HOO-RIZON 1: SUBSCALE SOUNDING ROCKET

“SOMETHING IS WRONG”: TRACING THE LIFECYCLE OF SAFETY IN HIGH-RISK AEROSPACE SYSTEMS

A Thesis Prospectus

In STS 4500

Presented to

The Faculty of the

School of Engineering and Applied Science

University of Virginia

In Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Aerospace Engineering

By

Nikita Joy

November 4th, 2024

Nikita Joy	**Ethan Fouch**	**George Hubbard**
Ben Cohen	**Youchan Kim**	**Jacob Lewis**
Tyler MacFarlane	**Jean-Pierre Manapsal**	**Connor Owens**
Omid Sayyadli	**Swedha Skandakumar**	**Laurel Supplee**
Christian Vergason	**Kushi Sethuram**	

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

ADVISORS

Caitlin D. Wylie, Department of Engineering and Society

Haibo Dong, Department of Mechanical and Aerospace Engineering

Introduction

On September 12th, 1962, a crowd was forming in the Rice University stadium. Students gathered in the rafters, fanning themselves in the humid Texas heat with folded pamphlets to watch President John F. Kennedy speak.

Holding onto the podium and taking sharp but directed glances, the President emphasized the need for the next generation of engineers to continue to innovate and pioneer not only because they can, but because with the hardships came high rewards.”The growth of our science and education” he states, “will be enriched by new knowledge of our universe and environment, by new techniques of learning and mapping and observation, by new tools and computers for industry, medicine, the home as well as the school.” (Kennedy, 1962)

60 years ago, Kennedy had captured the essence of aerospace engineering’s purpose: to tackle humanity’s greatest challenges with unwavering determination and optimism. Today, one could argue the determination stands, but the optimism has wavered as the aerospace industry stands at the crossroads of unprecedented challenges and opportunities. As global demands for advanced space technologies grow, the field is experiencing a rapid shift in priorities, driven by the increasing focus on space exploration, commercialization, and sustainability. At the same time, the work environments of aerospace engineers are becoming increasingly complex, characterized by compressed timelines, resource constraints, and mounting pressures to innovate. These changing conditions often lead to a deprioritization of safety—historically the bedrock of aerospace engineering. Engineers, faced with competing demands, may inadvertently compromise safety standards in the pursuit of performance or expedience, creating significant risks for both industry stakeholders and the public.

Compounding this challenge is the gap in aerospace education. Many academic programs are not evolving at the pace required to address the growing importance of space technology. While safety and technical rigor remain focal points in the curriculum, there is an urgent need for capstone projects and hands-on learning opportunities that reflect the realities of modern space-focused engineering. These experiences are essential to equip graduates with the skills and mindset necessary to excel in the space sector, where innovation must coexist with rigorous safety protocols.

This paper explores the intersection of these challenges, examining how changing work environments and shifting industry priorities are affecting safety practices while highlighting the critical role of updated aerospace curricula in addressing the growing demand for space technology expertise. By identifying gaps and offering actionable recommendations, this discussion underscores the importance of fostering an aerospace workforce that is not only adaptable and innovative but also unwavering in its commitment to safety

---

Technical Topic

In 2022, the Under Secretary of Defense R&E department defined “Space Technology” as a Critical Technology Area (CTA) as part of their National Defense Strategy, highlighting the existing commercial sector activity and the need for expansion to maintain US technological advantage (USD R&E, 2022). In turn, there is a growing trend among university aerospace engineering programs to expand student interest in spacecraft design. The Bureau of Labor Statistics expects the employment of aerospace engineers to grow 6% from 2023-2033–faster than the average for all occupations– with an average of 4,200 openings projected each year

(BLS, 2024). With this growth, the industry expects a two tailed problem; a *labor* shortage of aerospace engineers, and a *knowledge* shortage with the incoming aerospace engineers when it comes to spacecraft design. While the labor shortage concern is an extremely complicated issue, one could argue that the knowledge shortage could be caused by a lack of space-related engineering courses in the aerospace curriculum. Additionally, there is a lack of precedence within UVA's Mechanical and Aerospace Engineering (MAE) department with the use of experiential learning models in capstones, especially in regards to building a subscale-sounding rocket. The Class of 2024 designed a rocket for their capstone, but had multiple issues that resulted in a failure to launch. Gaining experience in these design concepts through hands-on capstone work is imperative to ensuring engineers can apply their practical knowledge in the field. Thus, lessening the skill gap in their careers and ensuring the quick advancement of these technologies for future applications.

Sounding rockets are small, suborbital rockets that are usually used to carry instruments to a high enough altitude to measure/characterize the upper atmosphere. Its overall time in space is brief, usually 5-20 minutes, but they are critical for scientific research as they can be "carried out at very low cost" and "enable scientists to react quickly to new phenomena" (NASA, 2023). This capstone project, aptly titled the Hoo-Rizon 1, provides the opportunity to expand this impact on research in an entry-level way while opening the doors for future expansion of impacts from the success of this project.

Our team uses a combination of system-level and subsystem-level tools and methods to fulfill the mission goals and objectives. We have adopted (1) NASA's life-cycle management structure, (2) a systems-oriented iterative design process, and (3) numerous project, cost, and schedule management practices. Furthermore, we have adopted numerous sub-system level methods to support the Aerobody, Avionics, and Propulsion subteams. As one of our methods, our team uses NASA's project life-cycle management structure and presents our progress using three deliverables: a project pitch, a conceptual design review, and a preliminary design review. NASA uses key documents to map and organize program pre-formulation, formulation, and implementation. Given our team's two-semester time constraint, we are using a condensed version of that management structure. Furthermore, our team is using an iterative design process to create a closed-form solution that meets the mission goals and objectives. For example, we'll evaluate the rocket's max-altitude given preliminary aerobody dimensions and motor thrust curves, and we'll update those parameters accordingly. Finally, our team utilizes project management tools such as Gantt Charts, risk matrices, Google Drive, and Discord to organize and facilitate team logistics.

STS Topic

Working in a discipline where every value is treated as an absolute, failure is a multifaceted problem that can't be accounted for with a simple check of a pen due to its systematic and propagative nature. This can best be seen through the discipline of aerospace engineering, a relatively new field given most advancements have occurred in the past century. It took less than forty years to go from First Flight to the creation of the first jet powered aircraft, and then just another thirty years after to launch Apollo 11 to the moon (AIAA, n.d). Sadly, such speed of innovation comes with consequences. Failures throughout this history, including the catastrophic Challenger and Columbia disasters, have led to the creation of regulations aimed at improving safety.

The Challenger disaster in 1986 occurred when a faulty secondary O-ring seal–meant to prevent the combustion gases from releasing from the booster–failed due to record low cold temperatures at launch, leading to a catastrophic explosion just 73 seconds into flight. The first O-Ring seal was confirmed to have been broken before launch, and heavy reliance was placed on the redundant system. The Columbia disaster in 2003 involved the space shuttle disintegrating upon re-entry due to the failure of the Thermal Protection System (TPS) by a piece of foam breaking off during launch and hitting the wing, which NASA Personnel were aware had occurred (Post, 2014). These disasters resulted in the loss of 14 total crew members, and investigations into these tragedies revealed organizational failures, such as poor communication and risk management, that allowed unsafe practices to persist unchecked. The resulting reforms, such as the establishment of NASA's Office of Safety and Mission Assurance (OSMA) and requirements for independent technical oversight, were designed to address these systemic weaknesses and create safer practices within aerospace organizations.

However, this oversight system is far from perfect, and recent scandals highlight that external pressures to mitigate safety issues need to be combined with internal prioritization of safe workplace practices. The Boeing 737 aircraft scandals, in which multiple of their planes had been found to harbor manufacturing defects, led to increased scrutiny of their manufacturing line and their 'business-first' prioritization practices. Specifically, interest has risen with the idea of safety culture, with the Department of Transportation through the FAA stating "There must be a shift in the company's safety culture to holistically address its systemic quality assurance and production issues" (Whitaker, 2024). Safety culture in this context is defined as an organization's values, approaches, and behaviors when addressing safety concerns from the CEO to the shop floor. The factors that can cause a lapse in good safety culture are hard to quantify, as it is a very human-centric topic. However, the perception of safety culture within the aerospace industry is extremely important to address, as failure to do so could create an environment in which human life is not prioritized in the design space and can result in detrimental effects down the line.

In my STS paper, I will analyze the Challenger and Columbia disasters from a safety culture perspective, utilizing Dr. Diane Vaughan's idea of the "Normalization of Deviance" as my theoretical framework (Vaughan, 1996). I will look into workplace practices that propagate the normalization of deviance, and devise a theoretical process that I believe would explain the eventual normalization of bad safety practices. To do this, I plan on analyzing and applying ideas such as the CollingRidge Dilemma and Zimbardo's "Bad Apples, Bad Barrels, and Bad Barrel Makers" schema (Collingridge, 1982; Zimbardo 2007), . Additionally, I will compare and contrast Safety Climate with Safety Culture, and briefly explore the relationship between the two when it comes to internal and external workplace pressures. By the end of my research, I hope to help identify factors that can influence aerospace safety culture so that further researchers could create metrics and plans to help mitigate the risks that bad safety culture creates.

Conclusion

In conclusion, my STS and technical papers address the socio-technical challenge of advancing aerospace technology in an innovative yet safe manner. By examining the role of capstone projects like Hoo-Rizon 1, my technical paper highlights how hands-on learning equips students with critical technical skills and instills a foundational awareness of safety. Simultaneously, the STS paper explores safety culture through case studies such as the Challenger and Columbia, applying theories like Vaughan's "Normalization of Deviance" to reveal how organizational practices can lead to major failures.

Together, these topics underscore that engineering is not just about technological mastery, but about responsible innovation that considers societal well-being. We can gain a deeper understanding of how safety culture can be integrated into engineering education, preparing future engineers to prioritize safety from the outset of their careers. Ultimately, this dual focus on education and safety culture has the potential to create a pipeline of engineers who are not only technically skilled but also equipped with the ethical and practical frameworks necessary to advance aerospace technology safely. This approach could shape a future where groundbreaking innovations are achieved without compromising human life or societal trust.

References

Technical Topic: Subscale Sounding Rocket

Kim, G., Dubikovsky, S., Wang, P. H., & Sterkenburg, R. (2020). Open-ended capstone project: Designing and manufacturing of a low-cost carbon fiber reinforced composite suborbital rocket payload housing using a 3D printed core. *International Journal of Aviation, Aeronautics, and Aerospace*. doi:10.15394/ijaaa.2020.1492

This paper investigates the effectiveness of open-ended capstone projects in fostering creativity and hands-on learning in aerospace engineering. The research question explores how such projects, specifically the design and production of a carbon-fiber rocket payload housing, can enhance students' problem-solving and technical skills. The authors utilized a case-study approach, describing the project process, challenges faced, and student outcomes. The paper presents evidence from the successful completion of the project and student reflections. While the argument for open-ended projects promoting deeper learning is persuasive, the study could benefit from more formalized metrics to assess skill development. Nonetheless, the source is reliable, published in a peer-reviewed journal and authored by experienced researchers in the field of engineering education. This source taught me how open-ended capstone projects encourage students to tackle complex, real-world engineering problems, which is something that I should keep in mind for my capstone. Our capstone shares similarities with the project outlined in this paper, with a hope to provide hands-on, experiential learning and emphasize material design and manufacturing processes. However, the

focus on low-cost, 3D-printed components in Kim's project offers a unique angle compared to my project’s broader focus of following NASA/DoD design protocols to prepare students for job prospects. Compared to other sources, Kim’s work reinforces the idea of capstones as invaluable for developing problem-solving skills but introduces a more student-driven, cost-conscious approach. This might shape my argument by highlighting the benefits of integrating more open-ended, cost-effective solutions within capstone design to foster innovation

Miller, D. W., & Brodeur, D. (2002). The Cdio capstone: An innovation in undergraduate systems engineering education. *2002 American Society for Engineering Education Annual Conference and Exposition*, 7.1128.1-7.1128.12. doi:10.18260/1-2--10978

This reference explores how the CDIO (Conceive-Design-Implement-Operate) framework enhances systems engineering education through a hands-on capstone project. The research question examines whether the CDIO framework provides students with practical skills that mirror industry demands. The methods employed include qualitative analysis of student experiences and performance data from CDIO-based courses. Miller supports his argument with evidence from student feedback and academic performance, showing improved engagement and professional readiness. One concern with this source is its reliance on qualitative data, which, while valuable, could benefit from more robust quantitative analysis. However, the publication is reliable, as it comes from a recognized conference in engineering education (American Society for Engineering Education Annual Conference and Exposition), and Miller’s extensive

academic background lends credibility to the argument. From this source, I learned how the CDIO framework emphasizes experiential learning, much like the capstone project in my aerospace engineering class, which involves creating a high-powered rocket. Both emphasize applying classroom knowledge in a real-world context to develop technical and soft skills. However, the CDIO approach differs by its structured focus on systems engineering, while my project centers on aerospace engineering. Compared to other sources that discuss capstones broadly, this paper strongly aligns with arguments about the benefits of multidisciplinary collaboration, as seen in its findings on capstone confidence. It shapes my argument by reinforcing the need for capstone projects to simulate real-world engineering challenges to bridge classroom learning with industry expectations, a key aspect of my own capstone experience.

STS Topic: "Something is Wrong": Tracing the Lifecycle of Safety in High-Risk Aerospace Systems

American Institute of Aeronautics and Astronautics. (n.d.). Aerospace history timeline. Retrieved November 4, 2024, from https://www.aiaa.org/about/History-and-Heritage/History-Timeline#1900s

Bureau of Labor Statistics, U.S. Department of Labor, Occupational Outlook Handbook, Aerospace Engineers,

at https://www.bls.gov/ooh/architecture-and-engineering/aerospace-engineers.htm (visited November 29, 2024).

Collingridge, D. (1982). The social control of technology. Cambridge University Press.

Dumitru*, I. M., & Boşcoianu, M. (2015). Human Factors Contribution to Aviation Safety. *AFASES*, *1*, 49-53. Retrieved from https://www.researchgate.net/profile/Gheorghe-Savoiu/publication/347984143_SEARCHING_FOR_SHREADS_OF_ORDER_THE_STRUCTURE_OF_TODAY'S_INTERNATIONAL_SYSTEM/links/5feb57a245851553a004d0a0/SEARCHING-FOR-SHREADS-OF-ORDER-THE-STRUCTURE-OF-TODAYS-INTERNATIONAL-SYSTEM.pdf#page=51

I.M. Dumitru et al.'s paper, investigates how human factors, such as decision-making, communication, and fatigue, impact aviation safety. The research question examines whether addressing human errors can reduce aviation accidents. The authors employ a case-study approach, analyzing real-world aviation incidents and applying human factors models to demonstrate their influence on safety outcomes. Evidence is drawn from accident reports and human factors research, supporting the argument that understanding and mitigating human errors is critical to improving safety. The source seems reliable, but I have not heard much about the publishing company, which seems to be based through the Romanian Air Force. However, the argument is well-supported through detailed case analyses, though the focus could benefit from more quantitative data. This source reinforces my understanding of the human factors involved in aviation safety, aligning with my STS project on what factors to consider when exploring safety culture within aerospace engineering. Dumitru's paper emphasizes psychological and organizational elements more deeply. Compared to other sources, it offers a more

human-centered view on safety culture, complementing technical approaches found in other studies, which might shape my argument by stressing the integration of human factors in engineering safety management

Ellis, K., Prinzel, L., Krois, P., Davies, M., Oza, N., Stephens, C., & Infeld, S. (2022). A future in-time aviation safety management system (IASMS) perspective for commercial air carriers. doi:10.2514/6.2022-3220.vid

This paper explores the potential of integrating real-time data monitoring and predictive analytics into aviation safety management systems. The research question examines how IASMS can proactively identify and mitigate safety risks before incidents occur. The authors employ a systems analysis approach, reviewing existing Safety Management Systems (SMS) and proposing enhancements using advanced technologies like machine learning and big data analytics. The evidence, grounded in simulations and conceptual models, supports the argument that IASMS could significantly improve safety outcomes by enabling immediate risk detection. This peer-reviewed article is reliable, though its focus on theoretical frameworks rather than real-world application limits its current practical validation. This source complements my STS topic by emphasizing technological advancements in safety management, contrasting with sources like Sarter's focus on human error detection. It shapes my argument by highlighting the importance of combining both human factors and cutting-edge technology in enhancing aviation safety, suggesting a future where data-driven insights play a critical role in proactive safety management.

Kennedy, J. F. (1962, September 12). We Choose To Go to the Moon Speech [Speech transcript]. Rice University. https://www.rice.edu/jfk-speech#:~:text=We%20choose%20to%20go%20to%20the%20moon%20in%20this%20decade,to%20postpone%2C%20and%20one%20which

NASA. (2023, September 22). *Sounding rockets overview*. NASA. https://www.nasa.gov/soundingrockets/overview/

Panagopoulos, I., Atkin, C., & Sikora, I. (2017). Developing a performance indicators lean-sigma framework for measuring aviation system's safety performance. *Transportation Research Procedia*, *22*, 35-44. doi:10.1016/j.trpro.2017.03.005

This paper focuses on integrating Lean-Sigma methodologies to create a framework for measuring aviation safety performance, investigating how Lean-Sigma principles can enhance safety measurement by reducing variability and improving data-driven decision-making. Panagopoulos employs a case study approach, using real aviation system data to develop and test the framework. The evidence supports the argument that Lean-Sigma can provide more accurate and actionable safety performance indicators (PIs) by streamlining processes and eliminating inefficiencies. The paper is reliable, drawing on established Lean-Sigma principles and published in a peer-reviewed journal, though the lack of long-term case results limits its practical validation. This source complements my STS topic by offering a systematic approach to safety measurement, contrasting with the more qualitative safety culture studies like Von Thaden's. It shapes

my argument by suggesting that combining human factors with Lean-Sigma techniques may offer a more holistic approach to improving aviation safety performance.

Piric, S., De Boer, R. J., Roelen, A., Karanikas, N., & Kaspers, S. (2019). How does aviation industry measure safety performance? current practice and limitations. *International Journal of Aviation Management*, *4*(3), 224. doi:10.1504/ijam.2019.10019874

This article critically examines the existing methods used to assess safety in the aviation industry. The research frame centers on the effectiveness of current safety performance indicators (PIs) and their limitations. Kaspers utilizes a comprehensive review of industry practices, regulatory frameworks, and case studies to identify gaps in safety measurement, particularly in capturing latent risks and human factors. The argument convincingly shows that while PIs are useful, they often fail to reflect complex, underlying safety issues. The source is reliable, published in a respected journal and grounded in industry data, though it would benefit from more detailed recommendations for improving PIs. This source adds depth to my STS topic by highlighting the challenges in measuring safety effectively, aligning with other studies on the inadequacy of current PIs, such as Roelen's work. It supports my argument that safety measurement requires both technical indicators and human-centered (cultural) approaches.

Post, S. (2014). Space shuttle case studies: Challenger and Columbia. 2014 ASEE Annual Conference & Exposition Proceedings, 24.1094.1-24.1094.17. https://doi.org/10.18260/1-2--23027

Roelen, A. L., & Klompstra, M. (2012). The challenges in defining aviation safety performance indicators. *European Safety and Reliability Conference*. Retrieved from https://www.researchgate.net/profile/Margriet-Klompstra-2/publication/267406066_The_challenges_in_defining_aviation_safety_performance_indicators/links/5492e3d00cf2302e1d074598/The-challenges-in-defining-aviation-safety-performance-indicators.pdf

This reference explores the difficulties in establishing clear and effective performance indicators (PIs) for monitoring aviation safety. The research question focuses on identifying why current indicators often fail to provide an accurate reflection of safety performance. Roelen uses a comparative analysis of various safety models, examining limitations in current PIs and how they might not fully account for complex systems and latent risks. Evidence is drawn from industry data, regulatory frameworks, and case studies on safety oversight. The argument persuasively highlights the gap between theoretical models and practical applications, though more real-time examples of PI failures could enhance the discussion. As a publication from a respected aviation journal, it is reliable and well-researched, lending strong credibility to its findings. This source offers insight into the nuanced difficulties of measuring safety. While my project focuses on adherence to protocols, Roelen's work emphasizes the shortcomings in measuring safety performance itself, offering a different perspective. Compared to sources like Dumitru's human factors study, this article addresses more systemic, operational concerns. This complements my argument by showcasing that, while protocols are crucial, accurately measuring their effectiveness remains an ongoing challenge in safety management.

Sarter, N. B., & Alexander, H. M. (2000). Error types and related error detection mechanisms in the aviation domain: An analysis of aviation safety reporting system incident reports. *The International Journal of Aviation Psychology*, *10*(2), 189-206. doi:10.1207/s15327108ijap1002_5

This reference investigates the types of human errors and the mechanisms used to detect them in aviation. The research question focuses on identifying prevalent error types and understanding how these errors are detected and mitigated. Sarter uses an in-depth analysis of Aviation Safety Reporting System (ASRS) incident reports, categorizing errors and the detection mechanisms employed by aviation professionals. The evidence shows that communication breakdowns, misinterpretations, and procedural lapses are common error types, while early detection often relies on vigilance and cross-checks. The publication is highly credible and based on empirical data from a trusted reporting system, though its scope is somewhat narrow, focusing mainly on human errors without addressing broader systemic issues. This source informs my STS topic by emphasizing human factors in error detection, complementing studies like Dumitru's on safety culture. It shapes my argument by underscoring the importance of addressing human errors and fostering proactive safety measures within aviation systems.

Thaden, T. L., Weigmann, D. A., Mitchell, A. A., Sharma, G., & Zhang, H. (n.d.). Safety Culture in a Regional Airline: Results from a Commercial Aviation Safety Survey.

International Symposium on Aviation Psychology. Retrieved from https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=01acebd8e6cf3e4b8ac5caebbcc51f3f691f5945

This article examines the safety culture within a regional airline through a comprehensive safety survey. The research explores how internal perceptions of safety, communication, and management influence overall safety performance in a commercial aviation setting. Von Thaden uses a mixed-method approach, combining quantitative data from safety surveys with qualitative insights from interviews and observations of airline personnel. The evidence highlights discrepancies between management's safety priorities and frontline employees' experiences, suggesting that organizational safety culture plays a pivotal role in preventing accidents. The article is well-supported, with its reliability grounded in thorough survey data and reputable publication. However, it could benefit from more longitudinal data to assess long-term safety culture shifts. This source broadens my understanding of safety culture, particularly its emphasis on the disconnect between management and frontline staff, aligning with my focus on safety regulations and how they are perceived in engineering environments. Von Thaden's findings differ from sources like Roelen's, which focus on systemic safety indicators, by diving deeper into human factors and organizational behavior. This article shapes my argument by reinforcing the importance of consistent, positive safety culture across all levels of an organization, suggesting that safety cannot merely be about following protocols—it must be internalized within the workplace culture.

Under Secretary of Defense Research and Engineering. (2022). *Technology Vision for an Era of Competition*. https://www.cto.mil/wp-content/uploads/2022/02/usdre_strategic_vision_critical_tech_areas.pdf

Vaughan, D. (2010). Vaughan, Diane: The normalization of deviance. Encyclopedia of Criminological Theory. doi:10.4135/9781412959193.n269

Whitaker, M. (2024). https://www.transportation.gov/faa-oversight-boeings-broken-safety-culture-0. Retrieved from U.S Department of Transportation website: https://www.transportation.gov/faa-oversight-boeings-broken-safety-culture-0 Statement of Michael Whitaker, Administrator for The Federal Aviation Administration. Hearing before the United States Senate Committee on Homeland Security and Governmental Affairs, Permanent Subcommittee on Investigations. Took place on September 25th, 2024.

Zimbardo, P. (2008). The Lucifer effect: Understanding how good people turn evil. Random House Trade Paperbacks.

Zhang, X., & Mahadevan, S. (2021). Bayesian network modeling of accident investigation reports for aviation safety assessment. *Reliability Engineering & System Safety*, *209*, 107371. doi:10.1016/j.ress.2020.107371

This reference explores the application of Bayesian networks to analyze aviation accident investigation reports. It investigates how this modeling technique can enhance safety assessment by identifying causal relationships among contributing factors. Zhang employs a quantitative approach, constructing a Bayesian network model based on data

from multiple accident reports to assess risk factors and their interdependencies. The evidence demonstrates that this method can effectively uncover hidden patterns and provide a more nuanced understanding of accident causes. The publication is reliable, appearing in a peer-reviewed/established journal, and leveraging robust statistical methodologies, although it could benefit from case studies demonstrating practical applications. This source would enrich my STS paper by offering a data-driven approach to safety analysis, aligning with the emphasis on technological advancements found in other studies. It illustrates the potential of statistical modeling in identifying risk factors, reinforcing the need for integrating data analytics with traditional safety management practices in aviation.