Integrating Accident Lessons into Foundational Aviation Education

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Aviation safety is a fundamental component of professional pilot education; however, the safety-related topics are sometimes taught as stand-alone courses and may not be integrated into courses throughout the curriculum. Early exposure to aviation safety concepts may help shape the professional identity of future pilots and aviation leaders. Engineering and technology students may also be introduced to safety concepts and analysis early in their studies. This research presents the development and pilot implementation of a structured plan to incorporate safety concepts in an introductory undergraduate-level aviation course. This study explores how aviation educators can introduce safety into the curriculum by incorporating the Federal Aviation Administration (FAA) *Lessons Learned from Civil Aviation Accidents* resource into weekly class activities during an introductory aviation course. The pedagogical approach implemented in a pilot study builds on prior research indicating that case-based learning may help students think critically and increase safety awareness early in aviation degree programs. The implementation plan combines safety concepts with the aviation coursework to help students develop a deeper understanding of human factors and aviation safety culture. Research methods include a literature review of the benefits and challenges of safety training in aviation, engineering, and medicine, as well as an analysis of instructors' reflections on integrating materials from the *FAA's Lessons Learned from Civilian Aviation Accidents Library*. Deliverables of this research include the case-based teaching materials: 1) selected FAA accident cases, 2) discussion questions, and 3) guidance on connecting technical concepts to real-world events. Preliminary findings of this pilot implementation may support aviation educators in promoting safety awareness by incorporating authentic FAA cases into introductory aviation curricula and connecting real-life events to the concepts covered in an introductory aviation course. Future studies may use this study's findings to explore integrating safety concepts early in curricula, using real-life examples from other professional and engineering programs.

Keywords: Aviation safety, Safety culture, Human Factors & Risk management.

Introduction

Safety is recognized as a prerequisite for any air transport operation. However, integrating aviation safety concepts early in the curriculum remains an area that deserves attention from the aviation education community. Parallels may be drawn to other students in fields requiring high levels of safety. The modern air transportation system functions as a socio-technical system (STS), in which safety emerges from the interaction among technology, organizational structures, and regulations [1]. This evolution in safety science, as described by Ziakkas & Henneberry [2], illustrates the transition from Safety I to Safety II, where the focus is on developing a safety system that is resilient, adaptable, proactive, and able to recover from disruptions or unexpected events. An increasing number of aviation operations, combined with a growing interest in leveraging the benefits of Safety Management Systems (SMS), evidences the need to continue advancing aviation safety curricula [3].

Educational research highlights the importance of integrating safety early in professional identity formation. The freshman and sophomore years represent a critical period in professional flight programs, during which students internalize aviation norms, standards, and behaviors that shape their attitudes and decision-making processes throughout their training and future careers in aviation. The SMS implementation and engagement on safety-related topics in collegiate aviation programs benefit from increasing the students' exposure across their degrees [4].

Pedagogical research across different safety-critical professions demonstrates the benefits of using case studies to reinforce safety concepts by helping to bridge the gap between theory and practice. Previous studies in aviation, engineering, and medical education have shown that case-based learning is effective for introducing complex safety concepts, as it enables students to analyze real-world outcomes without advanced technical proficiency or robust knowledge of safety programs [5],[6]. Accident case reports provide narrative context through which abstract concepts such as human factors, system interactions, and organizational influences become tangible, enabling new learners to engage in higher-order cognitive processes such as analysis and causal reasoning [7]. Despite broad agreement on the importance of safety and Safety Management Systems (SMS) in aviation operations, formal training in aviation safety, human factors, and systems thinking is often offered, typically in upper-level or specialized courses. This study explores the use of *Case-Based Learning* using the *FAA's Lessons Learned from Civilian Aviation Accidents Library* [8] as a tool to teach aviation safety concepts early in the professional flight program curricula. This study contributes to ongoing efforts to increase safety in collegiate aviation education programs.

Literature Review

Aviation safety, as a concept, has evolved from considering only the reliability of equipment or the performance of an individual to evaluating safety in terms of the system's performance. In socio-technical systems (STS), safety is typically defined as an outcome of interactions among operators, organizational structures, and the regulatory framework. As described by Leveson [9], an accident can be explained by control failures, ineffective constraints, and a lack of coordination across the organizational structure. In aviation, an accident is explained by multiple supervision, organizational, and human performance failures. Early STS studies on safety performance demonstrated the influence of the organizational approach to performance and productivity, and their relationship to the training programs. Rasmussen [10] described how individuals learn to operate within acceptable performance boundaries, shaped by the constraints, feedback, and priorities emphasized by their organizations. In training contexts, human performance may be bound by the limits and priorities established by the organizations. Reason [11] described how the organization's latent conditions (e.g., training philosophies, instructional priorities, and normalization of deviance) influence the operator performance and the system's safety outcomes. Recently, safety science expanded its understanding of the implications of training for STS safety performance. Hollnagel [12] differentiates between Safety-I techniques, which prioritize the prevention of failure, and Safety-II approaches, which concentrate on understanding how systems overcome or respond to unexpected events. From an educational standpoint, this distinction holds that training should extend beyond mere rule compliance or error avoidance to equip learners to identify variability and trade-offs between productivity and safety performance. Dekker [13] illustrates how routine modifications by proficient professionals frequently include learned reactions to systemic restrictions. Introducing these concepts early in training may allow the students to frame technical instruction within a broader understanding of system behavior, supporting the development of adaptive decision-making processes.

Prior research across aviation, engineering, and medical education suggests that case-based learning is particularly effective for introducing complex, safety-critical concepts; because it allows students to reason about real-world outcomes without requiring advanced technical mastery . Foster and Adjekum [14] examined safety motivation and reporting behaviors among collegiate flight students, highlighting the importance of ongoing safety training throughout the degree. This study [14] highlights the challenges of promoting a culture of safety as the student progresses through flight training and suggests implementing initial and ongoing safety training as a strategy to enhance involvement and attitudes toward risk management and Safety Management System (SMS) concepts. Empirical evidence in safety science suggests that safety culture is shaped by educational experiences and correlational processes. Panik et al. [15] demonstrated that undergraduate students across different engineering majors exhibit markedly different attitudes toward safety, even prior to workforce entry. These differences in safety culture attitudes from students of other areas may be explained by differences in the curricular emphasis and relevance of safety education within the program.

Within aviation, there is a regulatory emphasis on risk management and proactive safety practices; however, in aviation education, safety courses are usually introduced in upper-level courses. Velazquez and Bier [3] revealed a gap between industry expectations for Safety Management System (SMS) competence and what is formally taught in accredited undergraduate aviation programs. A delay in introducing safety into curricula may reinforce a technical-first mindset, in which safety is perceived as a compliance requirement or managerial function rather than an integral component of everyday operational decision-making. Pollock and Sørensen [16] illustrated how embedding safety instruction throughout the curriculum (i.e., beginning in the first year) can normalize safety as a core professional value rather than an ancillary topic. According to the authors, repeated exposure to safety throughout the curricula allows students to frame technical learning within a broader understanding of system behavior, human performance limitations, and organizational issues. Active learning is needed to create an environment where safety is a fundamental part of the professional identity of the future generations of aviators.

Case-based learning offers a practical alternative for gaining a deeper understanding of aviation safety concepts. A study by Tsui and Thatcher [17] found that undergraduate aviation students recognized the value of SMS training for improving hazard identification and risk mitigation skills. The educational logic behind case-based learning forces learners to connect evidence to judgment and ask high-order questions: 1) what information mattered, what controls failed, which constraints contributed to the accident, and what organization influences shaped operators' decisions and performance. Allchin [18] explored the use of case-based learning approaches to gain real-world experience. For engineering courses, the Murdough Center for Engineering Professionalism at Texas Tech University [19] offers real engineering ethics case studies and other ethics materials that involve safety. In addition to the FAA cases [8], Roskam's *Lessons Learned in Aircraft Design: The Devil is in the Details* [20] provides aviation-specific design failure cases that offer complementary perspectives on safety education. Instead of using simplified textbook approaches, case-based learning enables the discovery of the complexities of an STS, such as aviation, and the understanding of interactions among stakeholders. A systematic evaluation of health professions education found that case-based learning tends to outperform lecture-based approaches for higher-order outcomes such as critical thinking and problem-solving, while still supporting core knowledge acquisition. In safety-critical industries such as aviation, case-based learning can enhance learning, enabling students to achieve higher-order outcomes.

Methods

In this research paper, archival analysis was used by the authors to examine the number of events, accident categories, and common themes among real aviation accidents. The *FAA's Lessons Learned from Civilian Aviation Accidents Library* [8] is used as a source of materials in the development and implementation of safety concepts early in the aviation curriculum. This approach focused on three sequential activities: 1) exploratory review of the FAA's database [8], 2) purposeful selection and categorization of representative accident cases, and 3) development of instructional material. The exploratory review of the *FAA's Lessons Learned from Civilian Aviation Accidents Library* [8] served as a starting point to identify the population (number of cases recorded on the FAA's library), and explore the registered primary metadata (e.g., "Threat Category," "Key Safety Theme," and "Operational Groups"). The purposeful case selection was limited to 10 aviation accidents to align with the weekly plan for in-class activities. The criteria for selecting the cases included 1) pedagogical relevance and completeness of the information, 2) representation of the transport airplane, small airplane, and rotorcraft categories, 3) representation of the FAA's threat categories, and 4) representation of interactions between human and technical factors. Cases that did not meet the inclusion criteria were discarded to prioritize key safety concepts and avoid cognitive overload for students.

The development of the instructional material aligned the selected cases with the introduction to aviation topics, such as aerodynamics, aircraft systems, regulations, and meteorology, among others. Each weekly topic was associated with a specific case from the FAA's Library aligned with the curriculum plan, covering 10 weeks of the 15-week semester schedule. This study is scoped as a pilot study to develop a curriculum for incorporating safety concepts early in the aviation professional flight programs. Deliverables of this exploratory study include a summary of the *FAA's Lessons Learned from Civilian Aviation Accidents Library* [8], a selection of cases aligned with course topics during 10 weeks of classes, and guided questions to be used during the in-class activities.

Results

The analysis of the *FAA's Lessons Learned from Civilian Aviation Accidents Library* [8], provided a total of 121 aviation accidents distributed in three (3) categories: 1) transport airplane (96 accidents), 2) small airplane (13 accidents), and 3) rotorcraft (12 accidents). The transport airplane category accounted for the majority of cases, beginning with the accident of the *British Overseas Airway Corporation - Flight 783*, on May 2, 1953, and ending with the accident of the *National Airlines - Flight 102, on April 4, 2013.* The top three common themes include *Flawed Assumptions* (64 cases), *Human Error* (54 cases), *and Organizational Lapses* (46 cases). The small-airplane category was dominated by the operational (13 cases) and maintenance subcategories. The first accident recorded in this category describes the *Dwyer Flying Service* accident on February 3, 1959, in Clear Lake, Iowa. The rotorcraft category includes 12 accidents in which Low Altitude Operations (LALT) (5 cases) and Loss of Control – In flight (LOC-I) (5 cases) are more frequently encountered. Table 1 summarizes the number of accidents, categories, and operational groups included in the FAA's accident library.

Table 1. Accident Cases by Aircraft Category, Threats, and Operational Groups from [8]

FAA's Library Category	Number of Cases	Dominant Threat Categories	Leading Operational Groups
Transport Airplane	96	1. Crew Resource Management 2. Structural Failure 3. System Isolation/Segregation	Approach & Landing Loss of Control - In-flight Automation Management
Small Airplane	13	1. Loss of Control - In-flight (LOC-I) 2. Icing (In-flight & Ground) 3. Structural Failure	VFR Flight into IMC* Stall/Spin Dynamics Mid-Air Collision
Rotorcraft	12	1. Controlled Flight Into Terrain 2. Post-Crash Fire 3. Fuel Management	Inadvertent IMC Low Altitude Operations Autorotation Entry
Total	121	1. Human Error 2. Flawed Assumptions 3. System Isolation/Segregation	Loss of Control (LOC-I) across all sectors.

Note: IMC-Instrument Meteorological Conditions

After the initial exploration of the FAA's accident library, ten accidents were selected based on the topics covered in the curricula for the introduction to aviation course, prioritizing pedagogical relevance and clear links between technical content and human or organizational factors. Among the ten accidents selected for the case studies, seven (7) represent the transport airplane category, two (2) represent the rotorcraft category, and one (1) from the small airplane category. Table 2 summarizes the list of accidents, course topics, and guided questions used by the instructor during the classes to guide the conversation regarding the safety concepts and lessons learned from each accident.

Table 2. Selected Accident Cases from [8] and Associated In-Class Discussion Topics

Week	Accident ID	Course Topic	FAA Threat Category	Sample Guiding Discussion Questions
1	Eastern Air Lines 401	Human Factors	*Situational Awareness / Distraction*	1. How does "fixation" keep you from seeing bigger threats? 2. Who was flying the plane when everyone was looking at the light? 3. Texting while driving makes a driver less aware of their surroundings. How is that similar to this situation? What are other similar situations?
2	Air Florida 90	Aerodynamics	*Icing / Contamination*	1. How does ice on a wing act like 'sandpaper' to destroy lift? 2. The Co-Pilot tried to warn the Captain, but wasn't forceful. Why might it be hard to speak up to a boss? 3. Why must you visually check the wings/rotors yourself rather than assuming they are clean?
3	Beechcraft 35	Meteorology	*VFR Flight into IMC*	1. Why do your eyes and inner ear 'lie' to you when you can't see the horizon? 2. What external pressures (e.g., VIP passengers, late departure, others) might have convinced the pilot to fly in bad weather? 3. If the weather looks worse, what is the safest decision?
4	Sikorsky S-92	Aircraft Systems	*System Limitations / Gauges*	1. The pilots assumed the oil gauge was 'simply glitching'. Why might people think it's a false alarm? 2. The gearbox could run for 30 minutes without oil, but it broke down in 11 minutes. Why is it risky to push a limit? 3. What does 'Land Immediately' signify to you? Finish the flight? Land in the nearest field?
5	Air Midwest 5481	Performance	*Weight & Balance*	1. The airline used 'average' weights for passengers. How can carrying more weight impair aircraft performance? 2. If a student mechanic tightened the cable too much because he was new, what can we learn from this? Why and when should you ask for help? 3. How does a 'tail-heavy' plane handle differently than a 'nose-heavy' plane?

6	United 173	Decision Making	*Fuel Management / CRM*	1. The plane ran out of fuel while circling to fix a gear light. What should have been the #1 priority? 2. The engineer hinted, 'We have low fuel.' What is it about 'hinting' that could be potentially dangerous in an emergency? 3. Have you ever been so focused on a task that you didn't hear someone talking? Are there other examples of not hearing something critical?
7	Liberty Helicopters *(AS350, NYC)*	Regulations	*Passenger Safety / Compliance*	1. Passengers were tied in with harnesses they couldn't open. Who is responsible for passenger briefing? 2. The pilot couldn't reach his knife to cut them free. Why is organizing your cockpit critical *before* takeoff? 3. Is it ethical to sell a 'doors-off' photo flight if it compromises safety for cool pictures?
8	Asiana 214 *(B-777, San Francisco)*	Automation	*Automation Dependency*	1. The pilots thought the computer was maintaining the speed steady, but it wasn't. Why do you always have to "fly the plane" first? 2. The sky was clear and sunny. How could being too relaxed or complacent kill you? 3. No one said "Go Around" until it was too late. What does "Go Around" mean to you?
9	Continental Express 2574 *(Embraer 120, Texas)*	Maintenance	*Maintenance Communication*	1. A mechanic had removed 47 screws. Why are 'shift notes' critical? 2. What shortcuts did the inspector take? Why are shortcuts dangerous in safety jobs? 3. If you see a tool or part left behind, what is your responsibility?
10	Pinnacle 3701 *(CRJ-200, Missouri)*	Safety Culture	*Professionalism / Hazardous Attitudes*	1. Did the pilots fly too high just to 'have fun'? Why is an airplane not a toy? 2. Were the pilots too embarrassed to tell ATC they lost both engines? What choices did they make? 3. Define 'Professional'. Is it task skill level, or is it making smart choices when no one is watching, or?

Discussion and Conclusion

The results of this study suggest that it is feasible to incorporate aviation safety into the curricula of foundational courses by introducing short in-class activities and readings that enrich students' understanding of the importance of safety in aviation operations. The in-class activities and case-based learning provided an early entry point into complex safety concepts. Across aircraft categories, recurring themes such as loss of control, flawed assumptions, and organizational influences were evident, reinforcing the systemic nature of aviation accidents. An analysis of accidents across a variety of aircraft categories may increase understanding of common issues among the transport, small airplane, and rotorcraft categories. During the in-class activities, students are not asked to memorize accident facts, but to reason through decisions, constraints, and competing priorities. This approach allows the instructor to connect the topics covered in the introduction to the aviation course to real scenarios. Case-based learning also allows instructors to surface ambiguity and uncertainty, rather than presenting safety as a checklist-driven exercise [14]. This approach aligns with contemporary safety science [12], which emphasizes adaptation and trade-offs rather than simple rule compliance.

Instructor Observations and Preliminary Insights

This section presents the lessons learned and the instructor's reflection after completing the ten case-based activities. During implementation, the instructor observed several indicators of learning effectiveness. Students demonstrated increased willingness to discuss safety-related trade-offs and in subsequent technical lessons, which may suggest transfer of safety thinking beyond the case study activities presented in the classroom. Compared to the previous semester, which used the traditional approach to present safety concepts. During the pilot study, student engagement and participation increased, and the quality of the discussion shifted from conceptual definitions and descriptive responses to more analytical ones. During the pilot study, the students referenced previous case studies when analyzing new technical concepts such as cognitive biases, expectation bias, and confirmation bias, among other safety concepts, indicating retention and application of safety lessons. These preliminary observations suggest the approach merits more rigorous assessment in future offerings.

Lessons learned during this pilot implementation, and recommendations for instructors seeking to adapt this approach, should consider the following. Each discussion took about 15-20 minutes of class time. Incorporating the ten case studies on the current syllabus did not require eliminating technical content from a 15-week semester course. Beginning the discussion with specific questions grounded in the scenario helped guide students who were unfamiliar with systems thinking approaches to have a successful discussion. The coupling of the case with the technical topic that week reinforced both the operational relevance of the technical topic as well as technical considerations for safety. Discussing accidents related to icing during the week of flight mechanics made the material more relevant to operations. Lastly, the FAA case library is organized by threat categories and operational descriptions, and it includes guided discussion questions. While an aviation-focused case library was useful for our course, engineering professors could likely leverage a library of engineering failures, such as those compiled by the Murdough Center for Engineering Professionalism at Texas Tech University [19].

The preliminary findings and the exploratory character of this study must be understood in light of the following limitations. The absence of formal pre- and post-measurements and control groups, and reliance on the instructor's observations, affects the generalizability of this pilot study. Similarly, the preliminary findings of this pilot study are based on a single semester and a single institution. The FAA's Lessons Learned [8] repository is an authoritative, official repository for analyzing and learning from aviation accidents. Repositories of accident cases in engineering, medicine, and other high-risk fields may provide similar experiences for students in other disciplines. Further research is needed to identify, categorize, update, and prepare for educational contexts and accidents related to contemporary or recent operations, such as mid-air collisions involving drones, advanced automation, and complex airspace operations. While this study focuses on aviation-related degrees, the implementation plan and pedagogical approach described in this study can be applied to other engineering degree programs. Panik et al. [15] demonstrated that safety culture attitudes vary significantly across engineering disciplines prior to workforce entry. Case-based safety learning may offer a strategy to address this variation and strengthen professional identity across programs.

The preliminary findings and instructional materials developed during this pilot study may help improve the pedagogical approaches used in aviation safety and engineering-related courses. Given the complexity of aviation technology and multimodal transportation systems, there is a need to implement diverse pedagogical strategies to help students understand operational aviation safety risks. Early exposure to real-world accident analysis may help shape students' professional identity by normalizing safety as a core operational consideration rather than an ancillary compliance requirement. While formal, longitudinal, and multi-institutional assessment of learning outcomes remains necessary, preliminary instructor observations suggest that case-based approaches may increase students' engagement and improve higher-order thinking about human factors, system interactions, and organizational influences on safety.

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