentially alien life forms (Madhavan Nair et al., 2008; Santomartino et al., 2023). Therefore, to ensure our cosmic endeavors are successful, just, and responsible, it is imperative that we analyze these activities through various ethical lenses. This paper examines the ethics of space exploration from five principal ethical philosophies' perspectives: Utilitarianism (Bentham, 1789; Bentham et al., 1807), Deontological Ethics (Kant 1785; 1788), Virtue Ethics (Aristotle; Darwall, 2003; Devetter, 2002; Gardiner, 2005; Hursthouse & Pettigrove, 2018; Russell, 2013; Swanton, 2003; Taylor, 2002), Environmental Ethics (Chua, 2022; Di Paola, 2024; Hourdequin, 2021; Palmer et al., 2014; Valera et al., 2021), and Feminist Ethics (Brabeck, 2000; Brennan, 1999; Card, 1991; Superson, 2024; Tong, 1993).

Each of these philosophical frameworks offers unique insights into the moral dimensions of space exploration. For example, *Utilitarianism* asks us to weigh the benefits against the harms, promoting actions that maximize overall well-being. This approach might justify significant risks in space exploration if the potential gains (e.g., knowledge, resources, or even species' survival) are substantial (Munévar, 2014). *Deontological Ethics* shifts the focus from outcomes to adherence to moral duties, rules, or categorical imperatives—such as the duty not to harm others or the environment—which might oppose the exploitation of space irrespective of the potential benefits (Martínez-Frías et al., 2011). *Virtue Ethics* emphasizes the character and virtues of the individuals and organizations involved, advocating for space exploration that promotes virtues such as bravery, prudence, and humility (Reiman, 2009). And to further complicate the ethical landscape, *Environmental Ethics* raises questions about our moral obligations toward non-Earth environments. This perspective challenges the anthropocentric view by considering the intrinsic value of space and the potential life forms it might host (Daly & Frodeman, 2008). Finally, *Feminist Ethics* offers a viewpoint that stresses inclusivity, equity, and social justice (Riley, 2013).

The importance of these ethical considerations becomes especially pronounced in light of space exploration's international and multi-generational impacts. As we stand on the precipice of becoming an interplanetary species, the decisions made now will shape the future of humanity and other potential forms of life across the cosmos. This paper aims not only to delineate these ethical dimensions, but also to outline a path toward an ethical framework that can universally

guide how nations and private entities behave in space. As such, this paper aims to contribute to dialogues among policymakers, scientists, and the global community to help ensure that our ventures into the great unknown are taken with wisdom, foresight, and ethical integrity.

Literature Review

The ethical considerations of space exploration have garnered considerable attention in recent years as humanity expands its presence in space, driven by the advent of private space travel and the discussion of crewed missions beyond the Moon. As we expand our footprint throughout the solar system, humanity faces multifaceted ethical dilemmas inherent in the exploration of outer space. These concerns range from planetary protection to the health and well-being of the crew.

A primary ethical concern in space exploration is planetary protection, which is the set of measures designed to prevent the contamination of other celestial bodies and Earth's biosphere during space missions. Coustenis et al. (2023) state that as access to space becomes more democratized through traditional and non-traditional actors, robust international frameworks, such as those proposed by the Committee on Space Research (COSPAR, 2024), are necessary to ensure that environmental stewardship remains a priority. This is crucial to ensure that extraterrestrial ecosystems remain pristine and to maintain the integrity of planetary science, as contamination could significantly alter our understanding of other worlds.

Moreover, the ethical implications of human spaceflight must be examined, considering the dramatic health challenges that crew members will face due to prolonged exposure to space environments. Rutter et al. (2020) indicate that missions to Mars or other celestial bodies will involve a diverse cohort of astronauts who will face significant physical and psychological stressors. They highlight the establishment of international standards for space omics to address health risks related to factors such as microgravity. The obligation to ensure the safety and well-being of astronauts includes mental health considerations, which have been less addressed (Rutter et al., 2020).

The intersection of technological advancement and ethical considerations presents opportunities and challenges. With the growth of commercial spaceflight activities, ethical responsibilities towards diverse stakeholders have become prominent. The discourse on responsible research and innovation (RRI) emphasizes inclusion and responsiveness, enabling stakeholders to participate meaningfully in discussions about ethical implications (Giulio et al., 2016). As space exploration evolves, the ethical frameworks governing these enterprises must ensure that various perspectives are considered in decision-making processes.

Finally, the ethical landscape of space exploration must also consider broader societal implications, including issues of justice and environmental ethics. Barnett (2016) argues that moral concerns should extend beyond anthropocentrism, raising questions about obligations to non-human entities and ecosystems in space (Bernthal et al., 2016). As humanity enters an era of interplanetary exploration, these ethical considerations will need continuous reassessment to align with evolving technological capabilities and societal values.

The ethical dimensions of space exploration include planetary protection, health considerations for astronauts, inclusivity in decision-making processes, and broader ethical obligations towards non-human entities. Addressing these challenges will be essential as humanity continues to explore beyond our planet, ensuring that new frontiers are approached with responsibility and foresight.

Methodology

This paper employs a comparative ethical analysis to examine space exploration through five philosophical frameworks: Utilitarianism, Deontological Ethics, Virtue Ethics, Environmental Ethics, and Feminist Ethics. Rather than testing hypotheses or collecting empirical data, the goal is to analyze how each framework interprets moral dilemmas associated with space activities. This approach is grounded in normative ethics, using case-based reasoning to explore the implications of different ethical lenses. To ensure consistency and comparability across philosophies, we apply each ethical theory to a shared set of representative case studies, including:

- Mars colonization efforts (e.g., SpaceX's Mars program),
- Asteroid mining and resource extraction,
- Planetary protection protocols,
- Crew decision-making under high-risk conditions, and
- Equity and access in space exploration initiatives (e.g., the Artemis program).

These case studies were selected for their diversity, relevance, and presence in public, governmental, and academic discourse. They illustrate key tensions in space ethics, such as risk vs. reward, autonomy vs. oversight, preservation vs. progress, and inclusion vs. tradition. By analyzing how each ethical theory interprets these scenarios, we assess the strengths and limitations of each framework. This analysis will lead to the development of an integrative ethical framework, designed to synthesize the most compelling elements of each philosophy into a coherent guide for space policy and practice. The integrative conclusion emerges from identifying overlapping values, contrasting priorities, and unaddressed ethical gaps. This structured comparison allows for a more robust understanding of how diverse moral theories can inform decision-making in an environment as complex, novel, and high-stakes as outer space.

Utilitarianism and Space Exploration

Utilitarianism, a normative ethical theory, advocates actions that maximize happiness and minimize suffering (Bentham, 1789; Bentham et al., 1807). This principle focuses on the consequences of our actions. In the context of space exploration, *utilitarianism* encourages us to weigh the potential benefits against the inherent risks. According to utilitarianism, the central question when considering space exploration is: Do the positive outcomes of space ventures outweigh their financial costs and the risks to human safety?

Application for Space Exploration

Applied to space exploration, *utilitarianism* assesses decisions based on their outcomes, including scientific knowledge, economic gains, and humanity's long-term survival. This philosophy supports activities that promise significant benefits—such as finding solutions to Earth's resource limitations, advancing technology and biology, and protecting humanity from existential threats like asteroid impacts or planetary catastrophes (International Space Exploration Coordination Group, 2013).

Case Study 1: Establishment of a Human Presence on Mars

The endeavor to colonize Mars, led by organizations like SpaceX, presents a compelling case for *utilitarian* analysis. Establishing a human settlement on Mars offers profound potential benefits. First, it could serve as a "plan B" for humanity, providing a backup in the event of catastrophic disasters on Earth and potentially securing our future (Levchenko et al., 2019). Second, exploring Mars could lead to groundbreaking scientific discoveries and technologies that may turn out to be essential for humanity's long-term survival in space (Seedhouse, 2009, p. 8). From a utilitarian perspective, we must find ways of quantifying the significant costs and the long-term benefits. If we can ensure that the benefits significantly outweigh the costs, then utilitarianism would suggest that this is a justifiable endeavor. The ethical challenge lies in quantifying these benefits and ensuring they are attainable without causing undue harm.

Case Study 2: Asteroid Mining

Asteroid mining is another area of space exploration with significant implications according to *utilitarian* ethics. Asteroid mining involves extracting resources like water, minerals, and metals from near-Earth asteroids. Companies such as Planetary Resources and Bradford Space (formerly Deep Space Industries) propose that asteroid mining could supply essential materials to sustain space exploration and potentially bring valuable resources back to Earth (Skauge, 2020; Yarlagadda, 2022). The *utilitarian* benefits include the immense economic value of metals like platinum and gold, and reducing environmental strains on Earth by shifting resource extraction into space. Peter Diamandis, founder of Planetary Resources, has noted that a small asteroid about 100 feet in length could contain between \$25 and \$50 billion worth of platinum (Klotz, 2012). Additionally, the technology developed for asteroid mining could advance our capabilities in space travel and enable permanent space habitation. However, according to *utilitarianism*, the financial costs, technological challenges, and risks to human life involved in such missions must be carefully weighed against these anticipated benefits.

Critical Analysis: Strengths and Limitations

Utilitarianism provides a straightforward way to evaluate space exploration initiatives: actions are justified if they lead to a net positive effect, (defined by the principle of utility, often interpreted as the "greatest happiness" principle). This clear-cut approach appeals to policymakers and stakeholders because it focuses on tangible outcomes. However, this method has its limitations: Predicting the consequences of complex, long-term space missions is very difficult, as outcomes are uncertain. The risks and rewards, which may unfold over decades, are

challenging to quantify accurately. Moreover, *utilitarianism* might not fully address the rights and well-being of individuals involved—like astronauts facing extreme danger or people on Earth who could be exposed to alien diseases or toxins brought back from space missions. Additionally, *utilitarian* ethics could unintentionally justify harmful actions if the benefits are deemed to outweigh the costs. For instance, aggressive mining on celestial bodies might be considered acceptable due to substantial material gains, even if it violates planetary protection protocols or causes long-term ecological harm.

While utilitarianism offers a strong framework for assessing the ethics of space exploration, it needs to be applied with care and a well-rounded understanding of the possible outcomes. It also needs to be determined who will be making the decisions. For example, due to communication limits imposed by Einstein's Theory of Special Relativity (Einstein, 1905), the mission's commander might be the only one making real-time decisions. This scenario could hinder ethical oversight of their choices unless an AI-based system is implemented to guide the decision-making process.

Deontological Ethics in Space Exploration

Deontological ethics, rooted in Immanuel Kant and others' philosophy, holds that an action's morality is determined by whether it follows a set of rules or duties, rather than by its consequences (Kant 1785; 1788; 1991; Wick, 1995). This ethical approach holds that certain principles—such as the duty to act properly, and the inherent value of human dignity—are fundamental and must be maintained, regardless of the outcome. In the context of space exploration, deontological ethics stresses the importance of adhering to these ethical standards and obligations, ensuring that all actions taken in space are inherently moral and just.

Application to Space Exploration

Deontological ethics asserts that space exploration must follow universal moral principles, such as respecting the autonomy and inherent worth of every individual involved and ensuring that no being—human or otherwise—is used merely as a tool to achieve objectives. This approach scrutinizes the morality of potentially harmful activities by focusing on their intrinsic rightness, regardless of any beneficial outcomes they might generate.

Case Study 1: The Preservation of Planetary Environments

In the current discussion surrounding planetary protection's focus on preventing biological contamination during space missions, *deontological* ethics are being enacted. As a result of this way of reasoning, NASA and other international space agencies have implemented strict planetary protection protocols both to ensure that Earth-based life does not contaminate other celestial bodies and to avoid bringing any potentially harmful extraterrestrial organisms back to Earth (Rummel & Pugel, 2019).

From a *deontological* standpoint, the duty to prevent contamination is crucial because it honors the perceived inherent value of celestial bodies, ensuring that they are neither harmed nor exploited. Historically, NASA missions have worked to avoid contaminating planets that might

support life. For instance, during the final phase of the Cassini mission, scientists intentionally directed the spacecraft to crash into Saturn instead of one of its moons, as moons like Enceladus and Titan are believed to have the potential to harbor life. Therefore, crashing Cassini into Saturn helped to protect these potentially life-supporting environments from possible contamination (Bolles, 2023).

Case Study 2: The Use of Autonomous Robots in Exploration

Deontological ethics is also crucial in the deployment of autonomous robots for space exploration, such as rovers on Mars or drones on Titan (Coeckelbergh, 2014; Owe et al., 2022). The ethical issues here center on these robots' autonomy and safety, particularly as relate to their programming and the tasks that they are designed to perform. From a deontological perspective, these robots deserve respect, considering their roles and the resources invested in their development. While *utilitarian* ethics might emphasize the scientific and economic benefits of missions that use these robots, even if they are risky or destructive, *deontological* ethics focuses on the inherent need to respect the robots' operational limits and intended purposes. This means not overloading their systems or pushing them beyond their functional capacities just to collect more data, as doing so would disregard the craftsmanship and the purpose their creators designed them for.

Critical Analysis: Strengths and Limitations

A *deontological* ethical perspective does not waver in its assessment of a situation, even when ignoring them could lead to significant scientific advancements. For example, directly exploring the subsurface waters of Europa—a moon of Jupiter that is believed to potentially harbor life—without taking proper precautions could result in contamination. Under *deontological* ethics, this action would be inherently wrong, regardless of any scientific knowledge that might be gained.

In the context of space exploration, *deontological* ethics' focus on moral absolutes and the inherent rightness of actions is beneficial, as this provides clear and consistent ethical guidelines regardless of changing circumstances or outcomes. This is especially important in space, where actions' consequences can be highly uncertain or take a long time to manifest. However, the limitations of this approach become evident in complex situations where strictly following rules might lead to questionable outcomes. For example, always adhering to non-interference policies could prevent beneficial actions like terraforming Mars to make it livable for humans. While *deontological* ethics offers a strong foundation for ensuring that space is explored with strong moral integrity, such a perspective needs to be balanced with practical considerations in light of actions' broader consequences. This balance is essential for ethical decision-making in space exploration, where both the inherent rightness of actions and their potential outcomes play critical roles.

Virtue Ethics: Character and Space Exploration

Virtue Ethics focuses on the importance of character and virtues in moral philosophy, rather than on rules (deontology) or outcomes (utilitarianism) (Aristotle; Darwall, 2003;

Devetter, 2002; Gardiner, 2005; Hursthouse & Pettigrove, 2018; Russell, 2013; Swanton, 2003; Taylor, 2002). It suggests that ethical behavior arises from developing good character traits—or virtues—which lead to moral actions. In the context of space exploration, this approach highlights the virtues of the people and organizations involved, such as integrity, courage, and responsibility.

Application for Space Exploration

Virtue ethics encourages us to look closely at the motivations and character traits of everyone involved in space exploration, including astronauts, scientists, and corporate and governmental organizations. This approach evaluates how having—or lacking—certain virtues can affect the decisions made during space missions. Virtue ethics is especially important in the high-stakes and high-risk world of space exploration, where the moral character of individuals making decisions can greatly influence both how missions are carried out and their ultimate success. This focus on character is crucial for future deep space missions, too, where communication delays can span hours, depending on the distance from Earth. For example, Table 1 illustrates the distances in Astronomical Units (the distance from the Sun to the Earth) and the corresponding time it takes for a round-trip message to travel.

Table 1

Communication Round-Trip Times in Deep Space

Location	Distance from Earth in AUs	Round-Trip Time
Mars	1.5	25 minutes
Ceres	2.77	46 minutes
Jupiter	5.2	1 hour, 27 minutes
Saturn	9.58	2 hours, 40 minutes
Uranus	19.22	4 hours, 20 minutes
Neptune	30.06	8 hours, 5 minutes
Pluto	39.48	11 hours
Makemake	45.81	12 hours, 40 minutes
Alpha Centauri	268,770	8.9 years

Note: AUs = Astronomical unit (1 AU is about 150 million km)

Case Study 1: Astronauts and Decision-Making Under Pressure

One relevant case study highlights astronaut behavior and decision-making under the extreme conditions of space travel. For example, consider the actions of astronauts aboard the International Space Station (ISS) during emergencies, such as the Nuka module mishap in July 2021. After successfully launching and docking the new science module, Nauka, to the ISS, the module accidentally fired its thrusters. This misfire caused the ISS to spin approximately 540 degrees and come to a stop upside down (Bartles, 2021; De La Cruz, 2021; Gorman & Ivanova, 2021). This situation required the crew to initiate emergency procedures and regain control of the spacecraft's orientation. In such moments, astronauts and cosmonauts needed prudence to accurately assess the problem, courage to take necessary risks to resolve it, and temperance to manage their fears and anxieties to maintain operational effectiveness (Dole, 1967). From a

virtue ethics perspective, these qualities are not just beneficial, they are essential for the mission's success and the crew's safety.

Case Study 2: Ethical Leadership in Space Agencies

Another example of *virtue* ethics in action is seen in how the leadership of space agencies and their approach to mission planning and risk management has historically been evaluated. Consider NASA's decisions during the Space Shuttle era, particularly the Challenger and Columbia disasters. Analyses of these tragedies have highlighted failures in leadership and organizational culture, where virtues like honesty and responsibility were compromised due to political pressures and tight schedules. Despite engineers' warnings about the O-ring seals' performance in cold temperatures, NASA management decided to proceed with the launch due to increased government pressure (Bowman, 2024; Rogers et al., 1986). This breakdown in communication and proper risk management, combined with heightened media scrutiny and governmental demands, led to the unethical decision to launch despite the known risks.

Virtue ethics would critique these scenarios by highlighting the lack of ethical leadership and the abandonment of virtues for expediency or external approval. This ethical framework suggests that cultivating virtues such as honesty, justice, and humility within organizational cultures is essential for preventing such tragedies. Promoting ethical leadership would involve individual virtue and developing institutional practices that encourage transparency, accountability, and ethical deliberation in decision-making processes.

Critical Analysis: Strengths and Limitations

One of the primary strengths of virtue ethics in space exploration is its emphasis on individual moral development. This view promotes a holistic approach to ethics that integrates personal character and professional actions. This focus on character virtues makes individuals more likely to navigate ethical dilemmas in space exploration thoughtfully and morally.

However, virtue ethics' limitations lie in its relative subjectivity and difficulty in defining and measuring virtues across different cultural and organizational contexts. What one culture or organization deems a virtue, another might not. This tends to result in inconsistent ethical standards and practices across contexts. Moreover, the emphasis on individual character does not always address systemic or organizational issues that can lead to ethical failures, as seen in the case of the Space Shuttle disasters. Therefore, while virtue ethics offers profound insight into a character's role in conducting ethical space exploration, it should be applied alongside other ethical frameworks to address the personal and systemic dimensions of ethics in space activities. This balanced approach can help ensure that space exploration is pursued with technological and scientific excellence and moral integrity.

Environmental Ethics and Extraterrestrial Environments

Environmental ethics, a branch of philosophy that studies the moral relationship between humans and the environment (Chua, 2022; Di Paola, 2024; Hourdequin, 2021; Palmer et al., 2014; Valera et al., 2021). This perspective challenges anthropocentric views by emphasizing

that non-human elements of the environment are intrinsically valuable and deserve our consideration. When applied to space exploration, *environmental* ethics urges us to consider the ethical implications of our actions in non-Earth environments (Daly & Frodeman, 2008; Randolph & McKay, 2014).

Application for Space Exploration

Environmental ethics in the context of space exploration advocates a cautious and respectful approach to interacting with extraterrestrial environments. This includes minimizing contamination, preserving the natural state of celestial bodies, and preventing the exploitation of space resources in ways that could cause irreversible harm—views that deontological ethics share. By extending the principles of environmental stewardship beyond Earth, *environmental* ethics urges us to act as responsible caretakers of space by ensuring that our exploratory pursuits do not come at the expense of extraterrestrial integrity.

Case Study 1: Protecting Martian Ecosystems

With its potential to harbor microbial life, Mars presents a significant ethical dilemma in space exploration. The discovery of liquid water on Mars intensifies concerns about the contamination of Martian environments by Earth-originating life forms (Mason, 2021). The principles of *environmental* ethics compel us to consider the intrinsic value of Martian ecosystems. As such, these *environmental* ethics advocate strict planetary protection measures to prevent biological contamination.

The Committee on Space Research (COSPAR, 2024) and NASA's Planetary Protection group (Keith, 2024) have established guidelines to minimize the risk of contaminating Mars and other celestial bodies with terrestrial microbes. These protocols include sterilizing spacecraft and limiting landings to areas with low probability of life. The ethical rationale is that introducing Earth life to Mars could irreversibly alter its environment, potentially destroy native life forms or disrupt the planet's natural state.

From an *environmental* ethics perspective, the duty to protect Mars comes from a moral obligation to respect and preserve planets' natural environments, as this perspective recognizes these environments' intrinsic values, irrespective of their utility for humans. This approach calls for us to act based on precautionary principles, according to which we give the benefit of doubt to the unknown potential for life and ecological balance on Mars. This guides us to prioritize preservation over exploration.

Case Study 2: Ethical Considerations in Asteroid Mining

As discussed above, asteroid mining, which is seen by some as a solution to Earth's resource limitations, poses significant ethical challenges according, also, to *environmental* ethics (Xu, 2020). The extraction of minerals and water from asteroids involves altering these celestial bodies in potentially harmful ways (New Space Economy, 2023). Environmental ethics questions the moral justification for exploiting these extraterrestrial resources while urging us to consider the broader ecological impacts.

According to *environmental* ethics, the potential for ecological disruption is a primary ethical concern in asteroid mining. Mining activities could cause debris and alter their orbits, posing risks to Earth and other planets (New Space Economy, 2023). NASA's Double Asteroid Redirection Test (DART) mission proved that a kinetic impact on an asteroid could vastly alter its course (Bardan, 2022). This highlights the importance of understanding celestial mechanics to prevent an asteroid from being changed to impact Earth. Mining activities could alter the trajectory of an asteroid, causing untold cascading effects. Moreover, the aggressive pursuit of asteroid mining could lead to a "space rush," where entities race to exploit resources with little regard for environmental consequences (Heins, 2021).

Companies like Planetary Resources and Bradford Space argue that asteroid mining could alleviate resource shortages on Earth and drive technological advancement (Skauge, 2020). However, environmental ethics advocates for a balanced approach, where the potential benefits are weighed against the moral obligation to preserve the natural state of space environments. This perspective suggests that asteroid mining should be conducted with caution and transparency, and that strict regulations are needed to minimize ecological disruption and ensure that the exploitation of space resources does not lead to unforeseen and potentially catastrophic consequences.

Critical Analysis: Strengths and Limitations

Environmental ethics provides a robust framework for evaluating space exploration's moral implications, emphasizing extraterrestrial environments' intrinsic value. This perspective promotes a cautious approach that prioritizes the preservation of astronomical objects and the prevention of ecological harm. By challenging anthropocentric views, environmental ethics expands our moral considerations to include non-Earth environments, fostering a sense of stewardship.

However, environmental ethics also has the potential to hinder the scientific progress and economic development of space exploration. For example, adhering too strictly to principles of preservation may restrict exploratory activities and resource utilization, which could delay technological advancements and solutions to Earth's pressing issues. Additionally, the intrinsic value of lifeless space is contentious, with some arguing that ethical considerations should focus on the potential benefits to humanity. Environmental ethics does provide essential guidance for ways to explore space responsibly, but these approaches must be balanced with practical considerations and the potential benefits of space activities. By integrating environmental ethics and other ethical frameworks into a more balanced approach, we can ensure that our endeavors in space respect the natural world.

Feminist Ethics and Space Exploration

Feminist ethics, which emphasize relationships, care, and empathy, challenge traditional ethical frameworks that often prioritize abstract principles over individuals' lived experiences (Brabeck, 2000; Brennan, 1999; Card, 1991; Superson, 2024; Tong, 1993). This perspective highlights the significance of inclusivity, equity, and social justice in ethical decision-making. In

the context of space exploration, feminist ethics calls for a thorough assessment of how space policies and practices affect various groups and marginalized communities (Szocik, 2021). It promotes an inclusive approach that is designed to ensure equitable participation and benefits for all involved (Kittay, 2001).

Application for Space Exploration

Within space exploration, feminist ethics centers on advancing gender equity, inclusivity, and social justice. This perspective involves addressing gender gaps in space programs, ensuring diverse representation in decision-making, and considering the wider social and ethical effects of space activities on different communities. By focusing on care and relational ethics, feminist ethics urges the creation of space policies that respond to the needs and experiences of individuals who have historically been excluded from space-related ventures.

Yet feminist ethics argues for more than mere representation. It emphasizes cultivating supportive, inclusive workplaces that tackle the distinct hurdles that women face in these environments—such as gender bias, challenges with work-life balance, and unequal access to resources or opportunities. Enacting comprehensive policies that uphold gender equity and inclusivity at every level of space programs is critical to ensuring fair distribution of space exploration's benefits.

Case Study 1: Gender Equity in Space Programs

A key challenge in space exploration is the underrepresentation of women and members of other marginalized groups (National Academies of Sciences, 2022). Historically, 12 white men have set foot on the Moon, reflecting the longstanding dominance of men in space exploration. In this field, women have often faced systemic barriers to entry and advancement (National Academies of Sciences, 2022; West, 2023). In response, feminist ethics advocates for proactive efforts to achieve gender equity across every aspect of space exploration, from recruiting and training to mission assignments and leadership positions (West, 2023).

In fact, in response to the gender and racial imbalance of the Apollo missions, NASA's Artemis program aims to land the first woman (and the first person of color) on the Moon by 2026 (Creech et al., 2022; NASA, 2023). By prioritizing gender diversity, the Artemis program strives to foster a more inclusive and equitable environment in space exploration (NASA, 2023) and it aims to inspire future generations of women to pursue careers in STEM fields. Space exploration endeavors—particularly those involving resource extraction and satellite deployment—can significantly affect marginalized communities, both socially and environmentally (Dick & Launius, 2007). Feminist ethics encourages us to evaluate these effects and guarantee that space activities do not heighten existing inequalities or produce new injustices (Szocik, 2024).

Case Study 2: The Impact of Space Activities on Marginalized Communities

Major satellite constellations launched by companies like SpaceX and Amazon to provide worldwide internet coverage have sparked worries about space debris and its impact on

vulnerable communities (DiBenedetto, 2022). These satellites can overcrowd low Earth orbit, increasing the collision risk, potentially triggering the Kessler Syndrome and creating debris that endangers future space operations (Undseth et al., 2020). Additionally, the resulting light pollution can hinder astronomical research and disrupt cultural practices of Indigenous communities who depend on dark skies for traditional knowledge (Safronova, 2023).

From a feminist ethics standpoint, an inclusive decision-making process—one that actively involves the voices and concerns of marginalized groups—is vital. This requires comprehensive impact assessments and direct engagement with the communities affected to fully understand their perspectives and reduce any negative outcomes. Moreover, it is crucial to ensure that satellite technology benefits everyone.

Critical Analysis: Strengths and Limitations

Feminist ethics offers a valuable framework for addressing inclusivity, equity, and social justice in space exploration. By prioritizing care, empathy, and relational ethics, it supports a more holistic, responsive stance on ethical decision-making. This approach promotes policies and practices that uplift and include diverse groups, and this helps policymakers, organizations, and leader to build a fairer space exploration arena.

However, feminist ethics may be criticized for focusing too heavily on gender and social issues at the expense of other important ethical considerations. There is also [often unjustified] concern that emphasizing diversity could overshadow merit-based selection, potentially creating a crew less prepared for emergencies. Striking the right balance among different ethical priorities can be complex, but interweaving feminist ethics with other ethical frameworks can yield a more comprehensive and precise approach to ethical issues in space. By stressing gender equity and accounting for the broader social effects of space endeavors, feminist ethics not only enriches efforts to make humanity's expansion into space more inclusive and ethically sound, but it could improve performance given that research often shows that diversity improves team performance.

Comparative Analysis of Ethical Philosophies in Space Exploration

Space exploration encompasses numerous ethical challenges, and these can be interpreted according to diverse philosophical lenses. Utilitarianism, Deontological Ethics, Virtue Ethics, Environmental Ethics, and Feminist Ethics each offer distinct insights. Therefore, comparing them sharpens our understanding of the ethical factors surrounding humanity's push beyond Earth. Although these five philosophies diverge in their priorities—ranging from maximizing benefits, upholding moral duties, and nurturing moral character to valuing non-human environments and championing social justice, they all underscore the importance of ethics in space exploration. They also address space exploration's long-term implications, although they differ in which issues they emphasize and how they approach them. Utilitarianism and Deontological Ethics clearly contrast evaluating outcomes with following moral principles. Utilitarianism supports making decisions based on their results, whereas Deontological Ethics insists on adhering to ethical duties, regardless of their consequences. Virtue Ethics focuses on cultivating moral character and virtues in individuals and organizations, whereas Environmental Ethics highlights the innate worth of non-human realms and calls for humans to act carefully as

their stewards. Feminist Ethics focus on inclusivity, equity, and social justice, especially on gender equity and the interests of marginalized communities. While Utilitarianism offers a practical framework centered on maximizing collective benefits, Deontological Ethics stresses our unwavering moral duties. Virtue Ethics underscores the importance of moral character in decision-making, while Environmental Ethics broadens our perspective to respect and safeguard extraterrestrial environments. Feminist Ethics ensures that inclusivity, equity, and social justice remain front-and-center, so that space exploration's benefits and impacts are shared. Integrating these five distinct viewpoints can lead to a thorough and adaptable ethical guide for humanity's ventures into space, combining each philosophy's strengths for a more conscientious approach.

Potential Limitations of Ethical Philosophies and Integrative Approach

Since each philosophical approach has inherent limitations, integrating these frameworks enables us to fill the gaps and develop a more comprehensive and robust ethical approach to guide humanity's ventures into space. While Utilitarianism provides a pragmatic focus on outcomes and maximizing overall well-being, accurately predicting and quantifying long-term consequences can be challenging (Mulgan, 2017). This approach may also overlook individual rights and welfare, potentially justifying harmful or exploitative actions if they are seen to yield significant benefits. By emphasizing aggregate happiness, Utilitarianism can lead to ethical oversights, particularly when the interests of minorities or marginalized groups are sacrificed for the perceived greater good. Deontological Ethics stresses moral duties and adherence to ethical principles regardless of outcomes. However, this strict observance of rules can result in undesirable consequences in complex situations where ethical duties conflict (Cheville & Heywood, 2020; Rice et al., 2024). The rigidity of this framework can make it difficult to address nuanced scenarios that demand a balance between duties and outcomes. Moreover, Deontological Ethics may not sufficiently consider the broader impacts of actions on future generations or non-human entities. Virtue Ethics emphasizes the moral character and virtues of individuals and organizations, promoting ethical behavior through personal development. Although this perspective encourages thoughtful engagement with ethical dilemmas, it can be subjective when defining and measuring virtues across different contexts (Molina, 2022). By focusing on individual character, Virtue Ethics may overlook systemic or organizational challenges, and it often lacks explicit guidelines for decision-making in specific situations, relying instead on the discernment of virtuous individuals. Environmental Ethics prioritizes the intrinsic value of non-human environments, advocating for their preservation and respectful treatment. While this view confronts anthropocentrism and encourages environmental safekeeping, it may also impede scientific advancements and economic progress (Rose, 2002). Emphasizing preservation can lead to restrictive policies that limit exploration and resource utilization. Additionally, the idea that lifeless celestial bodies possess inherent worth remains contentious and is not universally accepted. Feminist Ethics has its focus centered on inclusivity, equity, and social justice, emphasizing the experiences and needs of marginalized communities. Although this framework provides a comprehensive and responsive approach to ethical decision-making, it can be perceived as overly focused on gender and social issues (Pullen & Vachhani, 2021). Balancing diverse ethical priorities is challenging, and Feminist Ethics may not fully address other critical considerations, such as environmental sustainability or technological innovation.

Integrative Approach: Filling in the Gaps

By assessing and integrating all five ethical philosophies, we can address their individual limitations and develop a more comprehensive and nuanced ethical framework for space exploration.

Balancing Consequences and Principles: Merging Utilitarianism and Deontological Ethics reconciles a results-based outlook with a principled stance, ensuring respect for human rights while also aiming for the greatest good. This approach would guarantee the justification of harmful actions solely based on their outcomes.

Incorporating Character and Systemic Considerations: Blending Virtue Ethics with these other frameworks covers both personal moral development and broader systemic factors. Virtue Ethics encourages ethical conduct through character formation, while Utilitarianism, Deontological Ethics, Environmental Ethics, and Feminist Ethics provide structural and rule-based guidance.

Environmental and Human-Centered Concerns: Integrating Environmental Ethics ensures that the inherent value of extraterrestrial environments is factored in, alongside concerns for human well-being found in the other frameworks. This promotes a balanced perspective that preserves non-human realms while meeting human needs.

Inclusivity and Equity: Including Feminist Ethics underscores the importance of sharing space exploration's rewards and challenges equitably. By merging feminist ideals with other ethical approaches, decision-makers can better address the interests of marginalized groups and uphold social justice.

Addressing Complex Ethical Dilemmas: Employing all five philosophies together offers a well-rounded approach to dissecting and resolving ethical dilemmas in space exploration. As each philosophy supplies a unique lens, combining them can offer more comprehensive and well-considered answers that encompass the multifaceted, interconnected nature of space activities. While each of these frameworks has shortcomings on their own, merging them allows us to mitigate their respective weaknesses and establish a more reliable, wide-ranging ethical strategy for space exploration. Balancing outcomes with principles, uniting character development with systemic norms, harmonizing environmental care with human welfare, encouraging inclusivity, and tackling inherent moral challenges collectively can lead to a responsible way forward in our cosmic pursuits.

Conclusion

Exploring and potentially establishing a human presence in space presents unparalleled opportunities, combined with novel challenges. Examining various ethical philosophies provides valuable insights into this complex moral landscape. To this end, Utilitarianism centers on maximizing benefits and minimizing harm, while Deontological Ethics underscores the importance of adhering to moral duties and principles, ensuring that our actions in space remain inherently right and just. Virtue Ethics highlights the character and virtues of individuals and

organizations, encouraging moral development and ethical behavior. Meanwhile, Environmental Ethics questions our human-centered perspective, urging us to recognize the intrinsic value of non-human environments and to safeguard them. Finally, Feminist Ethics emphasizes inclusivity, equity, and social justice, drawing attention to gender disparities, ensuring diverse representation in decision-making, and considering the broader social and ethical impacts on marginalized communities. Each of these ethical philosophies has distinct strengths and addresses specific aspects of the moral dilemmas posed by space exploration. However, their limitations highlight the need for an integrative approach. By combining these varied perspectives, we can forge a more comprehensive and nuanced ethical framework that can address the multifaceted nature of space exploration. We contend that embracing this more holistic approach will allow us all to pursue space endeavors successfully, while remaining true to high moral values.

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Advancing Aviation Safety Through In-Time Safety Management, Resilience, and Learning from All Operations

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Reactive, accident-oriented safety management can no longer keep pace with the complexity and tempo of modern air operations. This position paper advocates advancing aviation safety by fusing three complementary developments. First, an In-Time Aviation Safety Management System (IASMS) brings predictive analytics and real-time data fusion to the flight deck, shifting risk control from retrospective analysis to live mitigation. Second, Resilience establishes the conceptual and practical foundation for crews, organizations, and technologies to adapt gracefully when novel challenges arise, preventing escalation. Third, a Learning from All Operations (LFAO) philosophy systematically mines routine flight data, voluntary reports, and observational audits to drive continuous improvement in training, procedures, and algorithms. Together, these elements recast pilots as active partners in safety creation rather than a residual source of error, combine machine intelligence with human expertise, and form a closed loop in which operations both inform and benefit from safety interventions. The paper offers implementation steps centered on data governance, human-machine interface design, cultural adaptations, regulatory actions, and resilience training to implement this architecture within commercial air transport.

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Introduction

Aviation safety has long been flying by the rearview mirror, fixated on what went wrong rather than empowering what goes right. Traditional safety management has been largely reactive, investigating accidents and human errors after the fact (Holbrook et al., 2019). The oft-cited statistic that roughly 70–80% of aviation accidents involve human error led to increased automation and stricter procedures, but this tells only half the story. Flight crews routinely prevent incidents in daily operations: studies show pilots must intervene in about 20% of flights to manage malfunctions or off-nominal situations (PARC/CAST Flight Deck Automation Working Group, 2013). In other words, human expertise regularly averts problems and contributes positively to safety.

Every incident-free flight partly owes its success to human capabilities, not just the absence of error. As Barshi (2024) notes, while human limitations play a role in most accidents, human skills and adaptability are factors in every safe flight. This recognition marks a paradigm shift – rather than treating humans as the weakest link, there is growing emphasis on their role as critical contributors to safety. Given how rare accidents have become, a purely reactive, accident-focused model yields diminishing returns for safety improvement. It also overlooks the wealth of safety data on successful flights every day. The industry needs to evolve its approach to flight deck safety by integrating real-time risk management, building system resilience, and continually learning from all operations – not only failures.

Purpose Statement

The purpose of this position paper is to assert that the next leap in aviation safety will come from uniting three concepts: In-Time Aviation Safety Management Systems (IASMS), resilience engineering, and a “Learning from All Operations” (LFAO) philosophy. This paper introduces a proactive, data-driven, and human-centered safety approach to reduce flight risks. A central theme is reframing the human role in safety: pilots should be seen as an essential partner in safety (not merely a source of error) whose actions often create safety rather than simply produce errors (Barshi, 2024). This paper reviews current research and developments in IASMS, mechanisms to enhance resilience at both individual and organizational levels, and methods to capture and learn from everyday flight data. This paper also addresses contrasting viewpoints – for example, the argument that more automation alone can solve human error or skepticism about “Safety-II” and resilience concepts – to ensure a balanced evaluation. Finally, it proposes an actionable plan for advancing flight deck safety by leveraging real-time systems, human resilience, and continuous learning, thus complementing and transcending the traditional accident-focused model. The main research question addressed in this paper is: How do IASMS, resilience engineering, and LFAO work together to improve safety during line operations?

Methodology

This manuscript is a position paper based on literature synthesis and conceptual integration. Sources were selected through targeted searches (2010–2025 with seminal earlier works) across peer-reviewed journals, National Aeronautics and Space Administration (NASA)/Federal Aviation Administration (FAA) technical reports, Flight Safety Foundation

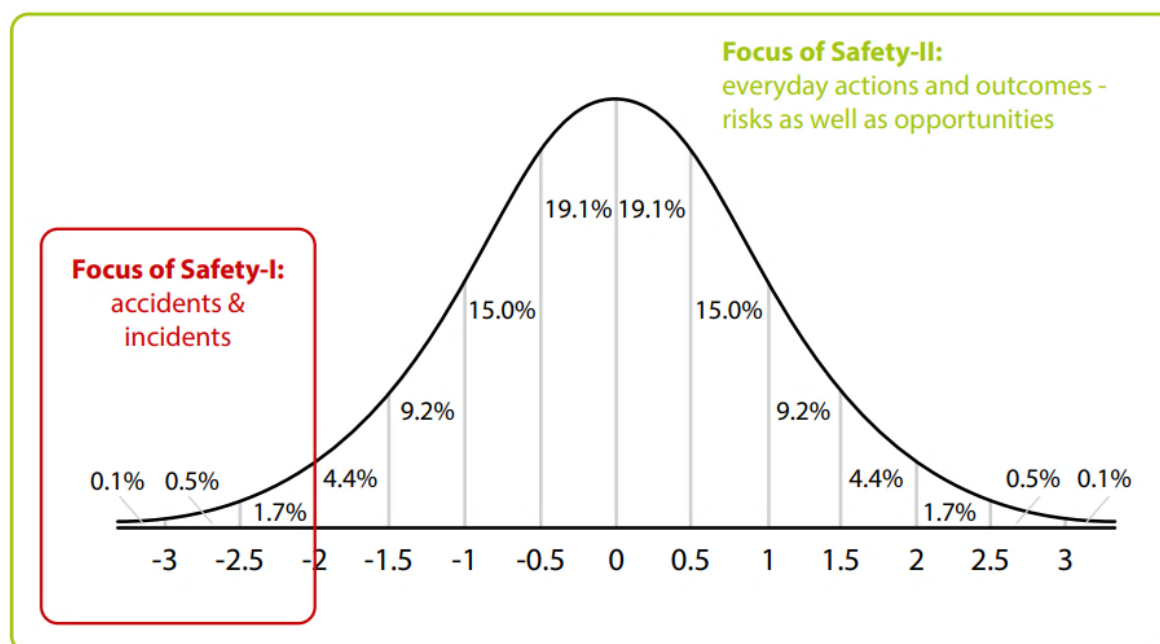
papers, relevant conference proceedings, and industry guidance referenced herein. Inclusion emphasized relevance to:

- In-Time Aviation Safety Management (IASMS),
- Safety-II, High-Reliability/Resilience Engineering, and
- Programs that learn from routine operations, such as Flight Operations Quality Assurance (FOQA), Line Operations Safety Assessment (LOSA), the Aviation Safety Reporting System (ASRS), the Aviation Safety Action Program (ASAP), and the Advanced Qualification Program (AQP).

Priority was given to empirical studies, official frameworks, and technical concepts describing real-time risk monitoring, human performance, and organizational learning. The argument was constructed by mapping common mechanisms (anticipation, monitoring, response, and learning) onto IASMS functions and LFAO practices, then testing consistency against counter-arguments (automation-only claims, Normal Accident Theory concerns, and cost/resource constraints). This manuscript offers a structured synthesis of current knowledge intended to motivate a practical, staged path to implementation, without introducing new sampling, data collection, or statistical analysis.

From Reactive Safety to Proactive Learning: A Changing Safety Model

For decades, aviation safety was driven by “Safety-I,” which sees safety as the absence of accidents (Hollnagel, 2018; Prinzel et al., 2022). This reactive approach achieved significant gains – for example, the fatal accident rate fell from around 5–6 per million flights in the 1970s to about 0.5 in recent years (Ortiz-Ospina, 2024) – but as accidents became exceedingly rare, focusing only on failures yielded diminishing returns. A complementary “Safety-II” perspective defines safety as the presence of successful operations and seeks to understand and foster the conditions that make things go right (Holbrook et al., 2019). Within this view, humans are viewed not as hazards but as a source of flexibility and resilience who help create safety. Every routine flight that ends without incident is an opportunity to learn how systems and people successfully adapt to challenges. Hollnagel famously remarked that we had been looking at safety “through the wrong end of the telescope” by examining only what goes wrong instead of also studying normal successes (Hollnagel, 2017; 2018; 2022). The emerging model encourages capturing everyday performance and near-misses so that frontline insights can improve the system. See Figure 1 for a side-by-side view of Safety-I and Safety-II. The Flight Safety Foundation’s LFAO initiative calls for capturing routine performance, a practical embodiment of Safety-II thinking in aviation (Holbrook et al., 2019). This shift also aligns with Safety Differently (Dekker & Conklin, 2014), which centers everyday work and human expertise as sources of safety creation.

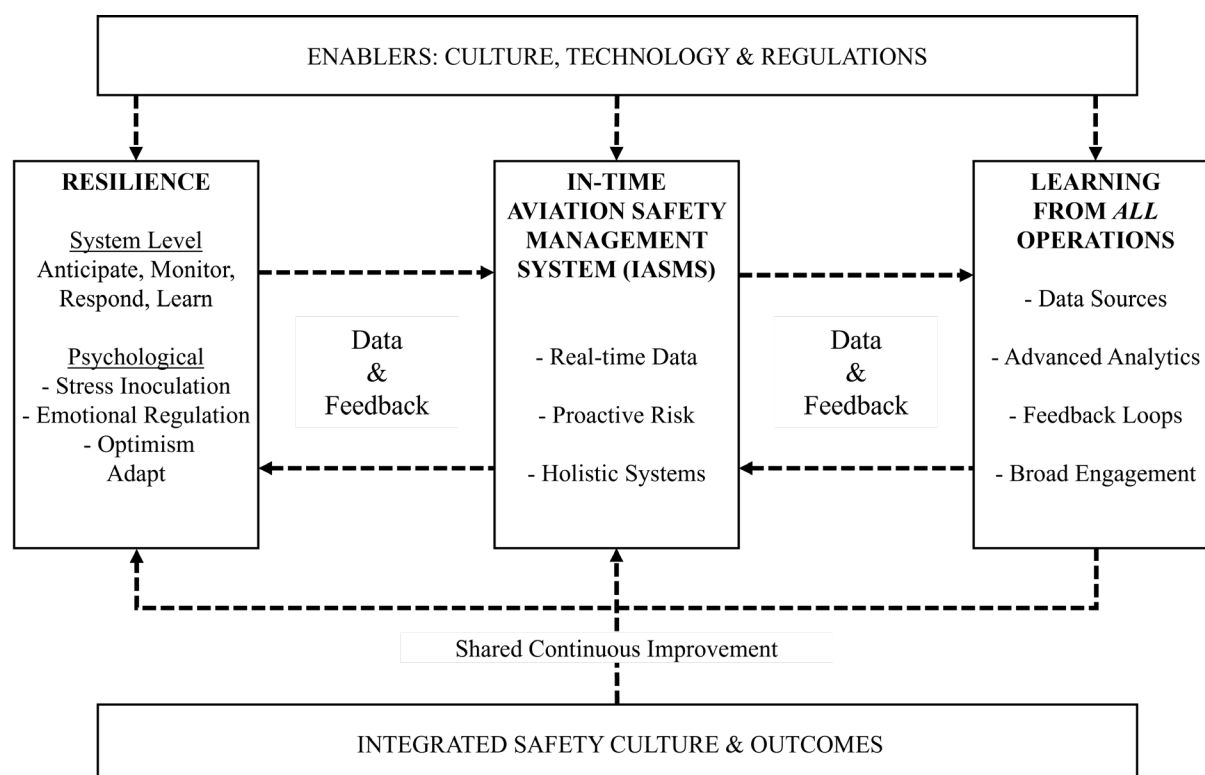
Figure 1*Safety-I versus Safety-II*

Note: Figure adapted from EUROCONTROL (2013) with permission for non-commercial purposes.

Modern aviation systems are highly complex and tightly coupled, meaning unexpected interactions can produce new hazards. Traditional hazard analysis – hindsight from accidents or foresight based on known failure modes – often fails to predict these emergent issues. High-Reliability Organization (HRO) theory and Resilience Engineering emphasize anticipation, monitoring, and rapid recovery as critical capabilities for safety management (Hollnagel et al., 2006). They assume surprises will occur and focus on preparing organizations to handle the unexpected (Hosseini et al., 2016; Kiernan et al., 2020). For example, a U.S. National Academies panel in 2018 urged the development of IASMS to enable real-time detection and mitigation of emerging risks in an evolving airspace (National Academies, 2018; Stolzer et al., 2023). This vision aligns with moving from a retrospective, reactive stance to a real-time, proactive approach. The following sections examine the three pillars of the new safety paradigm – In-Time Safety Systems, Resilience, and LFAO – and how together they reinforce a shift toward proactive safety management that builds on positive human contributions. A high-level view of these three elements and their connections appears in Figure 2.

Figure 2

Framework for Resilience, IASMS, And LFAO Working Together Under a Shared Safety Culture



In-Time Aviation Safety Management Systems

An In-Time Aviation Safety Management System (IASMS) is an integrated set of capabilities that identifies, assesses, and mitigates safety risks during ongoing operations rather than after the fact. It continuously aggregates data from multiple sources (e.g., flight data, aircraft health monitoring, weather, and air traffic systems) and uses predictive analytics to detect emerging hazards in real or near real-time (Ellis et al., 2021a; National Academies, 2018). The goal is to provide decision support or automated interventions *in time* to prevent an incident or accident, effectively shifting safety management closer to the operational timeline. This differs from traditional SMS, which relies on periodic audits, lagging indicators, and retrospective incident analysis (Ancel et al., 2022). Rather than waiting for an incident and then investigating, IASMS focuses on immediacy and proactivity: hazards are addressed as they arise, often before they materialize into adverse outcomes (Ellis et al., 2021a; Ellis et al., 2022b). For example, if predictive flight-data monitoring algorithms detect that an approach is trending towards becoming unstable, IASMS could alert the crew or airline operations center in real-time so that a go-around is initiated, preventing a hard landing or runway excursion. Implementing IASMS widely faces challenges: technological investment, industry coordination, and regulatory adaptation for proactive risk management (Ellis et al., 2022b; Stolzer et al., 2023). Early IASMS designs must also avoid crew task saturation and alert noise by using priority gating,

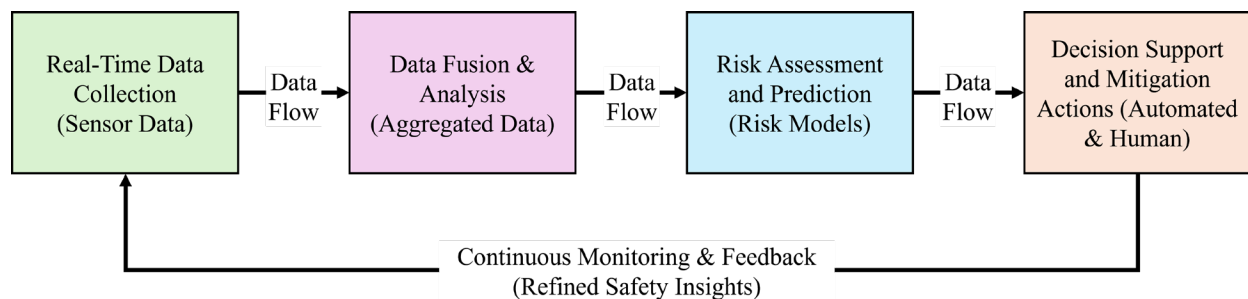
phase-of-flight suppression, and mixed-initiative automation; later sections detail alert quality and workload management.

Several technological enablers underpin IASMS development. Advances in data connectivity allow aircraft to serve as “flying data hubs,” streaming flight parameters to the ground in near real-time. The proliferation of sensors and the digital twin concept provides a richer picture of the aircraft’s state and environment (Aydemir et al., 2020). Big data techniques and machine learning can detect anomalies and predict failures from large datasets. For example, researchers have used machine learning to identify subtle human-factor deviations in normal operations that could lead to incidents if uncorrected (Chen & Zhang, 2014; Nogueira et al., 2023). Such algorithms can reveal precursors, like shifts in pilot control behavior or aircraft performance, that might be missed by traditional rule-based analyses (Soori et al., 2023). However, these approaches face challenges involving validation and false alarms. Experience shows that aviation machine-learning applications must address transparency, large-volume data needs, and rigorous verification before they are trusted in safety-critical roles (Sridhar, 2019). Implementing IASMS involves carefully integrating automated tools with human expertise, a key research priority for future systems (Prinzel et al., 2022).

An IASMS typically involves a structured data-driven safety loop (see Figure 3). First, real-time data collection from onboard sensors, air traffic systems, and the environment feeds into data fusion and analysis algorithms. These algorithms aggregate inputs into a comprehensive risk picture and apply predictive models or machine learning to identify indicators of potential safety threats. Next, the system performs risk assessment and generates decision support for mitigation – for example, prioritizing an alert to a crew or dispatcher or suggesting a specific remedial action. Finally, there is a feedback loop: outcomes and new data are fed back to continually refine the risk models, improving predictive accuracy over time. This sense-and-respond architecture enables hazards to be discovered and mitigated “on the fly,” shifting safety management from a forensic, hindsight-driven activity to an active, foresight-driven one.

Figure 3

Real-Time Data-Driven Risk Assessment and Mitigation Framework For IASMS



NASA and other organizations have been prototyping IASMS concepts, particularly to address emerging domains like uncrewed aircraft systems (UAS) and advanced air mobility (AAM) (Ancel et al., 2022; Ellis et al. 2023). The National Academies (2018) roadmap envisions progressively adding real-time safety assurance capabilities to the National Airspace System

over the next decades. Early implementations focus on real-time monitoring of known risks in limited operations, advancing toward adaptive real-time risk management in complex, multi-agent operations by the 2030s. One example is a system for small UAS that performs automated in-flight risk assessments and alerts the operator (or onboard autonomy) of impending safety threshold violations. Ancel et al. (2022) demonstrated an onboard risk management approach for UAS aligned with IASMS principles, using algorithms to continuously evaluate flight risk and trigger mitigating actions when needed. In the commercial air transport realm, Ellis et al. (2022a) describe a future IASMS concept for airlines that would ingest diverse data streams (flight parameters, crew reports, maintenance data, etc.) and provide a real-time risk picture to airline operations centers. Such a system could act as an “always-on safety radar,” highlighting flights or situations that need immediate attention.

From an organizational perspective, adopting IASMS implies significant changes in policy and culture. Airlines and aviation authorities will need to enable real-time data sharing and decision-making processes. For example, the ability to quickly transfer data from aircraft to ground systems is essential, as is a mechanism to rapidly disseminate safety advisories system wide. There are early signs of this shift: American Airlines has experimented with near-real-time analysis of flight data to give pilots immediate feedback after landing (a “virtually instant” debrief) (Pasztor, 2017). This demonstrates an appetite for using operational data dynamically to enhance safety and training. Regulators have also encouraged such approaches. The FAA’s FOQA program, for instance, was an early effort to collect and analyze routine flight data for proactive safety management (FAA, 2004). Likewise, LOSA involves observing normal flights to glean safety insights (FAA, 2023). An IASMS can be seen as a technologically advanced extension of FOQA/LOSA concepts, with automation and integration enabling a much faster turnaround from data to action.

To implement IASMS broadly, trust and data governance issues must be addressed. Operators may be concerned about data privacy or misuse of real-time monitoring information. It will be important to establish clear agreements that IASMS data is used for safety improvement not punishment, similar to the protections that exist for voluntary reporting programs like FOQA and ASAP (Air Charter Safety Foundation, 2024). With appropriate safeguards, an IASMS augments human vigilance rather than replacing it. Indeed, the greatest benefits occur when real-time technology is combined with resilient operators and a learning-oriented culture. IASMS provides the digital infrastructure for safety, but humans still need to exercise judgment, handle novel situations, and learn from the system’s outputs. The following sections examine those human elements – resilience and continuous learning – which ensure that the information and alerts generated by an IASMS are effectively used to enhance safety.

Resilience Engineering and Human Resilience in Aviation

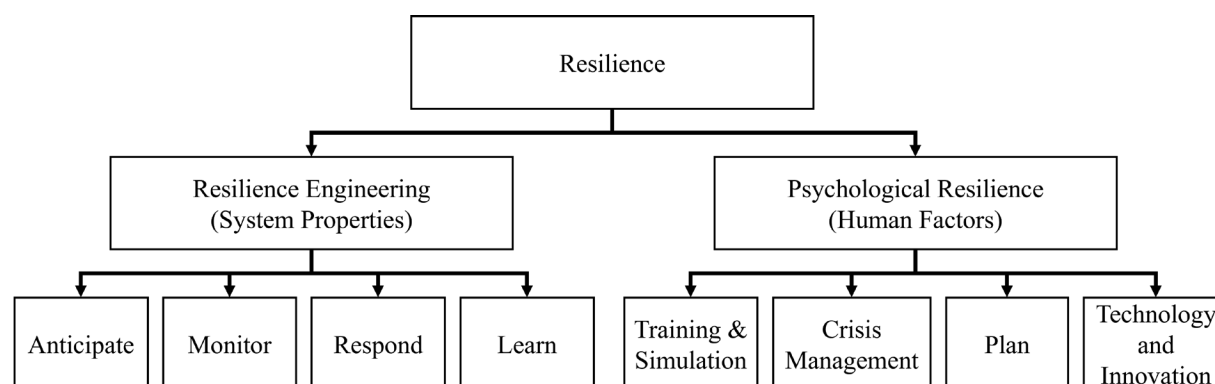
In safety science, *resilience* refers to a socio-technical system’s capacity to adapt to and recover from unexpected challenges while sustaining performance. In aviation, this maps to the ability of crews, organizations, and technologies to keep operations safe when conditions deviate from the norm. This modern understanding builds upon decades of foundational research, with the essential elements of resilience being continually revisited and refined (Woods, 2019). Resilience in this context has two interrelated dimensions: (1) *Resilience Engineering* at the

system level – designing and managing technology, procedures, and organizations so they can withstand perturbations – and (2) *psychological resilience* at the individual level – equipping pilots, ATC, and others with the mental and behavioral skills to cope with stressors and surprises effectively. Both dimensions are critical to flight deck safety, and in practice, they work together: a resilient cockpit team (through training, experience, and mindset) operates within a resilient system (through a supportive safety culture, flexible procedures, and built-in redundancies). As Leveson (2020) and Carroll and Malmquist (2022) observe, operational flexibility and system design must reinforce each other to achieve resilient performance.

Resilience Engineering as a field arose from the recognition that traditional safety engineering – which focused on preventing component failures and human errors – was not sufficient in complex socio-technical systems (Hollnagel et al., 2006). Instead of only building barriers and redundancies, Resilience Engineering asks: *How can we enhance the system's capacity to adapt in real-time to the unexpected?* Researchers often cite four key capabilities of resilient systems: monitoring (knowing the system's state and environment), responding (reacting effectively to disturbances), learning (updating assumptions based on experience), and anticipating (foreseeing potential disruptions). The capacity to escape failures of foresight is a cornerstone of this approach (Woods, 2009). Woods (2006) introduced this framework, and subsequent work (e.g., Blok et al., 2018) has even attempted to formally model how a complex air transport system might anticipate and dampen emerging issues. In aviation, these principles translate into practices like dynamic re-planning by crews, flexibility in ATC, and extensive use of simulators to prepare for rare or unexpected events. For instance, aircraft are designed with redundant systems so that single failures can be managed – a classical engineering form of resilience (e.g. multiple hydraulic systems or fail-operational flight control modes) (Downer, 2011). But beyond hardware, procedural resilience is built through crew resource management (CRM) training, which instills teamwork and decision-making behaviors for high-pressure situations. A resilient aviation system also relies on a safety culture that encourages people to report problems and anomalies so the organization can learn and improve. Recent studies have proposed models to assess organizational resilience in aviation, linking factors such as management commitment, communication, and mindfulness to safety outcomes (Adjekum & Tous, 2020; Teske & Adjekum, 2022). For example, Teske and Adjekum (2022) found that key HRO principles (e.g., sensitivity to operations, reluctance to simplify, and preoccupation with failure) were positively associated with effective SMS implementation in aerospace organizations. This suggests that cultivating an HRO-style safety culture (sometimes called a *resilience safety culture*) can make an aviation organization more resilient and can complement its formal SMS. Figure 4 illustrates how resilience integrates system-level properties and psychological resilience, emphasizing these capabilities in aviation safety.

Figure 4

Framework for Resilience in Aviation: Resilience Engineering and Psychological Resilience



On the human side, psychological resilience involves an individual’s capacity to handle high stress, recover from setbacks, and remain focused. Commercial pilots and controllers regularly face acute stressors (system failures, severe weather) and chronic ones (fatigue, high responsibility). Research shows that people with stronger resilience generally cope better with these challenges, make fewer errors, and experience lower burnout (Cahill et al., 2020; Schwarz et al., 2016). Similar patterns appear in other high-risk fields; for example, resilient firefighters show better health and performance (Blaney & Brunsden, 2015). Key resilience traits include adaptability, emotional regulation, and problem-solving under pressure (Dekker & Lundström, 2007; Perumal & Mariappan, 2023). Aviation increasingly fosters resilience through targeted selection, training, and practice. Military and space agencies include cognitive-behavioral techniques for managing extreme stress (McCall, 2019; McNerney et al., 2022; Whealin et al., 2013). In civilian aviation, CRM has evolved to address the “startle effect” and surprise management, teaching crews how to regain control after unexpected shocks like wind shear or dual-engine failure. Startle is an involuntary physiological and attentional response to a sudden stimulus that briefly degrades cognition and fine motor control (Lang et al., 1990). CRM literature now explicitly links resilience to performance (Martin, 2019). A simulator study by Landman et al. (2018) showed that exposing pilots to unpredictable scenarios improved their ability to handle novel emergencies, essentially “inoculating” them against surprise by building a reserve of adaptive capacity. Airlines now include more resilience-building exercises in recurrent training, and regulators, including the FAA (AC 120-111), mandate elements such as Upset Prevention and Recovery Training (UPRT), which covers both manual recovery techniques and psychological readiness.

Building resilience is not just the crew’s responsibility; it also requires organizational support (Samu et al., 2025). A resilient safety culture empowers employees at all levels to act on potential issues and support one another. Such a culture emphasizes continuous learning, flexibility, and empowerment (Akselsson et al., 2009). Just Culture, reporting errors or hazards without fear of reprisal, is vital to ensure the system learns and people remain willing to adapt and speak up (Hollnagel, 2006). For instance, many airlines’ ASAP allow voluntary, immunity-protected reporting of safety concerns or personal mistakes, feeding data back into system-wide improvements (Air Charter Safety Foundation, 2024). Further, organizations that invest in cross-

training and role redundancy so that crew or dispatch duties, for instance, can be handed off when workload spikes, demonstrate how safety arises from a system's adaptive capacity. Achieving industry-wide resilience demands a unified effort from regulators, manufacturers, and airlines to integrate resilience engineering into standards, training, and design.

Safety culture has four key components: a reporting culture that protects and encourages disclosure of hazards and mistakes; a learning culture that turns reports and routine performance data into concrete changes; flexibility (mindfulness, deference to expertise) that allows roles and procedures to adapt under stress; and leadership commitment to safety that supports the process and resists normalization of deviance (Cooper, 2000; Teske & Adjekum, 2022). These elements align with HRO principles and predict SMS effectiveness in aviation settings.

The benefits of resilience are evident in both everyday work and extreme situations. In normal operations, resilient behaviors by crews can prevent an incident chain from progressing – for example, detecting a subtle instrument anomaly and troubleshooting it before it leads to a larger failure. In abnormal or emergency scenarios, resilience often spells the difference between a safe recovery and an accident. A frequently cited case is the 2010 Qantas Flight 32 engine failure: the crew faced dozens of cascading system failures, yet through teamwork, adaptable problem-solving, and effective use of available resources, they managed to land safely. Analyses attribute this outcome to both the crew's skill and psychological resilience *and* the aircraft's design redundancies that contained the damage (Dekker & Lundström, 2007). Resilience does not mean errors never occur; it means errors do not inevitably lead to catastrophe because they are caught and corrected. As Woods (2015) noted, a resilient system exhibits “graceful extensibility,” meaning it can stretch its performance to handle surprises rather than collapse when something goes wrong.

In practical terms, advancing resilience in the flight deck involves:

- Selecting or assessing individuals for traits conducive to resilience (some ATC organizations, for example, use psychological tests for stress tolerance and adaptability in their hiring process) (Cosic et al., 2019);
- Training and experience that build adaptive skills – for instance, scenario-based training with novel and unexpected events (as discussed above) and CRM modules emphasizing decision-making under uncertainty;
- Providing tools and resources that support human adaptability (such as well-designed quick-reference handbooks for non-normal situations, or intelligent decision-support systems that help crews prioritize issues during high-workload situations); and
- Shaping a culture that values flexibility, open communication, and continual learning.

The last point ties directly into the next section: a culture of continuous learning from all operations ensures that both successes and failures inform improvements, thus continuously strengthening the system's resilience. In many ways, resilience and learning are two sides of the same coin – a system cannot be resilient if it does not learn, and what it learns should, in turn, enhance its resilience (Degerman & Wallo, 2024).

Learning from All Operations (LFAO)

Traditional aviation safety practice has relied on event-driven learning: the industry learns from accidents (and serious incidents) by investigating causes and implementing changes. While invaluable, this reactive learning approach has limitations in a high-reliability domain like commercial aviation, where accidents are extremely infrequent (Holbrook et al., 2019). The concept of Learning from All Operations (LFAO) is a more expansive approach that seeks to extract safety lessons continuously from the full spectrum of operations – normal, atypical, and everything in between (Flight Safety Foundation, 2021). The premise is simple: *every* flight is a rich source of data about what went right (or almost went wrong), and by analyzing these data, one can identify trends, precursors, and best practices that would remain invisible if one only studied accidents (Holbrook et al., 2019). This aligns with the Safety-II philosophy of also learning from success. LFAO operationalizes that idea by establishing processes and systems to gather and learn from routine performance, not just anomalies. Implementing LFAO requires a cultural shift to Just Culture, promoting open communication without blame or fear of reprisal.

The aviation industry has been applying these methods for some time through programs like FOQA, LOSA, and ASRS. FOQA continuously monitors digital flight data (from onboard recorders) for deviations or exceedances, allowing airlines to detect unsafe patterns and address them before an incident occurs. For instance, if FOQA data show a rise in unstable approaches at a specific airport, the airline can respond with extra pilot training or revised procedures (Pasztor, 2017). Essentially, FOQA learns from routine flights by flagging parameters that deviate from normal ranges. The FAA acknowledged FOQA's benefits in a 2004 Advisory Circular, advising airlines to adopt these voluntary programs and noting that early intervention can significantly improve safety (Federal Aviation Administration [FAA], 2004). Line Operations Safety Audit (LOSA) is another tool: trained observers ride in the cockpit jump seat on regular flights to catalog the threats crews face and how they manage them. The LOSA framework specifically focuses on effective threat and error management, not just failures (Klinect et al., 2003). It recognizes that each flight encounters challenges, such as weather, ATC delays, or minor malfunctions and that crew responses can determine whether these issues end safely or lead to an incident. By observing a broad sample of flights without interfering, LOSA captures resilient practices and hidden safety vulnerabilities. Studies like Klinect et al. (2003) show LOSA's value in identifying both strengths and areas of concern in everyday operations, such as how often crews spot errors and which countermeasures work best.

The ASRS, a national, de-identified reporting system created through a 1976 FAA–NASA memorandum of understanding following the 1974 TWA 514 accident, is a good source to learn from everyday routine operations (NASA, 2001). ASRS gathers voluntary, confidential reports from pilots, controllers, and others on safety issues or anomalies they observe. It holds a wealth of qualitative data on errors, hazards, and successful recoveries in the national airspace. Reporters often describe not only what went wrong but also how it was managed, effectively sharing lessons learned. Over the years, ASRS analysts have identified many systemic issues (e.g., confusing procedures, airport signage problems, automation quirks) by finding patterns in these reports, resulting in fixes without waiting for an accident. One limitation is that ASRS depends on self-reports, so it captures only what individuals notice and decide to share. Even so, it remains a strong example of learning from daily operations. A study by Vempati et al. (2023)

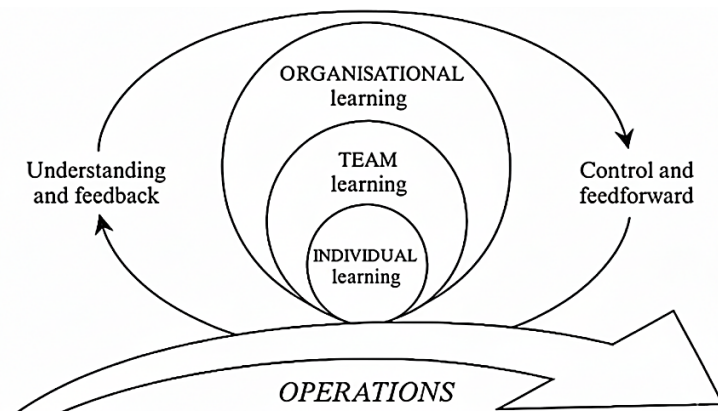
applied text mining to ASRS narrative reports to categorize human factors issues, showing how modern analytics can make the most of free-form data. Many airlines have similar internal ASAP initiatives, encouraging employees to report issues under non-punitive policies. These programs are valuable for uncovering latent problems and “near misses” in which only luck or quick action prevented an accident (Air Charter Safety Foundation, 2024).

Despite these initiatives, LFAO advocates for an even more comprehensive and systematic approach. In 2021, the Flight Safety Foundation published a white paper, “Learning from All Operations: Expanding the Field of Vision to Improve Aviation Safety,” essentially a call to adopt LFAO industry-wide (Flight Safety Foundation, 2021). It argues that in an era of ever-safer aviation, waiting for accidents to guide safety strategy is no longer tenable; instead, organizations should leverage all available operational data to drive safety improvements proactively. In 2022, the FSF followed up with a series of “Learning from All Operations” concept notes on operational resilience mechanisms, recognizing that routine operations harbor valuable information about how resilience is achieved or could be strengthened.

LFAO takes place at multiple interdependent levels – individual, team, and organizational learning – as illustrated in Figure 5. At the individual level, learning occurs through a pilot’s or controller’s personal experience, reflection, and debriefing. Technology can aid this (for example, flight replay software that allows pilots to review their performance shortly after landing, visualizing any deviations or maneuvers). At the team level, learning is facilitated by shared experiences and discussions – crew debriefs or hangar talks where insights into handling complex or unexpected situations are exchanged, improving collective know-how. At the organizational level, lessons from individuals and teams are consolidated to update training programs, standard operating procedures, and safety policies so that improvements discovered on the front lines become embedded in the system. This structured learning process creates both feedback loops (learning from experience) and feedforward loops (anticipating future issues), ensuring that lessons from routine operations continuously refine aviation safety at all levels.

Figure 5

Safety Learning at Three Levels



Note: Adapted from Flight Safety Foundation (2023) with permission for non-commercial purposes.

Concretely, LFAO means integrating diverse data sources: flight data (FOQA), safety reports (ASRS/ASAP), maintenance records, air traffic data, weather information, and even positive feedback mechanisms (like “what went well” reports). By analyzing these collectively, one can identify both emerging risks and exemplars of excellence. For example, Burnell et al. (2022) describe how operators can “create safety in an uncertain world” by studying normal operations to understand how crews successfully navigate uncertainty. They highlight operational practices that are not in manuals but nevertheless contribute to safety – the so-called “untold stories” of success. Some airlines have even established formal Learning Teams; for instance, the American Airlines *Learning and Improvement Team* (LIT), launched in 2020, brings frontline employees together to discuss not just incidents but also instances of exceptionally effective performance to glean practices that could be shared more widely (American Airlines, 2020). In its first phase, American’s LIT focused on “what goes well and why,” documenting successful strategies crews used in challenging situations (American Airlines, 2021). Such knowledge can then be folded back into training programs or SOP revisions. This approach shifts the safety narrative to also include praise and propagation of positive behaviors, not solely the correction of negatives.

Implementing LFAO on a large scale is greatly aided by technology. Modern data platforms and AI techniques can handle the big data generated by thousands of flights (Aydemir et al., 2020). For instance, Natural Language Processing (NLP) can sift through vast numbers of safety reports to find common themes (NASA has demonstrated this by applying machine learning to ASRS reports – Barshi et al., 2023). Data fusion can link disparate streams – for example, correlating a spike in unstable approach parameters from FOQA with an uptick in ASRS pilot reports about a particular runway’s optical illusion. As noted earlier, an IASMS provides an ideal infrastructure for LFAO: it is essentially the data “plumbing” and analytics engine that can facilitate continuous learning. Ellis et al. (2023) highlight that IASMS and LFAO are complementary – an IASMS enables LFAO by integrating safety management with everyday operational data. In fact, one envisioned function of an IASMS is to act as a real-time learning system, where each operational data point updates risk models and informs the next flight or shift in near real time (Nogueira et al., 2023).

Table 1 catalogs the main LFAO data sources; FOQA (parametric), LOSA (observational), ASRS/ASAP (narrative), AQP/IEP (training/assurance), and local debrief tools, plus typical uses and constraints. Two practical takeaways: parametric exceedances need context to avoid false signals, and narrative sources require trust and non-punitive protections to sustain reporting.

Table 1*Key LFAO Data Sources and Their Applications in Aviation Safety Management*

Data Source	What is Collected	Use in Safety Management	Challenges and Limitations
Flight Operational Quality Assurance (FOQA)	Digital flight parameters (FDR/QAR data) on normal ops, e.g. airspeed, altitude, attitude, config, event flags	Early risk detection via exceedance trending, pinpoint training/procedural gaps, proactive hazard fixes, refined SOP	High cost for data systems and analysis, pilot trust concerns, potential data overload, context missing if only numeric exceedances are used
Line Operations Safety Audit (LOSA)	In-flight observations by trained auditors capturing real-time crew actions, threat/error management, CRM usage	Identifies everyday ops successes and vulnerabilities, reveals how threats and errors are managed or mismanaged, shapes targeted safety improvements	Labor-intensive, sample limited to a few flights, potential Hawthorne effect, requires strong crew buy-in and non-punitive culture
Aviation Safety Action Program (ASAP)	Voluntary safety event narratives from employees (pilots, mechanics, dispatch) under ERC oversight, describing near misses or errors	Feeds SMS with insider operational insights, captures context behind incidents, fosters fix-before-accident approach, synergy with FOQA for root causes	Participation hinges on non-punitive trust, narrative is subjective, analyzing large unstructured text is resource-heavy, some events may remain under-reported
Aviation Safety Reporting System (ASRS)	National-level, de-identified, first-person incident reports from all aviation personnel, describing anomalies or close calls	Spotlights emergent hazards system-wide, prompts bulletins/alerts, fosters cross-industry lessons to close safety gaps without waiting for accidents	Entirely voluntary, might miss hidden or routine issues, can be incomplete or biased, no direct follow-up with reporters, a “big data” text-mining challenge
Advanced Qualification Program (AQP)	Extensive crew performance data from simulator checks, LOFT, plus operational data to shape training design, repeated skill evaluations over time	Enables data-driven, scenario-based training customized to actual line risks, continuous feedback loop ensures training evolves with new hazards	Implementation complexity, heavy data demands, requires instructor calibration, risk of “training to the metrics,” smaller ops find it expensive to maintain
Internal Evaluation Program (IEP)	Self-audit metrics across flight, dispatch, maintenance, ground ops, assessing compliance with regs and SOP, yields findings and recommended actions	Provides ongoing organizational “health check,” detects compliance drift or hidden hazards, supports early correction prior to incidents, merges into SMS for assurance	Possibly shallow if not strongly supported, risk of internal bias or ignoring negative findings, requires rigorous close loop fix enforcement
“Shop Talk” (e.g. American Airlines LIT)	Informal, facilitated discussions with flight crews capturing day-to-day successes, near misses, workarounds, or best practices, focusing on how operations really happen	Surfaces resilience strategies, small “wins,” unseen friction points, fosters an environment where line employees shape safety improvements, complements numeric data with context of “why it worked”	Demand on time for personal interviews, building trust so crews share openly, data is anecdotal, must be carefully codified to yield systemic improvements, scale is limited
Flight Data Replay Tools (CEFA etc.)	Post-flight high-fidelity flight animations derived from recorded flight parameters, enabling immediate 3D visual replays of the crew’s operation	Facilitates personal pilot debrief, helps them see subtle errors or successes, fosters a self-correcting culture in normal ops, synergy with FOQA if used to contextualize exceedances, strengthens continuous learning	Potential misuse or perceived punitive effect if not carefully implemented, demands robust software/EFB infrastructure, some flight parameters might be lacking detail, no direct organizational aggregator unless pilots voluntarily share insights

Note: Acronym definitions for terms used in this table are provided in Appendix A.

LFAO is not without challenges. A major challenge is data management and quality. Routine operations produce an ocean of data, and making sense of it requires robust analytical capabilities as well as discernment to separate signal from noise. The U.S. National Academies (2018) noted that aligning and fusing heterogeneous data sources is difficult, as is developing algorithms to reliably identify safety-relevant patterns. Not every exceedance or anomaly truly indicates a safety risk – context matters (for example, a steep approach angle might be intentional for a short runway). This means human expertise remains vital to interpret analysis outputs and to decide which findings are truly actionable. Another challenge is organizational culture and resource allocation. Committing to LFAO means investing time and money into analyzing data that, on the surface, did not cause an obvious incident. Organizations might be tempted to prioritize other areas with clearer immediate ROI. There is also a risk of information overload for frontline crews if feedback is not managed well – pilots cannot be inundated with

dozens of minor findings after every flight without diminishing returns. Effective LFAO requires focusing on the most important insights and presenting them in a way that supports improvement without overwhelming staff. However, these efforts need regulatory and organizational support.

Resistance to change may arise when implementing LFAO, as with any new safety program. Employees might worry that expanded monitoring equates to “Big Brother” surveillance of their work. *Trust* and *Just Culture* are crucial components of what scholar Amy Edmondson (2018) calls psychological safety — a shared belief that one will not be punished or humiliated for speaking up with ideas, questions, concerns, or mistakes. Without psychological safety, data from normal operations will not be shared freely for learning, and the LFAO data stream will dry up as personnel avoid reporting (Samu et al., 2025). The United States Government Accountability Office (GAO, 1997) observed that early FOQA efforts succeeded only after clear agreements ensured the data would not be used for individual discipline. The same principle extends to any LFAO initiative. Transparent communication about LFAO’s goals and safeguards — for example, stating that if a trend of unstable approaches is identified, the response will be additional training or procedure changes, *not* reprimands for individual pilots — can help alleviate concerns. Some skeptics of Safety-II initially worried that focusing on successes might breed complacency, but proponents clarify that it is *not* about ignoring problems — it is about capturing all data, good and bad, to get a complete picture of safety. Building an LFAO culture requires change management: people may resist new practices, especially if they see them as extra work or a threat to established routines. Management must be convinced of the long-term benefits and champion the effort. Showing “quick wins” from early LFAO efforts — for instance, how analyzing routine data *prevented* a potential incident or saved costs by improving efficiency — can build buy-in and momentum. These efforts must be supported by targeted investments in infrastructure and workforce.

Despite these hurdles, the opportunities presented by LFAO are enormous. By learning from day-to-day operations, aviation can address risks at an earlier stage — for example, discovering a subtle procedural issue that crews consistently work around (and fixing it) before it contributes to an incident (Burnell et al., 2022; Prinzel et al., 2024). Importantly, safety data often reveal operational inefficiencies where improvements benefit both safety *and* productivity, demonstrating how these frameworks collectively advance operational excellence. Integrating IASMS, LFAO, and Resilience does not merely mitigate risks; it raises a more adaptive, efficient, and optimized aviation ecosystem. Furthermore, LFAO feeds directly into resilience: understanding how and why operations succeed under varying conditions helps in training others to be more adaptable and in refining system designs to support those successful behaviors. The continuous feedback loop essentially turns the operation itself into a learning environment. As Hollnagel (2018) put it, *even when nothing bad happens, there is still something to be learned about why it went right*.

LFAO extends the scope of safety management to *every* flight, *every* day. It uses technology and human expertise to transform the vast amount of routine operational data into practical safety knowledge. Combined with an IASMS framework to gather and analyze data in real-time, and a resilience ethos that values human adaptability, LFAO is a key pillar of the evolved safety strategy. It ensures that the aviation system is not just waiting to react to rare

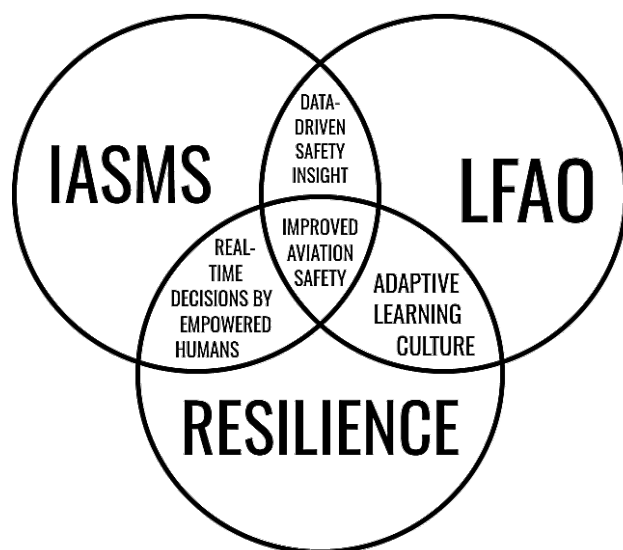
failures but is actively learning and improving from the constant flow of experiences in normal service.

Integration of In-Time Systems, Resilience, and Continuous Learning

Addressing the research question, this section shows how IASMS (real-time monitoring), resilience (adaptive capacity), and LFAO (continuous learning) operate as a single safety loop during line operations. Individually, IASMS, resilience, and LFAO each offer significant safety benefits. Together, as illustrated by overlapping circles in Figure 6, they form a mutually reinforcing triad that defines a new, holistic approach to flight deck safety. An IASMS provides the digital and procedural infrastructure for real-time monitoring and response – essentially the “nervous system” of the safety organism (Ellis et al., 2021a; 2022b). Resilience provides the muscles and reflexes – the ability of human and organizational elements to respond effectively to the signals the IASMS detects. LFAO serves as the memory and brain – continuously updating the system’s knowledge and improving both the IASMS’s algorithms and the humans’ strategies over time (Holbrook et al., 2019). Each component also reinforces the others: insights from everyday operations (via continuous learning) can feed into IASMS models so that automated recommendations reflect successful human strategies and resilience principles can guide the design of IASMS interventions, so the system supports human adaptability rather than undermining it. When these components operate in harmony, safety management becomes a dynamic, adaptive process grounded equally in technology and human expertise. Beyond safety gains, this integration drives overall operational benefits: streamlined workflows, reduced delays from proactive risk mitigation, and data-informed process optimizations that enhance both reliability and resource efficiency.

Figure 6

IASMS, Resilience, and LFAO Reinforcement Triad to Improved Aviation Safety



To illustrate how this integrated approach differs from a traditional one, consider a hypothetical scenario: A new avionics software update inadvertently causes occasional *spurious warnings* in the cockpit that startle or confuse pilots. Under a conventional Safety-I setup, if these false alerts do not directly lead to an incident, they might go unnoticed by safety managers for a long time (perhaps only a few pilot complaints or a maintenance log entry would trickle in). Under an integrated IASMS–Resilience–LFAO approach, several things would happen in short order. The IASMS, continuously monitoring flight data, might detect an uptick in unusual autopilot disconnects or button presses associated with the spurious warnings and flag this as an anomalous pattern (Nogueira et al., 2023). Pilots, feeling safe to report even non-critical issues thanks to a just culture, would submit ASAP reports about confusing or distracting alerts. The LFAO process would correlate these inputs (data and human reports) and quickly identify that the new software version is prompting unexpected crew responses. Because the organization values frontline feedback, an expedited safety assessment or user evaluation would be initiated. In the meantime, resilience in practice is shown by crews adapting – for example, they might develop a quick workaround or an extra verbal cross-check to verify whether an alert is real or false. Those resilient behaviors (if effective) would be captured via LOSA observations or debriefs and shared as interim guidance to other crews (i.e., learning from what operations are already doing to cope). Ultimately, engineering fixes the software bug – but in the interim, the integrated system *already mitigated* the safety risk through human adaptation informed by data (and ensured the workaround was disseminated). This example demonstrates the synergy: IASMS catches the early signs, human resilience manages the issue safely in real-time, and continuous LFAO disseminates the solution across the fleet.

Implementing this integration may require evolving an organization’s safety structure. Traditionally, flight safety departments analyze incidents, training departments train for known scenarios, and operational control centers focus on flight-following and daily efficiency. In a fully integrated model, these silos blur. We may see safety intelligence centers where data analysts (from safety) sit side by side with operations controllers, jointly using IASMS tools to inform decisions in real time (Stephens, 2023). Training departments would receive continuous feedback from LFAO outputs – if data show that pilots handle one scenario well but struggle with another, training programs can be adjusted within months rather than waiting for years or an accident to reveal the gap. In effect, continuous learning permeates into continuous training and procedure development. American Airlines’ approach with its LIT foreshadows this, as insights from frontline discussions were fed into new safety strategies and training in subsequent phases (American Airlines, 2020; 2021).

Integration also needs to extend beyond a single airline because the aviation system is highly interdependent. A resilient, in-time safety approach will likely involve real-time data sharing across stakeholders – airlines, ATC, manufacturers, and regulators. For example, if an airline’s IASMS detects a novel hazard (say, a rapidly forming microburst on an approach path or a confusing navigation anomaly), it could alert air traffic control and other nearby aircraft, essentially performing a real-time safety broadcast to the wider system. This suggests the need for system-wide IASMS interoperability and data standards. NASA’s vision of a “Sky for All” future airspace (with drones, air taxis, and other new vehicles) anticipates extensive data exchange and collaboration to manage safety in a complex environment, and IASMS is a cornerstone of that vision (Yu et al., 2022). Achieving it will require integrating technology,

human resilience, and learning at a broad scale – not just within one company but across the aviation ecosystem.

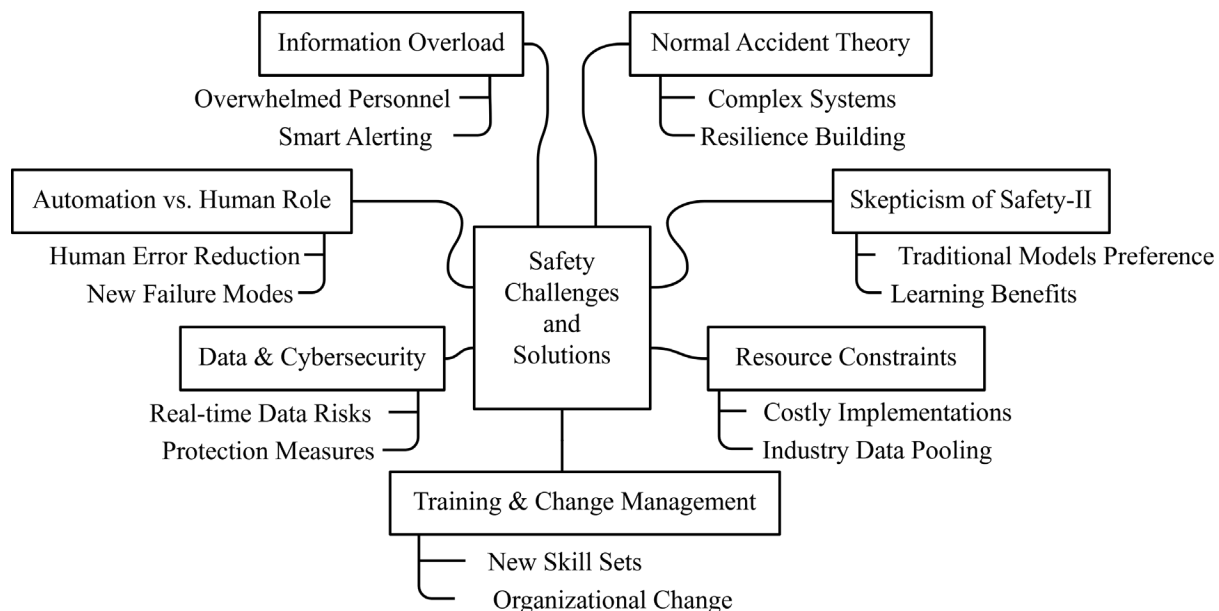
Integration means that IASMS (the technological nervous system), human/organizational resilience (the adaptive capacity), and LFAO (the continual learning process) are designed to function as one safety ecosystem. Data from operations feed the safety system; the safety system supports the humans; the humans adapt and innovate; and those innovations are captured as data and turned into new safety knowledge. This creates a reinforcing loop: the more we learn from operations, the more we can enhance both automation and training; the better our automation and training, the more resilient our operations become; and the more resilient and well-monitored the operations, the more data we gather and the fewer incidents we experience – allowing us to learn even subtler lessons. Over time, this should yield a safety performance that asymptotically approaches perfection (even if absolute perfection is unreachable, the gap becomes vanishingly small) while simultaneously advancing operational efficiency, adaptability, and systemic excellence. It is an ambitious vision, essentially aiming for an accident-free aviation system by harnessing the full capabilities of both humans and machines, a future where ‘safer’ unequivocally means ‘better.’

Contrasting Perspectives and Challenges

While the integrated approach of in-time systems, resilience, and LFAO is compelling, it is important to critically examine potential counterarguments, limitations, and implementation challenges (Figure 7). Not everyone in the aviation community is fully convinced of these new concepts, and legitimate concerns have been raised that must be addressed to ensure successful adoption.

Figure 7

Safety Challenges and Solutions in Aviation



Automation vs. Human Role

An automation-centric view argues that the solution to human error lies in removing or minimizing the human role through advanced automation or autonomous aircraft. Advocates see investments in human resilience or human performance learning as temporary measures, suggesting that highly automated or pilotless aircraft could eventually eliminate human variability. This perspective posits that automation alone can achieve higher reliability by standardizing responses to known risks and eliminating the unpredictability of human decision-making. Recent industry positions resisting single-pilot airliners cite workload, abnormal-event management, and the value of team resilience, consistent with treating humans and automation as a coupled team (States News Service, 2025; Varley, 2025). Rather than removing humans, this paper supports redefining their role: automation should manage routine tasks and known risks, while humans focus on high-level decision-making and adaptive responses to novel situations (Prinzel et al., 2023; Weick & Sutcliffe, 2007). The integrated approach treats humans and automation as a resilient team. Notably, growing autonomy in domains like Advanced Air Mobility has only reinforced the need for IASMS; NASA researchers emphasize that as autonomy increases, real-time safety assurance must also expand to manage new risk types (Ellis et al., 2022b).

Information Overload and HMI

A key concern from the human-factors perspective is information overload: could IASMS flood pilots and dispatchers with too many alerts and too much data? Poorly tuned systems may overwhelm crews with nuisance warnings or ambiguous guidance, risking distraction and degraded performance. The situation mirrors modern cars, whose excessive alerts prompt users to tune them out. To prevent this, human-factors engineering must be applied rigorously: alerts should be meaningful, properly prioritized, and minimally intrusive. Tiered or “smart” alerting systems can help — for example, suppressing lower-priority warnings during high-workload phases, much like the Traffic Collision Avoidance System (TCAS) and Enhanced Ground Proximity Warning System (EGPWS) defer non-urgent messages in critical flight segments. Research on adaptive interfaces supports this approach (Prinzel et al., 2024; Prinzel et al., 2023). The system should act like a well-trained copilot, offering the *right information at the right time*. This requires iterative design, testing, pilot, and operator involvement in development through simulations and trial programs, reinforcing the role of learning and feedback in building usable, trusted systems.

“Normal Accident” Theory and Complexity

Charles Perrow’s Normal Accident Theory (NAT) argues that, in complex, tightly coupled systems like aviation, accidents are inevitable (“normal”) due to unforeseen interactions. From this perspective, even with IASMS, resilience, and LFAO, incidents will still occur, and added complexity from new safety systems may introduce novel failure modes. A recent review by Muecklich et al. (2023) of NAT vs. HRO vs. Resilience Engineering noted that while NAT highlights irreducible risk, HRO and resilience frameworks provide ways to manage complexity. The integrated approach in this paper directly addresses NAT’s concerns: recognizing that surprises will happen, it focuses on enhancing the system’s capacity to cope (via resilience),

detect early signals (via IASMS), and adapt continuously (via LFAO). It is true that IASMS adds complexity and could itself fail—through bugs, data errors, or misclassification. To manage this, IASMS must be designed with fail-safe logic so that failures do not worsen outcomes, and its implementation should be incremental and carefully tested (for example, running it in advisory mode alongside normal ops before entirely relying on it) to ensure it does not inadvertently reduce safety.

Skepticism of Safety-II/Learning Approach

Some critics question whether the Safety-II philosophy and its emphasis on learning from success yield actionable safety improvements (Carson-Stevens et al., 2018; Lawton, 2018). Detractors argue it may distract from failure prevention or lack a clear methodology. This is especially common among those grounded in the Safety-I paradigm, where risk is managed by eliminating known causes of failure. Safety-II implementation has faced barriers in fields like healthcare due to vague guidance on collecting and applying data from everyday successes. However, such critiques hold less weight in aviation, where established practices like LOSA, ASAP, and FOQA already institutionalize learning from normal operations. For example, LOSA has led to procedure changes and training adjustments by uncovering crew strategies for managing threats and errors during regular flights (Klinect et al., 2003). Building a Safety-II culture requires organizational change. People and institutions can resist new practices, especially if they see them as extra work or threatening established routines. Management must be convinced of the long-term return on investment of practices like LFAO that may not show an immediate dramatic gain (since the gains are often *incidents that never happened* and thus “invisible”). Strong safety leadership and clear communication of the long-term benefits are key. Demonstrating some quick, concrete wins from early LFAO initiatives – for example, showing how analysis of routine data prevented a potential incident or saved money by optimizing operations – can help overcome skepticism and build momentum.

Resource and Cost Constraints

A practical challenge in implementing advanced safety systems like IASMS with sophisticated analytics, conducting LOSA observations, and analyzing extensive ASRS/ASAP datasets is the substantial resources and cost required (Ellis et al., 2021b). IASMS and advanced analytics require skilled personnel, advanced data infrastructure, computational architectures, data processing capabilities for large, disparate datasets, and sustained funding for technology, staffing, and operations (Stolzer et al., 2023). These demands can strain smaller operators, who often have limited financial resources and face challenges scaling SMS complexity to their size (National Academies, 2018). The high cost-to-benefit ratio can impede implementation, especially for operators unable to invest in new systems. Industry-wide data-sharing initiatives and centralized tools like ASIAs aggregate data across carriers, enabling the identification of systemic problems and emerging risks that individual carriers might miss while reducing the burden on smaller operators (Ellis et al., 2022b; Prinzel et al., 2023). Third-party providers also offer SMS services to assist smaller operators (Ellis et al., 2022b). Engaging pilots, controllers, maintenance staff, and leadership is necessary to ensure frontline feedback drives safety strategies (Danner & Geske, 2022). Voluntary, non-punitive reporting through platforms like ASRS remains critical for capturing frontline reports and identifying gaps between operations

and procedures, supported by strong non-punitive policies (Chialastri & Pozzi, 2008). Regulators can further promote adoption by offering incentives, facilitating shared services, and harmonizing measures among stakeholders (Danner & Geske, 2022; Ellis et al., 2023b). Given today's low accident rates, some question whether further investment delivers diminishing returns, making the cost-benefit argument difficult (PARC-CAST, 2013). However, as air traffic grows, even a stable accident rate results in more events, and a single major accident can impose immense human and financial costs (FAA, 2004). Preventing one catastrophe justifies the investment based on low-probability, high-consequence risk logic (Chialastri & Pozzi, 2008). These efforts can also yield tangible economic benefits, such as increased reliability, reduced fuel consumption, decreased maintenance costs, and increased operational efficiency by minimizing delays and equipment damage (Ellis et al., 2022b; Muecklich et al., 2023).

Training and Change Management

A key implementation challenge is cultivating the necessary skills and mindset among personnel. Pilots, dispatchers, and safety managers will need training to interpret and apply outputs from advanced analytics and decision-support tools. Tomorrow's airline pilot may need to work as comfortably with AI-generated safety recommendations as with traditional checklists, an area not typically addressed in current pilot training. Safety analysts may also require cross-training in data science to manage large-scale data flows effectively. This reflects a fundamental transformation of the safety professional's role, shifting from a compliance focus to one that actively engineers resilience into practice (Provan et al., 2020). Resistance from veteran staff accustomed to established practices is likely. Overcoming this resistance is essential for building system resilience (Laidoune et al., 2022). Organizational change management strategies, such as early stakeholder involvement, sufficient training, and strong leadership support, will be critical (Jacobs et al., 2013). Regulatory frameworks must also adapt. Current rules assume fixed reporting and procedural models that may not accommodate real-time safety management. Agencies like the FAA and EASA will need to provide guidance on operationalizing IASMS outputs and evaluating LFAO processes, as they did when implementing SMS requirements. Legal and liability questions will also emerge: for example, if an IASMS predicts a risk that is ignored and an accident follows, how is accountability determined? These issues must be resolved as the technology matures. Encouragingly, regulators are actively evolving the framework to support such advancements. While ICAO's 2016 Annex 19 update emphasized proactive safety management, Amendment 2 of 2025 signals a continued push towards more integrated and effective SMS implementation (FAA, 2025). By extending safety management principles to new sectors like remotely piloted aircraft and enhancing the links between state and service provider systems, this change underscores the regulatory trajectory towards the exact type of proactive, data-driven oversight that an IASMS would provide.

Data and Cybersecurity Challenges

There are also technical and logistical challenges to integration. For IASMS, one challenge is ensuring data interoperability and cybersecurity. Real-time data sharing between aircraft, airlines, and possibly ATC means a lot of data in motion. Protecting this data from cyber threats is critical – a compromised safety monitoring system could itself become a hazard (Mäurer & Bilzhause, 2018). Robust encryption, access controls, and fail-safe modes if data

become unreliable will be needed. Likewise, standard data formats and protocols must be developed so that different systems (across manufacturers or between aircraft and ground) can communicate seamlessly. Government and industry standards bodies will need to collaborate on this front (perhaps extend existing standards like ARINC or develop new ones specifically for real-time safety data exchange).

In weighing these counterpoints, while the integrated approach is not a cure-all and must be implemented carefully, its potential benefits far outweigh the drawbacks, provided the challenges are managed. Aviation history shows repeated success in balancing technology with human factors and overcoming initial skepticism, examples include early resistance to crew resource management and fly-by-wire systems, both now standard. This paper's position is that by acknowledging criticisms and addressing them through sound design, policy, training, and cultural adaptation, the aviation community can move confidently toward a proactive safety system. The following section synthesizes this discussion and outlines practical steps forward.

Limitations and Future Work

Current limitations include the IASMS–Resilience–LFAO model's reliance on established data infrastructure and governance, which some operators have yet to implement. The validation of machine-learning-based monitors can be complex and subject to false alerts. Reporting and acceptance of real-time feedback may be affected by organizational culture, while regulatory frameworks continue to adjust for in-time use of safety data. Cybersecurity and interoperability issues also impact real-time data exchange. Smaller operators may encounter resource constraints that impede adoption.

Future work priorities include: (1) human-machine interface research that reduces alert fatigue and supports prioritization under high workload; (2) quantitative measures for “time from hazard detection to mitigation” to track system performance; (3) data-ethics models for real-time safety use, including guardrails against punitive misuse; (4) methods to integrate ATC safety cues with airline IASMS tools; (5) replication studies that show incident-rate or precursor-rate changes from LFAO programs; and (6) scalable pathways for small operators (shared services, pooled analytics).

Conclusion and Recommendations for Advancing Flight Deck Safety

The analysis presented in this paper supports a clear position: the future of flight deck safety lies in a proactive, integrated safety management paradigm that fuses advanced real-time safety systems (IASMS), the cultivation of resilience at all levels, and continuous learning from the full breadth of operations. This integrated approach represents an evolution from the traditional accident-centric view of safety to one that harnesses both technology and human adaptability to prevent accidents and incidents *before* they occur. Rather than viewing pilots and other humans as problems to be managed, it treats them as essential partners in safety – agents whose actions often create safety and whose insights are invaluable (Barshi, 2024; Holbrook et al., 2019). In-Time Safety Management Systems provide unprecedented capability to detect and mitigate risks in flight; resilience principles ensure that both the system and the personnel can effectively handle those risks and surprises; and LFAO closes the loop by using everyday data to

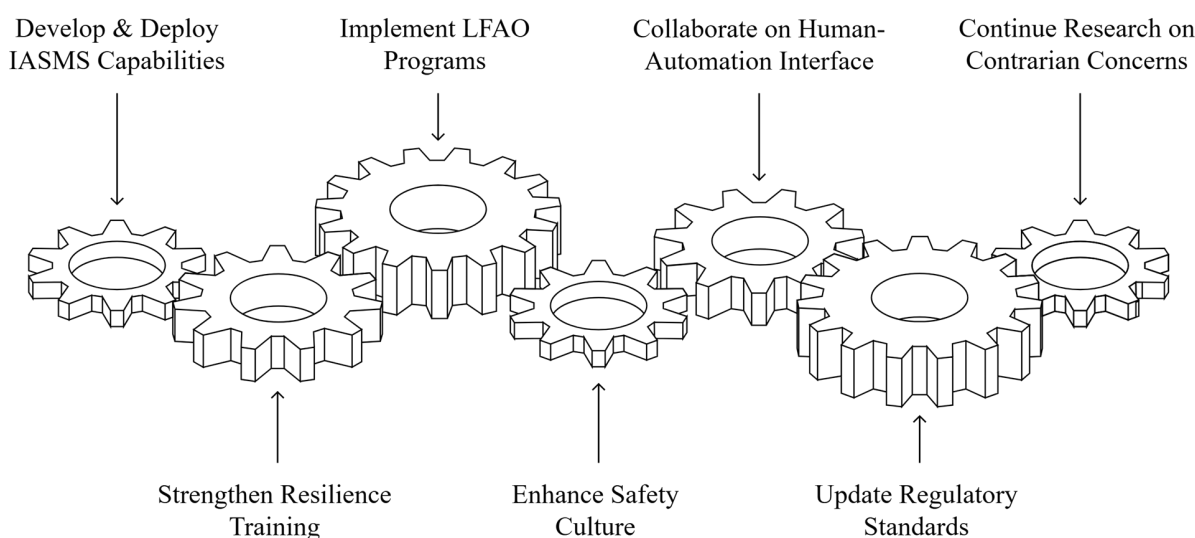
drive improvements in both technology and human performance. Together, these elements form a reinforcing cycle of safety improvement that can help aviation reach new levels of safety performance, even as the industry grows, and new complexities arise. This position is evidence-based: research and trials have demonstrated the feasibility and benefits of each component – from NASA’s IASMS prototypes (Ellis et al., 2023), to tangible safety gains from FOQA/LOSA programs (FAA, 2023; Klinect et al., 2003), to case studies of resilient responses averting disaster (Dekker & Lundström, 2007). By embracing this integrated philosophy, the aviation industry can move closer to the aspirational goal of zero accidents, while also enhancing efficiency and adaptability. Considering these findings, a multi-faceted action plan is proposed below to implement this vision. Together, the integration mapping (Figures 2–6), the line-ops scenario, and the operational metrics address the research question.

Action Plan

To advance flight deck safety in line with this position, a multi-faceted and phased action plan is necessary. Realizing this vision will also require a concerted industry-wide effort, including regulatory evolution and organizational culture change to embrace proactive safety management. The following recommendations (Figure 8) outline steps for industry stakeholders – airlines, regulators, manufacturers, and researchers – to implement the vision:

Figure 8

Multi-Faceted Aviation Safety Action Plan (Summary of Recommended Steps)



Develop and Deploy IASMS Capabilities Gradually

Collaborate on developing in-time safety management capabilities through pilot programs and incremental rollouts. For instance, airlines can introduce IASMS tools in a *shadow* (advisory-only) mode in their operations control centers to validate hazard-detection algorithms without affecting real flights. Regulators (e.g. FAA) should provide guidance and oversight into these trials, ensuring data accuracy and addressing any compliance issues. Early implementations

might focus on specific risk areas with well-characterized data – for example, real-time monitoring of approach-and-landing stability or of engine health parameters. Research by NASA and others (e.g. Ellis et al., 2022a; 2023 on commercial IASMS concepts) can guide system requirements. Over time, as confidence in the system grows, integrate IASMS alerts into decision-making processes: for example, allow airline ops controllers to recommend flight profile changes or proactive maintenance actions based on IASMS predictions (with appropriate training and protocols). Eventually, formalize IASMS as part of standard SMS processes, with regulatory acceptance, such that credit is given for hazards mitigated in real-time. A key part of this rollout is establishing data-sharing standards and cybersecurity measures. Industry committees (RTCA, EUROCAE, etc.) should develop common standards for IASMS data formats and protection, learning from existing ones (such as those for ACARS or for ASAP data).

Strengthen Resilience Training and Assessment

To make full use of in-time safety data and prepare for unexpected situations, the industry should formalize resilience training for flight crews and safety-critical personnel. Pilot curricula should include novel, unpredictable scenarios (building on UPRT and CRM) to strengthen adaptive decision-making (Green, 2023; Landman et al., 2018). Ground school should incorporate real-world examples of resilience, not just technical instruction. Beyond the simulator, workshops and debriefs (e.g., post-LOSA) can help crews reflect on and refine adaptive strategies. Regulators should embed resilience in competency frameworks (IATA, 2025). Though measuring resilience is complex, practical indicators include self-assessments (Pediconi et al., 2020), observed performance in surprise drills, and incident outcome trends (Taran, 2019). Cross-sector expertise—such as cognitive training from military domains—can strengthen program design (McCall, 2019; McGraw, 2023; McInerney et al., 2022). Organizations should formally recognize resilient performance. Normalizing resilience as a shared responsibility fosters a culture of adaptability and proactive safety.

Implement Comprehensive LFAO Programs

Airlines should support learning from all operations at both the individual and organizational level (Samu et al., 2025). To support LFAO at the individual level, airlines should enhance opportunities for continuous learning such as debrief tools and techniques. A telling indicator of change will be when debriefings after normal flights become as routine for noting successes as they are for dissecting problems. Industry conferences and publications should also regularly feature “what goes right” case studies, not just incident or accident analyses, reinforcing positive learning. Disseminating these findings ensures that the industry provides structural support for front-line workers to learn from all operations. At an organizational level, the industry should establish structures for sharing non-competitive safety knowledge. The FAA’s Aviation Safety Information Analysis and Sharing program (ASIAS) serves as a strong example, aggregating FOQA and ASRS data across airlines to identify systemic issues (for instance, industry-wide unstable approach trends) while preserving anonymity. Expanding ASIAS and similar initiatives globally, backed by broader participation and near-real-time data sharing of selected metrics, will amplify LFAO gains across the sector. Regulators should encourage or mandate airline involvement in these data-sharing networks as part of SMS

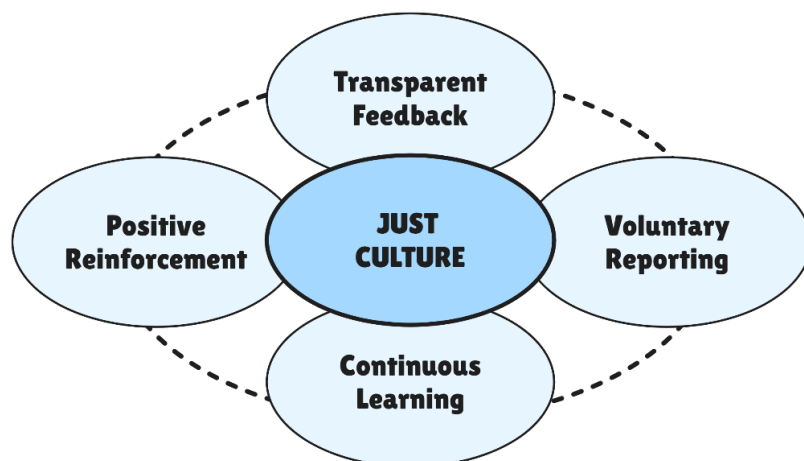
requirements, with suitable protections in place to maintain trust. Further, airlines must include frontline employees in driving organizational resilience for example, replicating programs like American Airlines LIT, which hold periodic “shop talk” sessions with pilots, flight attendants, and dispatchers to surface new ideas on improving safety and efficiency (American Airlines, 2020; 2021). These qualitative contributions supplement quantitative data, often revealing human, organizational, or design-related concerns that raw numbers alone might miss, for example, an awkward checklist that crews consistently find workarounds for. By adopting and acting on such feedback, airlines can make ongoing incremental refinements that, together, yield a safer system.

Enhance Safety Culture and Just Culture Policies

A positive, informed safety culture supports resilience and learning. Airline management must reinforce Just Culture principles and ensure that front line workers know that new data streams will not be used punitively but to drive improvement. Strong, effective leadership is key to resilience (Yu et al., 2022), so leaders must champion these cultural changes. Regulators can assist by providing legal protections for voluntary safety information sharing (as the FAA and NASA do with ASRS immunity in the U.S.). To acknowledge human contributions, organizations should collect information on positive human performance and return that information into training design to support and encourage an effective safety culture. Another cultural factor is mindfulness, in line with High Reliability Theory (Weick & Sutcliffe, 2007). Training and workshops on HRO principles, sensitivity to operations, deference to expertise, preoccupation with failure, can embed vigilance and open communication about possible safety concerns. For example, a ramp worker who notices an unusual pattern of ice accumulation might feel empowered to alert flight operations because the culture values speaking up, even outside one’s direct responsibilities. Because safety culture strongly affects performance (Cooper, 2000), organizations should regularly assess it (through surveys or audits; Freiwald et al., 2013) while implementing these Just Culture and learning-oriented policies. Figure 9 shows the safety culture ecosystem helping these practices.

Figure 9

Enhanced Safety Culture Ecosystem



Collaborate on Human–Automation Interface Improvements

As IASMS and other advanced tools enter operations, industry and academia must collaborate, so these technologies aid rather than hinder the humans in the loop. Research and development should continue in areas such as adaptive alerting, intuitive data visualization, and crew decision-support systems. End users (pilots, dispatchers, ATC) should be involved early in design through human-in-the-loop simulations.

Update Regulatory and Industry Standards

Regulators should integrate the principles discussed here into their safety oversight frameworks. New Advisory Circulars or guidance could be published on implementing LFAO or strengthening resilience, ensuring consistent adoption. Over time, elements such as IASMS may become expected components of an airline’s SMS. ICAO could fold in-time risk management and continuous monitoring into its safety management SARPs, which would then influence member-state regulations. Industry audit standards (e.g., IATA Operational Safety Audit) can add sections on how operators collect and employ operational data for learning, as well as how they foster resilience within their organizations. It is also recommended to form a cross-stakeholder task force to define metrics for success in this new paradigm. Traditional safety metrics (accident and serious incident rates) won’t fully capture the effects of proactive safety management. New metrics might include things like “time from hazard detection to mitigation” (to gauge IASMS effectiveness) or “number of actionable safety improvements derived from routine operational data per year” (to gauge LFAO productivity). These measures give operators a straightforward way to see how the combined approach is working in day-to-day line operations. It can also supplement the usual lagging indicators and provide a more proactive measure of safety health. By updating regulations and standards to formally recognize and reward proactive safety efforts, regulators can accelerate the shift.

Continuing Research on Contrarian Concerns

To continually improve the approach, the areas of contention identified earlier should remain research priorities. For example, address potential information overload by studying and refining alerting strategies; address algorithmic bias by testing IASMS algorithms on diverse scenarios and datasets. Independent audits or peer reviews of advanced safety systems should be periodically conducted to ensure they do not inadvertently introduce new risks.

Summary and Future Outlook

The action plans provided here are a sincere attempt to operationalize the concepts discussed and progressively achieve an even safer flight deck environment. The safety benefits will manifest as fewer incidents, better prediction and mitigation of emerging risks, and a robust safety culture that permeates all levels of operation. Importantly, this action plan is not a one-off project but an ongoing journey – the systems will continue to evolve, new data sources (like novel avionics or passenger-sourced data) will come online, and the cycle of learning and improvement will continue indefinitely. The synergistic combination of real-time monitoring, human adaptability, and continuous learning transforms safety management into a catalyst for

systemic improvement, where ‘safer’ inherently means ‘better.’ Evolving flight deck safety through in-time systems, resilience, and LFAO is not only feasible but *essential*. It leverages the best of modern technology and human expertise to proactively manage emerging risks. The positive contributions of humans, enhanced by intelligent systems and nurtured by an organizational thirst for learning, will be the cornerstone of aviation safety in the 21st century.

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Appendix A

Acronyms and Abbreviations Used in This Paper

Acronym	Full Term
AAM	Advanced Air Mobility
AQP	Advanced Qualification Program
ASAP	Aviation Safety Action Program
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
CEFA	Cockpit Emulator for Flight Analysis
CRM	Crew Resource Management
EGPWS	Enhanced Ground Proximity Warning System
ERC	Event Review Committee
FAA	Federal Aviation Administration
FOQA	Flight Operational Quality Assurance
FSF	Flight Safety Foundation
GAO	Government Accountability Office
HMI	Human–Machine Interface
HRO	High Reliability Organization
IASMS	In-Time Aviation Safety Management System
ICAO	International Civil Aviation Organization
LFAO	Learning From All Operations
LIT	Learning and Improvement Team
LOFT	Line Oriented Flight Training
LOSA	Line Operations Safety Assessment
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NLP	Natural Language Processing
SMS	Safety Management System
SOP	Standard Operating Procedure
TCAS	Traffic Collision Avoidance System
UPRT	Upset Prevention and Recovery Training

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Alternative Unleaded Fuels for General Aviation Piston Airplanes: A Pathway to Sustainability

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This position paper explores the transition from leaded 100 low lead (100LL) aviation gasoline to unleaded alternatives in general aviation (GA) piston-engine aircraft, motivated by environmental and public health risks underscored by the U.S. Environmental Protection Agency's (EPA) 2023 endangerment finding on lead emissions. Drawing on a comprehensive literature review and synthesis of sources, the study identifies and evaluates key unleaded fuel candidates: Auto Gas (Mogas), Swift UL94, GAMI G100UL, Swift 100R, and LyondellBasell/VP Racing UL100E. Each is assessed for regulatory status, engine compatibility, advantages, and challenges. The analysis also examines regulatory frameworks, such as the Federal Aviation Administration's (FAA) Eliminate Aviation Gasoline Lead Emissions (EAGLE) initiative targeting lead-free operations by 2030, alongside technical, economic, liability, and logistical hurdles. Findings highlight GAMI G100UL and Swift 100R as leading drop-in replacement fuel candidates, with LyondellBasell/VP Racing UL100E emerging as a contender under the FAA's Piston Aviation Fuels Initiative (PAFI). However, to make the transition to unleaded fuel feasible, the GA community in the US will need enhanced industry collaboration to overcome barriers, ensuring safe and viable GA operations amid projected piston-engine demand through 2043.

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Introduction

Background and Significance

The Clean Air Act (1970), passed by the United States Congress, required the phased removal of lead from most fuels. Currently, piston-driven general aviation (GA) airplanes operate on high-octane fuel that contains lead, also known as Avgas 100 low lead (100LL). Avgas/100LL is the last remaining fuel under the jurisdiction of the US Department of Transportation that contains lead. Lead has been recognized by the Environmental Protection Agency (EPA) to be detrimental to public health even in small quantities. Under court order in October of 2008, the National Ambient Air Quality Standard (NAAQS) dropped lead quantities by an order of magnitude from $1.5\mu\text{g}/\text{m}^3$ down to $0.15\mu\text{g}/\text{m}^3$ (Collin, 2006; EPA, 2010). Within the same year, the Friends of the Earth petitioned the EPA to determine if the lead in aviation fuel is a danger to public health (Friends of the Earth, 2006). In 2023, the EPA issued an “endangerment finding” under the Clean Air Act, determining that lead emissions from aircraft engines using leaded fuel contribute to air pollution that poses a risk to public health and welfare (EPA, 2023). Scientific research has linked lead exposure, even at low levels, to loss of intelligence quotient (IQ) in performance testing and to interference with brain development in children (Balbus, 2008).

Objectives

The objectives of this position paper are to 1) examine the status of the transition process to unleaded aviation fuel for GA piston engine aircraft, including regulatory, economic, liability, and distribution challenges; and 2) identify the most promising fuel candidates suitable to be used as drop-in replacements for 100LL fuel, evaluating their status, compatibility, advantages, and challenges.

Status of Leaded Aviation Gas

EPA Testing

In 2002, the EPA began conducting airport-specific lead emissions estimates and calculating the national inventory for lead emissions from leaded Avgas, utilizing methods to make the estimation of lead emissions like the methods used by the FAA to estimate inventories of other criteria pollutants emitted by aircraft in its Emissions and Dispersion Modeling System (EDMS) (EPA, 2008).

In addition to strengthening the lead NAAQS in 2008, the EPA enhanced the existing lead monitoring network by requiring monitors to be placed in areas with sources such as industrial facilities and airports with estimated lead emissions of 1.0 ton or more per year. According to the EPA (2023), monitored lead concentrations violated the lead NAAQS at two airports in 2012: the McClellan-Palomar Airport and the San Carlos Airport. However, at both airports, lead monitors were in proximity to the run-up areas, where the lead concentrations are expected to be higher and could have affected the results (Aircraft Owners and Pilots Association [AOPA], 2025; Santa Clara County Public Health Department, 2015).

The Role and Cost of Lead in Aviation Gas

Removing the lead from aviation fuel has been technically challenging. The lead is added to the fuel in the form of tetraethyl lead (TEL) and is used to reduce the fuel's tendency to detonate or spontaneously explode under high loads, high temperatures, and high pressures, especially in high-compression air-cooled aviation engines. Sustained detonation could cause catastrophic engine failure. The lead additive helps boost fuel octane and prevents valve seat recession, which can be a significant concern from a safety standpoint. The maximum lead concentration specified by the American Society for Testing and Materials (ASTM) for 100LL is 0.56 grams per liter or 2.12 grams per gallon (Chevron Corporation, 2006).

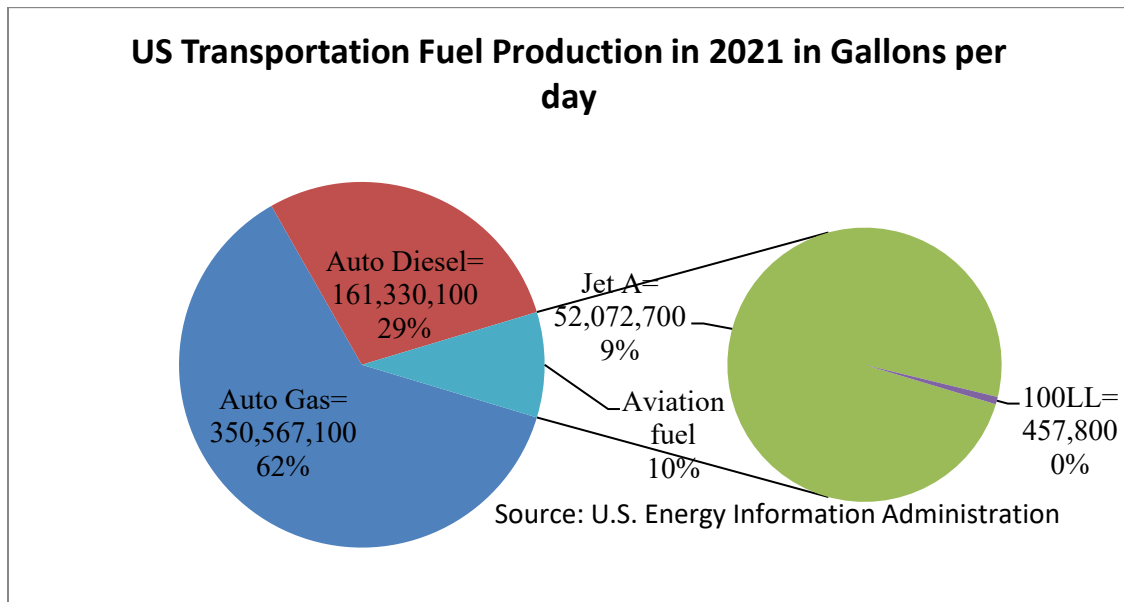
TEL is only produced by one plant in the world, so there is no price competition. To make 100LL, the refinery takes alkylate and re-distills it, where it is then pumped into tanks, and two grams of lead are added to each gallon of fuel (Price, 2013). Batches of 100LL aviation gasoline are tested, and if the octane rating falls below the 100/130 specification, a toluene concentrate is added to raise the octane level in compliance with ASTM D910 standards, which define the required properties of AvGas (ASTM, 2011). Because 100LL is a specialty product containing lead, U.S. pipelines will not allow it to soil their pipes. Therefore, 100LL must travel by truck or rail, costing about \$2,000 to ship 8,000 gallons 500 miles (Price, 2013).

Demand for Leaded Aviation Gas

The production of 100LL accounts for less than 1% of the total fuel production in the US, with approximately 457 thousand gallons per day as compared to 350 million for auto-gas in the U.S; therefore, aviation fuel is considered a “boutique fuel” (see Figure 1). North America is the primary market for both production and consumption of Avgas, producing 16 million gallons of fuel per year and consuming 17.5 million gallons per year. This type of fuel is already unavailable in some parts of Europe and Africa. It is estimated that by 2043, more than 50% of general aviation will be piston-powered aircraft, which means that aviation fuel will need to be produced to operate aircraft for at least the next 20 years (Ershov et al., 2023).

Figure 1

Fuel Production per Day in the U.S in 2024 in Gallons per Day (US Energy Information Administration, 2024).



Transition to Unleaded Aviation Gas

Efforts in Transitioning to Unleaded Aviation Gas

The transition from leaded aviation gas (Avgas), also known as 100LL, to unleaded fuel alternatives is essential, as the continued reliance on 100LL threatens environmental health, regulatory compliance, and future operational viability. In addition to the increasing global environmental issues, the dwindling global market demand for gasoline containing TEL has raised concerns regarding the continued use of 100LL by GA aircraft (AOPA, 2006).

In 2011, the FAA appointed the creation of the Unleaded Avgas Transition Aviation Rulemaking Committee (UAT ARC). The Piston Engine Aviation Fuels Initiative (PAFI) in 2014 was established as a result of the recommendations from the UAT ARC and in collaboration with the FAA and industry groups. This initiative was created to support the evaluation of candidate unleaded fuels to replace approved leaded gasoline, with the objective of ultimately qualifying a fleet-wide solution. In 2022, the PAFI program evolved into the Eliminate Aviation Gasoline Lead Emissions (EAGLE) initiative, under the FAA and critical government and industry partners. The main purpose of the EAGLE program is to safely eliminate leaded aviation fuel by the end of 2030 without impacting the safe and efficient operation of the piston-engine fleet (FAA, n.d.).

The FAA (2024) has two pathways available to obtain FAA authorization for the use of new unleaded fuel:

- 1) FAA fleet authorization process that was established by Congress, in conjunction with PAFI; and

2) Traditional FAA aircraft type certification, Supplemental Type Certificate (STC) process.

While the ASTM D7960 specification is not required, and fuels used in certified engines and aircraft are ultimately approved by the certifying authority (the FAA in the case of the US) (ASTM International, 2021). The advantage of obtaining an ASTM specification is that it would have gone through the industry consensus standards process of approvals, and therefore, it would have the “blessing” of the industry and the engine manufacturers as to their warranties. An ASTM specification, in the eyes of the aircraft and component manufacturers, has a liability protection that an STC does not (Schnitzler, 2024).

As part of its efforts to test and implement the fleet authorization process and assist in the transition to unleaded fuels, the FAA (2024) granted fleet authorization for Swift’s UL94/UL91 unleaded fuels in 2024. However, higher compression engines cannot use the lower-octane UL94 fuel because it may not prevent detonation (Baker, 2023). In 2022, General Aviation Modifications Inc. (GAMI) received FAA STC approval for its G100UL fuel, authorizing its use in all spark-ignition piston engines and airframes. This designation made G100UL the first unleaded 100-octane fuel to achieve fleetwide approval (GAMI, n.d.; *General Aviation News*, 2025, January 22). In 2024, Swift’s 100R received an FAA STC for Cessna 172R and 172S Skyhawk aircraft with Lycoming IO-360-L2A engines, with additional STCs under evaluation. In September of 2025, Swift 100R received the ASTM D7719 specification (Swift Fuels, n.d.). LyondellBasell/VP Racing UL100E is currently the only fuel undergoing full-scale engine testing under the PAFI program. Two other fuels passed the initial screening to be PAFI program candidates: a fuel produced by Shell and another fuel produced by Phillips. Both fuels suspended testing, leaving UL100E as the only candidate remaining under PAFI testing (Niles, 2024).

Aviation Fuel Characteristics

Energy content in aviation fuels is a key characteristic. Other important performance properties are knock-resistance, volatility, fluidity, stability, non-corrosivity, and purity (Chevron Corporation, 2006). Previous research indicates the most effective way to produce a 100LL equivalent is by combining traditional high-octane aliphatic components - mainly alkylate and isooctane with aromatic hydrocarbons, a small amount of oxygenates, and aromatic amines (Ershov et al., 2021).

Energy Content. Chemical energy stored in the fuel is converted into mechanical energy in aircraft piston engines. The energy content of the fuel can be measured by the heat released (also called heat of combustion) when a known quantity of fuel is burned under specific conditions (Chevron Corporation, 2006). The amount of power generated by a specific engine depends more on its design than on the fuel used.

Knock Resistance. Knocking or detonation occurs when an air-fuel mixture ignites spontaneously and burns too quickly, causing a rise in cylinder pressure and producing a knocking sound. This negatively impacts engine performance. The octane number indicates Avgas’s resistance to detonation, with numbers above 100 typically achieved by mixing isooctane and tetraethyl lead. Each engine is designed for a specific fuel with anti-knock

properties, and using a lower-octane fuel can lead to detonation and potential engine damage. Higher octane fuels are especially important for turbocharged and high-compression engines (Chevron Corporation, 2006).

Volatility. Volatility is the fuel's tendency to vaporize. Volatility is an important consideration because of carburetor icing and vapor lock.

Non-Corrosivity. It is essential that the fuel does not corrode any of the materials it comes in contact with, especially those in aircraft engines and fuel systems. Engine and airframe manufacturers conduct extensive fuel compatibility testing before approving material for fuel system use (Chevron Corporation, 2006). One of the problems with leaded fuels is that lead requires the addition of a bromine compound to scavenge lead residue from the engine. The burning of lead with the bromine compound is carried out with exhaust gases; however, a small amount remains in the engine. When it is mixed with water, metals, and oil, it can initiate corrosion processes that damage the engine or its components.

Fuel Purity. A fuel is considered "clean" when it is free of water, contaminants, and solid particles like rust or dirt, which could clog filters and other components. These solid particles could plug fuel filters or other components. Water will freeze at low temperatures encountered at high altitudes and will not burn in an engine; the resulting ice may also plug fuel filters as well as facilitate the corrosion of some metals and the growth of microorganisms in the fuel (Chevron Corporation, 2006). Due to the critical nature of aviation, the industry has developed strict quality control guidelines that are designed to ensure the quality of the fuel by recommending practices for transportation, storage, and delivery of the fuel (ASTM International & Gammon, 2009).

Methodology for Identifying Prospective Unleaded Fuels

This position paper is grounded in a synthesis of existing literature and a conceptual integration of findings across disciplines relevant to leaded aviation fuel and general aviation operations. Sources were identified through targeted searches conducted between 2000 and 2025, focusing on peer-reviewed journal articles, government reports, and authoritative publications from federal agencies, including the EPA, FAA, and the U.S. Energy Information Administration (EIA), as well as materials from recognized aviation advocacy organizations. A thematic analysis approach guided the synthesis, allowing recurrent concepts such as regulatory readiness, drop-in compatibility, scalability, environmental risk, and economic feasibility to be identified, organized, and integrated across sources. The goal of this approach was to develop an evidence-informed perspective that integrates technical, policy, and safety considerations, providing a coherent understanding of the issues surrounding leaded aviation fuel. This manuscript provides a structured integration of existing knowledge intended to clarify the readiness levels, limitations, and practical implications of leading unleaded Avgas candidates. Consistent with the purpose of a position paper, no new sampling, experimental testing, or quantitative analyses were performed; instead, the paper synthesizes credible evidence to support an informed, forward-looking perspective on the transition to unleaded fuels in general aviation.

Key Factors and Challenges in the Transition to Unleaded Fuels

A thematic analysis of the literature revealed several interrelated dimensions shaping the transition to unleaded fuels in general aviation, ranging from environmental and regulatory drivers to technical, economic, infrastructural, operational, and liability considerations. These key factors and the challenges associated with each are summarized in Table 1.

Table 1

Key Factors and Challenges in the Transition to Unleaded Fuels for GA

Key Factor	Challenge
Environmental and health benefits	The primary driver for replacement is eliminating lead emissions, which pose health risks, especially to communities near airports.
Regulations and policies	The FAA's Eliminate Aviation Gasoline Lead Emissions (EAGLE) initiative targets a lead-free aviation system by 2030.
Technical specifications and possible candidates	Replacements must match or exceed 100LL's 100-octane rating to prevent detonation in high-performance engines.
Compatibility and fleet impact	About 30% of the fleet can use lower-octane unleaded fuels like UL94, but the majority requires 100-octane options to avoid engine damage.
Economic implications	Unleaded fuels may cost more initially due to production scaling, refinement, and distribution investments, and infrastructure updates.
Infrastructure and distribution challenges	Building supply chains for unleaded fuels involves refiners, distributors, and airports.
Stakeholders and outlook	Key players include aviation advocacy groups like AOPA, EAA, GAMA; Government entities like the FAA and EPA; Oil companies, alternative fuel companies, airports, distribution suppliers, flight schools, and many more.
Liability	One of the main issues that concerns aircraft and component manufacturers, as well as fuel distributors, is liability and warranty.

Possible Unleaded Fuel Alternatives

As the GA community prepares a transition away from 100LL, several unleaded fuel candidates have emerged, each offering different levels of readiness, certification progress, and fleet applicability. These options range from low-octane fuels suitable for limited segments of the fleet to 100-octane formulations intended as universal drop-in replacements. The fuels outlined in this section represent the most current and promising alternatives, and their comparison highlights the technical, operational, and regulatory challenges that continue to

shape the pathway toward a viable unleaded future. See below the most current fuel candidates to replace 100LL.

Auto Gas (Mogas)

Description. Auto Gas, also known as Mogas, is an ethanol-free automotive gasoline, typically 91-94 octane, adapted for aviation use under STCs, meeting ASTM D4814 (automotive) rather than aviation-specific standards (Experimental Aircraft Association [EAA], n.d.).

Status. This fuel is available at approximately 75 U.S. airports and widely at automotive fuel stations, but aviation-specific supply is limited and requires STC compliance. FAA STCs are available through the Experimental Aircraft Association (EAA) and Petersen Aviation for specific low-compression aircraft (e.g., Cessna 150, Piper J-3 Cub). This fuel was not a primary focus of the EAGLE program as it is not aviation-specific, but it is used by some pilots mainly for cost savings and availability in remote areas (EAA, n.d.).

Compatibility. This fuel is compatible with low-compression engines (e.g., Continental O-200, Lycoming O-320, Rotax 912) in aircraft with STCs or experimental approvals. This fuel is not suitable for high-compression or turbocharged engines (e.g., Continental TSIO-520, Lycoming TIO-540) due to insufficient octane, risking detonation. Auto gas may cause vapor lock, seal degradation, or fuel system issues without modifications (e.g., fuel pumps, hoses) (EAA, n.d.).

Advantages. This fuel offers a cost-effective solution, typically priced at approximately \$2.5 to \$6 per gallon at fuel stations, making it significantly more economical than Avgas. It is also environmentally friendly as it does not contain lead. While ethanol-free mogas may be somewhat harder to find, they remain widely available at most automotive stations. Approved since 1982, this fuel has been successfully used in low-compression engines, such as the Continental 200 and Rotax 912, for decades, particularly in regions like Canada and Europe (EAA, n.d.).

Challenges. There is not an aviation-specific ASTM standard for this fuel, only an ASTM for automotive use, which raises safety, quality, and consistency concerns. There is limited compatibility, covering only approximately 30% of the GA fuel consumption in low-compression aircraft. Non-aviation sources of Mogas typically contain Ethanol, which can damage aircraft fuel systems and components. An STC is required for the use of Mogas in certified aircraft (EAA, n.d.).

94 UL (Swift UL94)

Description. A 94-octane unleaded aviation gasoline developed by Swift Fuels is specifically formulated to meet ASTM D7547 standards for aviation use. This fuel serves as a direct replacement for the 80/87 Avgas, and it is designed to cater to lower-compression engines (Swift Fuels, n.d.).

Status. Currently, this aviation fuel is commercially available at approximately 100 U.S. airports, predominantly used by flight schools and light aircraft, as of May 2025. An FAA Supplemental Type Certificate (STC) has been approved for around 1,600 aircraft models, which constitutes approximately 60-75% of the U.S. General Aviation (GA) piston fleet. Swift Fuels has announced plans to gradually phase out the UL94 as the Swift 100R becomes more widely available, projected around 2026 (Swift Fuels, n.d.).

Compatibility. The compatibility of this aviation fuel is limited to low- to mid-compression engines typically found in aircraft such as the Cessna 172 and Piper Cherokee. It is unsuitable for high-compression or turbocharged engines that necessitate 100-octane fuel, like those in the Cirrus SR22 or Beechcraft Bonanza. Certified aircraft require a Supplemental Type Certificate (STC) to use this fuel, which can be obtained through Swift's "Forever STC" program for a one-time fee of \$100 (Swift Fuels, n.d.). Moreover, this fuel can be intermixed with 100LL, provided that the aircraft's engine and airframe, or rotorcraft, are approved for the use of Swift Fuels UL94 (Swift Fuels, n.d.).

Advantages. 94 UL (Swift UL94) is ASTM-compliant for aviation use. This aviation fuel is widely tested and reliable for compatible aircraft, with a strong track record in flight schools. Utilizing this fuel reduces maintenance costs as it reduces the chances of spark plug fouling compared to 100LL. This fuel is available at a growing number of airports, especially on the West Coast of the US, and can be intermixed with 100LL at any ratio (Swift Fuels, n.d.).

Challenges. The use of UL94 fuel presents several challenges within the general aviation (GA) sector. Notably, this fuel is incompatible with approximately 25-40% of GA fleet high compression engines that require 100-octane fuel, thereby limiting its applicability. Additionally, there have been reports of valve seat recession during its use at the University of North Dakota (UND) with Lycoming engines, which raises concerns about its long-term suitability for certain engine models (Bertorelli, 2023). Furthermore, as Swift advances its approval process for Swift 100R, there are plans to phase out UL94. This impending transition could potentially disrupt users who currently rely on UL94 (Swift Fuels, n.d.).

G100UL

Description. A 100-octane unleaded aviation gasoline engineered by General Aviation Modifications, Inc. (GAMI), this fuel was designed as a drop-in replacement for 100LL. This proprietary fuel blend incorporates aromatic amines, including chemical constituents such as xylene and m-toluidine, to achieve a high-octane rating without the use of lead.

Status. G100UL fuel received FAA Supplemental Type Certificate (STC) approval in September 2022, authorizing its use in all spark-ignition piston engines and airframes. This milestone marks G100UL as the first unleaded 100-octane fuel to receive fleetwide approval (GAMI, n.d.; General Aviation News, January 2022). Currently, the fuel is commercially available at a select number of U.S. airports, with a notable presence in California, including Reid-Hillview, Watsonville, and Santa Maria. As of early 2025, production by Vitol Aviation has reached approximately 1.2 million gallons (General Aviation News, January 22, 2025). Despite its approval, GAMI has decided not to pursue the ASTM D7719 specification due to

timeline constraints, which have limited broader industry acceptance by fuel distributors, Fixed-Base Operators (FBOs), and Original Equipment Manufacturers (OEMs) (Aviation Consumer, January 29, 2025). This decision has led to ongoing scrutiny from OEMs such as Cirrus Aircraft, which has not approved G100UL for their aircraft, citing unresolved material compatibility and airworthiness concerns (Aviation Consumer, January 29, 2025). G100UL is supported by the FAA's EAGLE initiative as a transitional fuel. However, its long-term adoption remains uncertain due to competition from ASTM-compliant fuels like Swift 100R and UL100E (FAA, n.d.).

Compatibility. G100UL is compatible with all piston aircraft, including high-compression and turbocharged engines (e.g., Continental TSIO-550, Lycoming TIO-540), without modifications other than placards and a POH addendum. This fuel is intermixable with 100LL in any ratio, simplifying transitions. Some concerns have been raised by Cirrus Aircraft and other manufacturers about material compatibility (e.g., paint degradation, seal swelling, fuel bladder leaks), although GAMI disputes these claims.

Advantages. Fleetwide compatibility is G100UL's major advantage, covering all GA piston aircraft, making it the most versatile unleaded option. This remarkable compatibility ensures that it can seamlessly replace 100LL without compromising performance. In fact, G100UL not only matches but potentially exceeds the performance of 100LL, offering a slight increase in range, approximately 1% higher, thanks to its higher energy density. Additionally, the introduction of G100UL is expected to lead to reduced maintenance costs, such as those associated with spark plugs and oil changes, due to the absence of lead fouling. Another noteworthy advantage is its early market availability, as this fuel is already accessible at select airports, particularly in California.

Challenges. The introduction of G100UL fuel presents several significant challenges. One of the primary issues is the absence of an ASTM specification, which hampers its acceptance among fuel distributors, Fixed Base Operators (FBOs), and original equipment manufacturers (OEMs) such as Cirrus, Continental, and Lycoming. These entities have expressed concerns regarding liability and warranty, which are exacerbated by G100UL's lack of standardized specifications (Schnitzler, 2024). Furthermore, reports have indicated material compatibility problems associated with G100UL. Instances of paint staining, seal degradation, and yellowing of fuel caps have been noted. However, General Aviation Modifications, Inc. (GAMI) attributes these issues to improper handling or pre-existing conditions rather than the fuel itself (Schnitzler, 2024). Another critical challenge is the cost. G100UL is priced approximately \$0.70 to \$1.05 per gallon higher than 100LL, which could deter widespread adoption (General Aviation News Staff, 2025). Additionally, the distribution network for G100UL is currently limited, with availability confined to about three airports as of May 2025. Resistance from OEMs remains a significant hurdle. For instance, Cirrus has explicitly disapproved of using G100UL in their aircraft, citing concerns about airworthiness. The co-founder of GAMI has emphasized that GAMI has successfully submitted the requisite information to secure an ASTM specification. It was discovered that a major oil company, which had a representative on the ASTM committee, had used GAMI's confidential information to file a competitive patent (General Aviation News Staff, 2025). Braly further stated that the FAA recognized this issue and established an FAA-approved specification equivalent to an ASTM

specification (General Aviation News Staff, 2025). These multifaceted challenges underscore the complexities involved in the adoption and acceptance of G100UL as a viable aviation fuel alternative.

Swift 100R

Description. Swift 100R is a 100-octane unleaded aviation gasoline developed by Swift Fuels, designed as a drop-in replacement for 100LL. It uses a chemical called ethyl tert-butyl ether (ETBE) to raise the octane (Swift Fuels, n.d.).

Status. In September 2024, the FAA granted an STC approval for the Cessna 172R and 172S Skyhawks, both equipped with Lycoming IO-360-L2A engines. Additional STCs are currently under evaluation. Furthermore, in September 2025, Swift 100R fuel met the ASTM D7719 specification (Swift Fuels, n.d.). This fuel is available on a restricted-use basis at select U.S. airfields, primarily in California, for approved aircraft. By November 2024, approximately 22,000 gallons had been ordered.

Compatibility. The Swift 100R fuel is currently certified exclusively for use in Cessna 172R/S aircraft equipped with Lycoming IO-360-L2A engines. However, there are future plans to extend its applicability to all piston aircraft, including those with high-compression and turbocharged engines. Notably, Swift 100R can be intermixed with 100LL fuel without necessitating any modifications to the fuel system, apart from the addition of placards and STC documentation. Comprehensive testing has not indicated any material compatibility issues, with thorough evaluations conducted on paint, seals, and fuel bladders (Swift Fuels, n.d.).

Advantages. The Swift 100R fuel is engineered for comprehensive fleet utilization, delivering performance that matches or exceeds 100LL, making it suitable for all piston engines. Having an ASTM specification also increases industry acceptance. Notably, Swift 100R is lead-free, having undergone extensive toxicology and environmental testing, and aligns with EAGLE objectives. Additionally, Swift's "Forever STC," available for \$100, covers both UL94 and 100R, facilitating a smoother transition for airplane owners and operators (Swift Fuels, n.d.).

Challenges. The Swift 100R fuel has limited STC approvals (only Cessna 172R/S as of May 2025), delaying fleetwide adoption. This aviation fuel encounters significant competition from G100UL, which has received broader approvals, and UL100E, which is likely to obtain fleet authorization soon (Swift Fuels, n.d.).

LyondellBasell/VP Racing UL100E

Description. The UL100E fuel, which was developed collaboratively by LyondellBasell Industries and VP Racing Fuels, represents a significant advancement in aviation fuel technology. This 100-octane unleaded aviation gasoline is specifically designed to serve as a direct replacement for the widely used 100LL fuel. Currently, UL100E is undergoing rigorous testing under the FAA's PAFI, as reported by AOPA (2023). Notably, similar to Swift 100R, this fuel utilizes ETBE to enhance its octane rating, ensuring optimal performance and reliability for aviation applications.

Status. This fuel has undergone extensive full-scale testing under the Piston Aviation Fuels Initiative (PAFI). It successfully passed a rigorous 150-hour engine durability test in 2023 and has completed approximately 25% of the necessary materials compatibility, detonation, and performance testing by May 2025. The UL100E fuel is anticipated to receive fleet-wide authorization from the FAA by the end of 2025. This approval will necessitate only the addition of a placard and a Pilot's Operating Handbook (POH) addendum. An ASTM specification for this fuel is currently being developed, with the balloting process ongoing. This process is addressing feedback and criticisms from the initial rounds of evaluation (AOPA, 2023).

Compatibility. UL100E is designed to achieve fleetwide compatibility, covering all piston aircraft, including those with high-compression and turbocharged engines. Comprehensive testing has been conducted on ten engine models and eight distinct airframes. Notably, UL100E can be intermixed with 100LL without requiring any modifications beyond placards, pending final approval. However, LyondellBasell has highlighted potential performance limitations for certain engines, indicating that it may not serve as an ideal drop-in replacement for all high-performance models (AOPA, 2023).

Advantages. The UL100E fuel produces no lead emissions, aligning with EAGLE's 2030 lead-free goal. PAFI testing ensures rigorous evaluation of this fuel, enhancing safety and industry acceptance. ASTM specification pursuit supports distributor and OEM confidence, potentially easing supply chain integration. The authorization of this fuel for fleet use will streamline its adoption process by necessitating minimal modifications to existing aircraft (Aircraft Owners and Pilots Association, 2023).

Challenges. This fuel is not yet commercially available, with full-scale testing projected to commence in April 2024 and expected to conclude within 12 to 18 months. This suggests a tentative approval date around late 2025. However, there are concerns about performance limitations for some high-performance engines, potentially requiring operational adjustments. Current ASTM specification delays due to balloting criticisms could further postpone commercialization. UL100E faces significant competition from G100UL, which has already received approval, and Swift 100R, which is close to securing broader approvals (AOPA, 2023).

Both of these alternatives exhibit their own advantages and disadvantages and are strong contenders to replace 100LL. Meanwhile, LyondellBasell/VP Racing UL100E is currently undergoing full-scale testing under PAFI, positioning it as a potential third option. Table 2 provides a comparative analysis of these three fuels.

Table 2
Comparison Summary of Top Three Fuel Contenders to Replace 100LL

Fuel	Status	Compatibility	Advantages	Challenges
GAMI G100UL	- Has FAA fleetwide STC - Commercially available at a limited number of U.S. airports - No ASTM spec	- Compatible with all piston aircraft, including high & low compression & turbocharged engines - Intermixable with 100LL in any ratio	- Fleetwide compatibility - Intermixable with 100LL in any ratio	- No ASTM spec - Reduced acceptance due to liability and warranty concerns - Possible material compatibility issues - higher cost, approximately \$0.70-\$1.05/gal more than 100LL - limited distribution network
Swift 100R	- FAA STC for Cessna 172R and 172S Skyhawks with Lycoming IO-360-L2A engines only - ASTM D7719 specification - Available at limited airfields, mainly in California	Approved for Cessna 172R/S only, with plans to expand to all piston aircraft, including high-compression and turbocharged models.	Intermixable with 100LL	- limited STC approvals (only Cessna 172R/S) - Unknown materials compatibility
LyondellBasell/VP Racing UL100E	- This fuel has been in full-scale testing under PAFI - ASTM D7719 specification is in development for this fuel, with balloting ongoing and addressing criticisms from initial rounds	Aimed at fleetwide compatibility, potential performance limitations for some engines, may not be a drop-in replacement	Going through PAFI certification instead of STC	- Not commercially available - Concerns about performance limitations for some high-performance engines

Considerations for the Transition to Unleaded Fuel

Technical. Ensuring safety in aviation remains paramount, necessitating that an unleaded aviation fuel solution be compatible with 100LL, possess appropriate materials compatibility, and ideally serve as a drop-in replacement for the entire GA piston engine fleet (Fly Eagle, 2024). Both 100R and UL100E utilize ETBE, whereas G100L employs aromatic amines to boost octane. However, there are toxicity concerns regarding ETBE as it has been classified as possibly carcinogenic to humans (Group 2B) based on sufficient evidence of cancer in experimental animals (Turner et al, 2025). Aromatic amines, on the other hand, could potentially pose component compatibility issues.

Liability. By the mid-1980s, the GA industry in the US was nearing a state of collapse. This period marked significant challenges, with Cessna Aircraft halting the production of its piston aircraft and Piper Aircraft facing imminent bankruptcy. The primary factor contributing to this downturn was the escalating issue of product liability. Congress passed the General Aviation Revitalization Act (GARA) to shield most manufacturers of small GA aircraft from liability involving their products that are older than 18 years. The GA industry overall is very sensitive to liability (Wilson, 2024).

An STC approval grants legal permission to sell a product without risking the certification of the aircraft. This certificate will not provide any liability support in case of a problem. Many believe that while a product qualified against an ASTM specification does not directly provide legal liability protection, it may carry the support of an industry agreement in a court of law. This implies that the product should meet the requirements of all general aviation aircraft, rather than just those of the STC holder (Schnitzler, 2024).

Cost. One of the most significant challenges in transitioning to unleaded fuel is meeting the substantial demand that Avgas currently fulfills, which amounts to approximately half a million gallons per day (Wolfe, 2023). Recently, the Los Angeles city council decided that the city would cover the \$2-\$4 per gallon price difference between Swift Fuels and 100LL, in addition to covering the cost for the STC required for aircraft to legally use the fuel (Niles, 2024). In contrast, the co-founder of GAMI explained that scaling up from small-scale production to millions of gallons would be a gradual process due to supply chain limitations. Consequently, prices are not expected to align with 100LL until production increases significantly. GAMI has also introduced incentives, including a complete refund of the STC for pilots who purchased it and a voucher equivalent to their previous fuel purchase (Britton, 2024). Transition costs encompass various factors such as fuel storage, distribution, STCs, and maintenance. The pricing of UL Avgas will ultimately depend on fuel volume, airport location, and market conditions.

Distribution and Logistics. Airports and FBOs must ensure UL Avgas availability to support aircraft refueling across the country. As of June 2025, there are three airports in California, two in Texas, and one in Mississippi that offer G100UL (General Aviation News, 2025). In addition, approximately 99 airports across the United States provide 94UL. There is one airport in California that offers Swift fuel 100R, and this fuel is also available at other airports on a restricted (non-resale basis. Swift expects to have 100R broadly commercially

available by mid- to late 2025, pending approval of its ASTM production specification. Once certified, Swift Fuels expects to have its 94UL clients and airports transition to 100R (Fly Unleaded, n.d.; Swift Fuels, 2024).

AvFuel is one of the main aviation fuel distributors in the US and has expressed a commitment to supporting any viable UL avgas solution. The company plays a key role in managing the logistics associated with product distribution and in helping to establish a scalable supply chain capable of delivering G100UL Avgas to the market. AvFuel currently distributes both Swift and GAMI fuels at selected airports (Avfuel Corporation, 2022).

In June 2025, a California court denied a motion from the Center of Environmental Health (CEH) asking the court to require leaded Avgas to be banned once unleaded fuel alternatives were “commercially available”. The ruling upheld the terms of the 2014 settlement agreement between FBOs and fuel distributors, thereby maintaining the existing regulatory framework governing Avgas sales in the state (General Aviation News Staff, 2025).

CEH asserted that GAMI’s G100UL is FAA-approved and already being sold at FBOs in California and therefore contended that the court should enforce the terms of the prior settlement. However, the court noted that since G100UL has not received an ASTM specification, it cannot be considered “commercially available”. In the ruling, the court cites declarations received from aviation OEMs and trade organizations, including GAMA, Piper, Cirrus, Aviat, Diamond, Schweizer RSG, Robinson Helicopters, and Textron Aviation, which include Lycoming engines, Cessna, and Beechcraft. These organizations submitted information to the Court that stated the new unleaded Avgas variant was not approved or supported by manufacturers for use in their models, as they lacked sufficient data and information to verify its safety and material compatibility (General Aviation News, 2025).

Current Efforts to Adopt Unleaded Fuels

Several organizations have conducted testing and begun transitioning to unleaded fuels. Some of these organizations include:

Embry-Riddle Aeronautical University (ERAU). The Eagle Flight Research Center at ERAU has conducted testing on multiple unleaded fuels, including participation in PAFI fuel testing efforts. At GAMI’s request, ERAU, acting as an independent third party, completed a 150-hour engine durability test conducted on an engine that already accumulated more than 1400 hours of operation on 100LL. According to GAMI, the post-test engine teardown showed that the engine and combustion chambers were noticeably cleaner after operating for 150 hours on G100UL than they had been prior to the test. That testing at ERAU was closely monitored by the FAA with personnel from the Atlanta Aircraft Certification Office (GAMI, n.d.).

AOPA. In 2023, AOPA conducted a series of test flights using a twin-engine Beech Baron operating one engine on G100UL and the other on 100LL for comparison. The results indicated that the performance of both engines was nearly identical across fuel types. The evaluation included several full-power takeoffs and an extended high-power cruise at over 75% power (AOPA, 2023).

Utah Valley University (UVU). In 2023, UVU transitioned its flight training program to unleaded fuel using Swift UL94 for its 25 airplanes that include Diamond DA-40 and Piper Seminole (Kurtz, 2023; Bubel & Wedekind, 2021).

Purdue University. In 2020, the School of Aviation and Transportation Technology professional flight program purchased a new fleet of Piper aircraft certified to run in Swift UL94 (Pereira, 2019).

San Carlos Flight Center. As of November 2024, Swift Fuels 100R had been formally adopted, although the company had been operating exclusively on Swift Fuels UL94 since 2021 (Thurber, 2024).

University of North Dakota (UND). UND elected to transition to unleaded Avgas UL94 to **reduce** aircraft maintenance costs and to **adopt** a cleaner, more environmentally sustainable fuel alternative (Kurtz, 2022). However, after just four months of use of unleaded fuel, UND **elected** to transition back to 100LL, citing evidence of noticeable exhaust valve recession (Bertorelli, 2023).

While operating on UL94, UND's fleet accumulated approximately 46,600 flight hours, consuming 386,778 gallons of UL94, averaging 464 hours per aircraft (Wilson et al, 2025). Wilson (2025) notes that one potential cause of the excessive valve seat wear observed during this period is microwelding, a phenomenon in which the mating surfaces of valve and valve seat bond at high-temperature conditions. When lead was removed from US automotive fuel in the 1970s, heavy wear of engine exhaust valve seats was observed. Further research found that lead oxides present in leaded fuel had provided a protective layer between the valve and the seat. In the automotive sector, micro welding was ultimately addressed through the widespread adoption of hardened valve seat inserts (Forsberg et al., 2011; Khan et al., 2018). According to Swift, 5 US flight schools utilize 100R as well as 5 flight schools in the EU (Germany, Belgium, Austria, and the Netherlands) (Swift Fuels, n.d.).

Conclusions

It is the authors' position that the GA community in the US is not ready to completely transition to unleaded fuel yet. Before such a transition occurs, it is critical that the industry identifies a viable unleaded fuel alternative that can be safely and effectively adopted across the GA piston fleet. An acceptable solution must be fully interoperable with 100LL, exhibit comprehensive materials compatibility, and be suitable for use in all GA piston aircraft—ideally functioning as a true drop-in replacement.

Based on the alternative fuels discussed, the two candidates that appear closest to providing a viable unleaded replacement are GAMI G100L and Swift 100R. GAMI G100L holds a fleetwide FAA STC and is approved for both low-compression and high-compression piston engines. However, the absence of an ASTM specification has limited its acceptance among fuel distributors, FBOs, and OEMs, who cite concerns related to liability, warranty coverage, and long-term operational support. Material compatibility concerns have also been raised regarding the use of aromatic amines such as xylene and m-toluidine, which are employed in some

formulations to increase octane rating. Swift 100R possesses both an ASTM specification and an FAA STC, but it is currently approved only for use in the Cessna 172 R/S model, and its suitability with high compression engines has not yet been demonstrated. A third candidate, LyondellBasell UL100E, is emerging and undergoing fleet authorization through the FAA's PAFI program. Two other fuels that had initiated testing under PAFI, Phillips and Shell, ultimately suspended their efforts due to technical challenges and adverse findings, leaving UL100E as the sole remaining candidate under PAFI testing.

Theoretically, PAFI testing is designed to provide a pathway to fleet-wide approval; however, no PAFI fuel candidate has achieved success to date. UL100E remains considerably behind GAMI and Swift fuels as UL100E as it is not yet commercially available, and concerns persist regarding its performance in high-performance engines. It is also possible that a major oil company could ultimately license one of the existing unleaded formulations and leverage its established supply chain and distribution infrastructure to support broader market adoption. Both 100R and UL100E rely on ETBE as an octane enhancer, whereas G100L uses aromatic amines to achieve the required octane rating. Toxicological concerns have been raised regarding ETBE, which has been classified as possibly carcinogenic to humans (Group 2B) on sufficient evidence of carcinogenicity in experimental animals. Aromatic amines, on the other hand, may introduce risks related to component materials compatibility within aircraft fuel systems and engines. Thus, although the detrimental environmental effects of lead are well established, the octane boosting additives employed in unleaded alternatives also present potential safety and health risks that must be carefully considered.

Fuel additives and certain operational or hardware modifications, including mixture leaning procedures and hardened seat valve inserts, might be necessary when transitioning to unleaded fuels. A major concern among aircraft and component manufacturers, as well as fuel distributors, involves the potential transfer of liability from the fuel's patent holder to the operator and manufacturers of aircraft and associated components. Many industry stakeholders contend that while qualification to an ASTM specification does not directly confer legal protection, it may, in practice, provide stronger support in a court of law by signaling broad industry consensus that the fuel should be suitable for all GA aircraft rather than only for those covered under a specific STC. Additional challenges include cost, distribution logistics, infrastructure readiness, and long-term fuel availability, all of which require collaboration between the aviation industry, government agencies, and fuel manufacturers. This regulatory and technical uncertainty contributes to apprehension across the sector, potentially hindering investment and innovation. Projections indicate that through 2043, more than 50% of the general aviation fleet will continue to be powered by piston engines, meaning that Avgas, leaded or unleaded, must remain available for at least the next two decades. Ultimately, the widespread adoption of unleaded fuel is not solely a technical undertaking, but a long-term commitment to protecting public health and the environment.

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Appendix A – Acronyms

AOPA – Aircraft Owners & Pilots Association
ASTM – American Society for Testing & Materials
CEH – Center for Environmental Health
EAA- Experimental Aircraft Association
EAGLE – Eliminate Aviation Gasoline Lead Emissions
EDMS – Emissions & Dispersion Modeling System
EPA – U.S. Department of Environmental Protection
ETBE- ethyl tert-butyl ether
ERAU – Embry-Riddle Aeronautical University
FAA – Federal Aviation Administration
FBO – Fixed Base Operator
GA – General Aviation
GAMI – General Aviation Modifications Inc.
GARA – General Aviation Revitalization Act
IQ – Intelligence Quotient
LL – Low Lead
LTO – Landing & Takeoff
NAAQS – National Ambient Air Quality Standards
OEM – Original Equipment Manufacturer
PAFI – Piston Aviation Fuels Initiative
STC – Supplemental Type Certificate
TEL – Tetraethyl Lead
UAT ARC – Unleaded AvGas Transition Aviation Rulemaking Committee
UL - Unleaded
UND – University of North Dakota
UVU – Utah Valley University