DOT/FAA/AM- 24/22

Office of Aerospace Medicine

Washington, D.C. 20591

Human Factors Analysis of Helicopter Air Ambulance Accidents, Incidents, and Events (2013-2023)

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November 2024

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Technical Report Documentation

1. Report No. DOT/FAA/AM- 24/22	
2. Title & Subtitle Human Factors Analysis of Helicopter Air Ambulance Accidents, Incidents, and Events (2013-2023)	**3. Report Date** November 2024 **4. Performing Organization Code**
5. Author(s) Hannah M. Baumgartner, Justin Durham, Rebecca DiDomenica, Peter T. Hu	**6. Performing Org Report Number** Input text here
7. Performing Organization Name & Address Civil Aerospace Medical Institute 6500 S. McArthur Blvd. Oklahoma City, OK 73169	**8. Contract or Grant Number**
9. Sponsoring Agency Name & Address Federal Aviation Administration (AFS-220) 800 Independence Ave. SW, Washington, DC 20591	**10. Type of Report & Period Covered**
11. Supplementary Notes	

12. Abstract

Helicopter Air Ambulance (HAA) operations are subject to unique risks due to their time-sensitive and safety critical nature. The Civil Aerospace Medical Institute (CAMI) completed analyses of the National Transportation Safety Board's (NTSB) Case Analysis and Reporting Online (CAROL) aviation accident and serious incident database and the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS) data over a 10-year span. In total, 102 ASRS reports, 53 final NTSB accident reports, and 3 final NTSB incident reports involving HAA from 2013 to 2023 that occurred within the United States (U.S.) were coded for human factors and organizational risk factors. The analyses identified several human factors risks impacting HAA flightcrew related to situation awareness (SA), judgment and decision-making (JDM), adherence to procedures, and experience and training. Further, organizational issues influencing HAA operations, such as communication, safety culture, and those involving operator policy and procedure, were identified. Research recommendations based on the findings broadly involve investigating techniques to improve SA, reevaluating or assessing training needs, and providing additional resources for pilots and flightcrews in HAA operations.

13. Key Word Helicopter air ambulance, accident analysis, human factors, NTSB, ASRS		**14. Distribution Statement**	
15. Security Classification (of this report)	**16. Security Classification (of this page)**	**17. No. of Pages** 35	**18. Price**

Author Note

Funding	Flight Deck Program Directive/Level of Effort Agreement between the Federal Aviation Administration NextGen Human Factors Division (ANG-C1) and the Aerospace Human Factors Research Division (AAM-500)
Conflicts of Interest	None
Author Contributions	HMB: Conceptualization, Methodology, Formal Analysis, Data Curation, Writing – Original Draft, Visualization, Project administration. JD: Methodology, Formal Analysis, Data Curation, Writing – Reviewing and Editing, Visualization. RD: Methodology, Formal Analysis, Writing – Reviewing and Editing. PTH: Methodology, Formal Analysis, Writing – Reviewing and Editing
Data Availability	Data are available online from the National Transportation Safety Board's CAROL database and the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS), or available upon request.

Acknowledgments

The authors wish to acknowledge the assistance and collaboration of the research study sponsors (AFS-220) and program manager (ANG-C1) for their feedback and guidance on the direction of this project. In particular, thank you to Nolan Crawford, Tom Luipersbeck, Dr. Chuck Perala, Eddie Austrian, and Kevin Siragusa. Research reported in this paper was conducted under the Flight Deck Program Directive/Level of Effort Agreement between the Federal Aviation Administration NextGen Human Factors Division (ANG-C1) and the Aerospace Human Factors Research Division (AAM-500) of the Civil Aerospace Medical Institute.

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List of Abbreviations

Abbreviation	Definition
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
CAMI	Civil Aerospace Medical Institute
CFIT	Controlled Flight into Terrain
CRM	Crew Resource Management
FFP	Failure to Follow Procedures
HAA	Helicopter Air Ambulance
HFACS	Human Factors Analysis and Classification System
IFR	Instrument Flight Rules
IIMC	Inadvertent Entry into Instrument Meteorological Conditions
IMC	Instrument Meteorological Conditions
JDM	Judgment and Decision-Making
LOC	Loss of Control
Mx	Maintenance
NASA	National Aeronautics and Space Administration
NMAC	Near Mid-Air Collision
NTSB	National Transportation Safety Board
NVGs	Night Vision Goggles
OCC	Operational Control Center
SA	Situation Awareness
VMC	Visual Meteorological Conditions

Executive Summary

Helicopter Air Ambulance (HAA) operations are subject to unique risks due to their time-sensitive and safety critical nature. Research has identified multiple risks, primarily involving human factors, that contribute to HAA accidents and serious incidents. For example, HAA operations involve flights to/from unimproved sites, flights at lower altitudes with many obstacles, operate in a variety of environments, and often offer on-call 24-hour services. Further investigation into what human factors and other risks contribute to HAA accidents and incidents is particularly important given the addition of new regulations and guidance material for HAA operations. However, little research has analyzed HAA accident and incident databases from a human factors perspective.

The Civil Aerospace Medical Institute (CAMI) completed analyses of the National Transportation Safety Board's (NTSB) Case Analysis and Reporting Online (CAROL) aviation accident and serious incident database and the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS) data over a 10-year span. In addition, this report provides research opportunities that may inform mitigations of identified human factors risks in HAA operations, which are informed by previous reviews of HAA regulatory and guidance materials and scientific literature.

In total, 102 ASRS reports, 53 final NTSB accident reports, and 3 final NTSB incident reports involving HAA from 2013 to 2023 that occurred within the United States (U.S.) were coded for human factors and organizational risk factors. The analyses identified several human factors risks impacting HAA flightcrew related to situation awareness (SA), judgment and decision-making (JDM), adherence to procedures, and experience and training. Further, organizational issues influencing HAA operations, such as communication, safety culture, and those involving operator policy and procedure, were identified.

Risk factors are identified in Table 1 and encompass a range of human factors (e.g., SA, JDM, adherence to procedures, and experience and training) and organizational factors (e.g., communication, safety culture, and operator policy and procedure). Research recommendations based on the findings broadly involve investigating techniques to improve SA, reevaluating or assessing training needs, and providing additional resources for pilots and flightcrews in HAA operations.

Table 1
Analysis Topics and Future Research Opportunities

	Summary of Human Factors Topics & Future Research Opportunities
1	Situation Awareness (SA) • Investigate current visual scanning techniques and behaviors among HAA pilots • Examine the usefulness of new assistive technologies, such as head-worn displays (HWDs) and head-up displays (HUDs), in maintaining SA in HAA operations
2	Judgment and Decision-Making (JDM) • Examine operator and/or HAA pilot training on the identification and utilization of reliable, accurate, and authoritative weather sources • Examine the potential benefits of leadership and command training on JDM
3	Adherence to Procedures • Examine and identify potential vulnerabilities that may have an impact on adherence to procedures in HAA operations
4	Experience and Training • Examine the current state of training for helicopter differences • Examine the current state of training for unique/non-normal operating conditions
5	Communication • Examine the current state of Crew Resource Management (CRM) trainings for medical team members and Operational Control Center (OCC) specialists in HAA operations
6	Safety Culture • Evaluate the attitudes, perceptions, and behaviors within HAA operations to identify potential influences on safety outcomes
7	Operator Policies and Procedures • Examine potential challenges operators face with the development, coordination, dissemination, and implementation of policies/procedures

Background

Helicopter Air Ambulance (HAA) operations are responsible for the transport of medical personnel and patients or donor organs for the purpose of medical treatment (14 C.F.R. § 135.601). HAA operators typically offer on-call, 24-hour services to communities and hospitals. The time-critical nature and logistical considerations of HAA flight requests, along with the adverse effects of shiftwork on safety performance, present a unique set of safety considerations that can impact pilots, medical flightcrew, and patients alike (see Baumgartner et al., 2023). Further research and analysis to better understand the underlying human factors-related risks involved in HAA accidents and incidents may improve safety in HAA operations.

Greenhaw and Jamali analyzed HAA and non-HAA fatal helicopter accidents from 2008 to 2017 using the National Transportation Safety Board's (NTSB) aviation accident database and found that fatal accidents in HAA operations are twice as common compared to non-HAA operations (Greenhaw & Jamali, 2021). This study also found that low visibility or darkness and pilot judgment and decision-making were two primary contributing factors to HAA fatal accidents documented by the NTSB (Greenhaw & Jamali, 2021). Other researchers have conducted literature reviews and made recommendations to improve training in HAA operations using Crew Resource Management (CRM) principles (Rowley & Bryant, 2017). Moreover, Baumgartner et al. (2023) reviewed and annotated literature from 2014 to 2022 involving HAA operations to identify industry-specific human factors risks, including pilot fatigue, environmental conditions, training, and organizational culture.

Purpose

The purpose of this report is to provide information to enhance the FAA's understanding of potential vulnerabilities and risk from a human factors perspective in HAA operations. Human factors and organizational risks in HAA operations were investigated by evaluating NTSB accident and incident reports and events voluntarily reported to the National Aeronautics and Space Administration's (NASA) Aviation Safety Reporting System (ASRS) database. Analyzing the available data helps inform recommendations for the mitigation of future human factors-related accidents and incidents.

This report presents the findings of analyses of HAA-related report data using NASA's ASRS online database and the NTSB accident and serious incident database for events that occurred from 2013-2023. Results from both analyses identify underlying human factors and organizational factors involved in HAA accidents and incidents with the goal of informing safety recommendations for mitigations. This work is especially timely to assess changing industry risks after the addition of new rules specific to HAA operations (14 C.F.R. § 135 Amendment No. 135-141; 14 C.F.R. § 135; 14 C.F.R. § 91).[1]

[1] The Federal Aviation Administration (FAA) released a technical amendment to Helicopter Air Ambulance, Commercial Helicopter, and 14 C.F.R. § 91 Helicopter Operations effective on January 10, 2018 (83 F.R. 1188). This amendment does not add to nor modify existing regulations outlined in the 2014 final rule.

Data Sources and Analysis

ASRS Reports

CAMI researchers completed an analysis of documented data in ASRS reports that were submitted to the NASA ASRS database between 2013-2023 and involved air medical operations. Results were then filtered to include only rotorcraft-related reports. Specific search criteria used for the ASRS analysis can be found in Appendix A.

ASRS reports provide a unique source of information about the HAA industry by allowing the submitting party to anonymously report near misses, close calls, and other safety related events not otherwise captured through other reporting systems. These reports provide useful information about emerging risks within operations and are often benefited by the details included from first-person perspectives. However, analyses of ASRS reports rely on the reporting of safety data that are naturally limited by what the submitter chooses to report and what information the submitter has available to them. In addition, the reports detail the viewpoints of the submitters, who are not necessarily trained observers and who may have also been involved in the event. Finally, the anonymous nature of submissions also means that follow-up verification and assessment with submitters are not possible.

Overall, while the number of voluntary safety reports has been shown to correlate with the occurrence of aviation accidents (Gao et al., 2021), the information provided by ASRS reports does not necessarily represent the real-world frequency of accidents and serious incidents within HAA operations. This indicates that ASRS reports offer important insights into current operational trends but should not be treated as a standalone source, as they rely on voluntary submission. Further, the information that can be gathered from ASRS reports provides useful insights when paired with NTSB reports.

NTSB Accident and Serious Incident Reports

CAMI completed an analysis of documented data in final NTSB reports for accidents and serious incidents that occurred between 2013-2023 that occurred in air ambulance operations and in rotorcraft. Specific search criteria used in the NTSB CAROL database can be found in Appendix A.

Accidents and serious incidents are formally investigated by the NTSB, which provides detailed information through the publication of final reports. These final reports include a variety of objective data points along with subjective perspectives that are combined to provide a more holistic understanding of the accident or serious incident. During its investigations, the NTSB interviews involved individuals, gathers context about conditions within which the accident or serious incident took place, and offers a formal observation about the root causes and contributing factors to the accident. Sometimes, however, the flightcrew or individuals directly involved in the accident cannot be interviewed, leading to a lack of first-person narratives. This limits the insights that can be made about pilot judgment and decision-making, situation awareness, and internal pressures that the pilot may be facing, and ultimately affects the ability of the report narrative to accurately recreate the conditions of the accident or serious incident. Despite this constraint, the NTSB's accident and serious incident reports can offer comprehensive details about the events and context leading up to an accident or serious incident.

Report Analysis

NASA and NTSB both employ a coding scheme to evaluate reports for human factors risks. However, the coding schemes differ between the ASRS and NTSB databases, and little information is provided to assess rating consistency within each database. While environmental and descriptive data from these coding schemes were maintained in the present analysis (e.g., lighting conditions, phase of flight), a separate coding scheme that integrated both NASA and NTSB data was developed to identify human factors issues. Rather than leveraging an existing but more general accident analysis taxonomy (such as the Human Factors Analysis and Classification System [HFACS]; Shappell & Wiegmann, 2000), the current categories were identified for the coding scheme based on previous research on ASRS reports (Cardosi & Lennertz, 2017; DiFiore & Cardosi, 2006) and combined accident and incident analyses (PARC, 2014). The content analysis was further tailored to HAA risk mitigation and oversight needs based on subject matter expert feedback. Overall, this approach gives not only an overview of human factors-related risks and their consequences but also identifies safety aspects that would not be fully captured by either ASRS or NTSB reports alone.

This analysis is separated into two main sections. First, the “Accident and Incident Summaries” section provides general information about the reports analyzed, including descriptive data from the ASRS and NTSB databases, such as lighting conditions and the outcomes of the accidents and incidents. The “Human Factors Analysis Findings and Future Research Directions” section provides a summary of the human factors related to flightcrew actions and additional findings that focus on organizational culture among HAA operators.

Accident and Incident Summaries

Analyzed Reports

Search criteria used to identify ASRS reports and NTSB accident and serious incident reports can be found in Appendices A and B, respectively. Ultimately, the analysis included a total of 158 reports, including 102 ASRS reports, 53 NTSB accident reports, and 3 NTSB serious incident reports, detailing HAA operations within all 50 U.S. states from 2013-2023. All 3 NTSB serious incidents were mainly attributed to maintenance (Mx) errors, policy/procedural issues, or aircraft failure. Therefore, while these three serious incidents are included in the current accident and incident summaries, they were not included in the “Flightcrew Analysis Findings and Future Research Directions” section. Supplemental figures relating to ASRS and NTSB reports can be found in Appendices C and D.

Personnel

The identified ASRS and NTSB reports were coded for the contributing personnel factors, including (a) pilot or flightcrew, (b) maintenance (Mx) personnel, and (c) air traffic controllers (ATCs; see Figure 1 and Figure 2). Flightcrew was the most frequently identified personnel factor across both ASRS reports (*n* = 81; 79%) and NTSB accidents (*n* = 36; 68%). Notably, only one of the three NTSB serious incident reports was related to flightcrew actions (33%). A smaller portion of ASRS reports (*n* = 18; 18%), NTSB accident reports (*n* = 8; 15%), and NTSB serious incident reports (*n* = 2; 66%) involved Mx. Only ASRS incidents involved ATCs (*n* = 17; 17%).

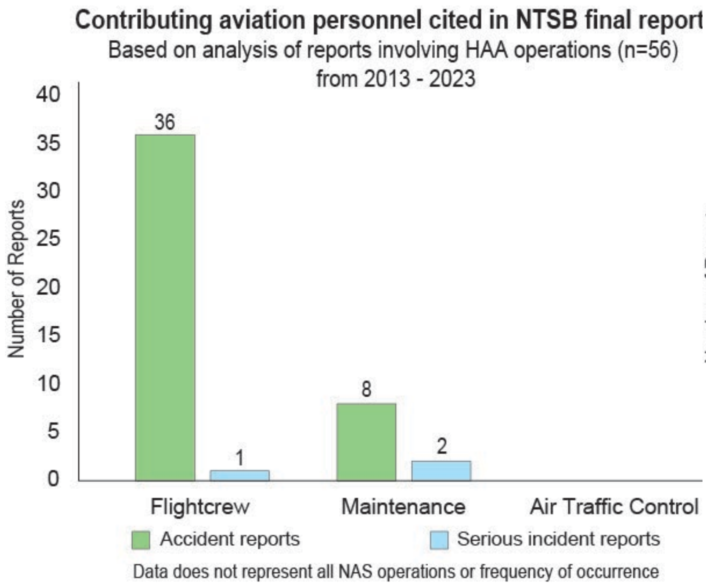

Figure 1. Personnel Related to Accident/Incident in NTSB Report

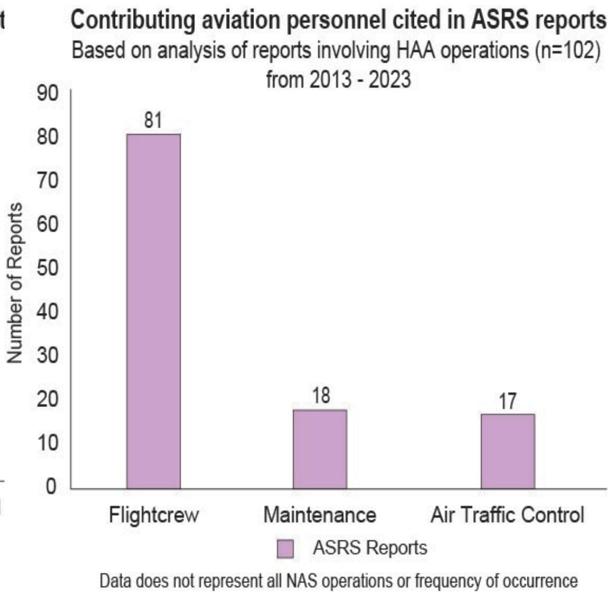

Figure 2. Personnel Related to Event in ASRS Report

Briefly, Mx-related reports generally indicated failures to follow procedures (FFPs; see Key et al., 2022) in both NTSB reports and ASRS reports. ATC-related events only occurred in ASRS reports and largely involved communication issues. For example, ATC communication issues included pilots misunderstanding issued clearance or pilots expressing an inability to get in contact with ATC over a busy frequency. Human factors risks identified from reports related to flightcrew are discussed below in the “Flightcrew Findings and Future Research Directions” section.

Environmental Risk Factors

Next, all 158 ASRS and NTSB reports were assessed for environmental risk factors. Environmental risks were identified in 19 of the 53 NTSB accident reports (36%), 1 of the 3 NTSB serious incident reports (33%; Figure 3), and 13 of the 102 ASRS reports (13%; Figure 5). Generally, weather-related risks included fog, notable wind conditions, and ceilings being lower than expected. Overall, instrument meteorological conditions (IMC) were reported in 5% of ASRS reports (*n* = 5) and 9% of NTSB accidents (*n* = 5). Other environmental factors that were noted include mountainous terrain (identified in 9% of NTSB accidents [*n* = 5]) and bird strikes (identified in 8% of NTSB accident reports [*n* = 4]).

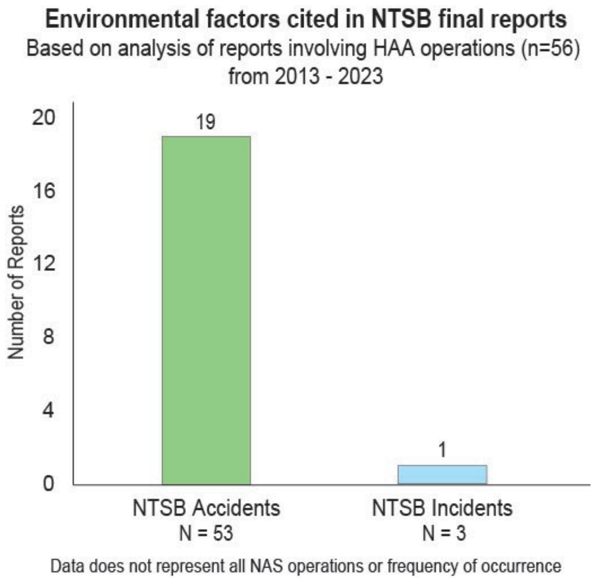

Figure 3. Environmental Factors in NTSB Reports

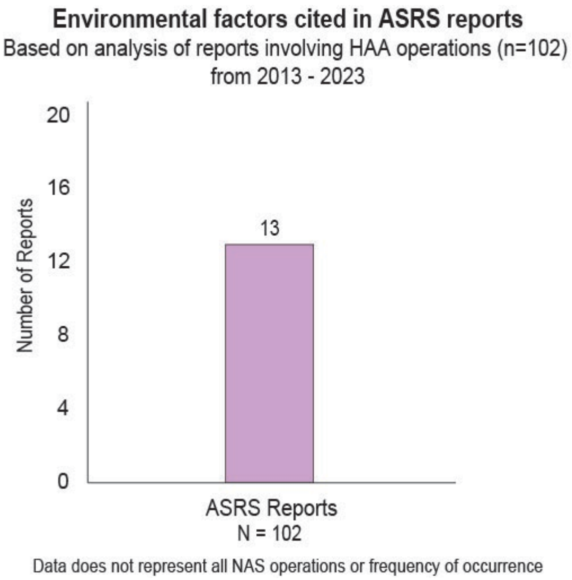

Figure 4. Environmental Factors in ASRS Reports

Nighttime lighting conditions were reported in 27% of ASRS reports (*n* = 28) and 36% of NTSB accidents (*n* = 19). Notably, some nighttime accidents and incidents may have been related to spatial disorientation. For example, one NTSB accident report stated, "*the pilot's decision to perform visual flight rules flight into night instrument meteorological conditions, which resulted in LOC due to spatial disorientation*" might have been a causal factor (NTSB Accident Number: ERA16FA140). Although not explicitly stated in all reports, it may be speculated that spatial disorientation illusions contributed to several additional nighttime accidents and incidents, given the correlation between spatial disorientation and night flying with the use of night vision goggles (NVGs; Braithwaite et al., 1998; Durnford et al., 1995).

Consequences

Consequences were first identified across NTSB and ASRS reports, then classified into Loss of Control (LOC), System or Component Failure, Controlled Flight into Terrain (CFIT), Near Mid Air Collision (NMAC), or Adverse Patient Outcome. For NTSB reports, LOC, System or Component Failure, and CFIT events were documented by the "Defining Event" section of the report or explicitly stated in the "Probable Cause and Findings" section. In ASRS reports, these same categories were coded based on explicit mentions of these events in the content of the ASRS report. Due to a trend of explicit mentions of NMACs in ASRS reports, this code was also added. Adverse patient outcomes were evaluated based on the narrative texts of both NTSB and ASRS reports. Together, these consequences are detailed in Figure 5 and Figure 6.

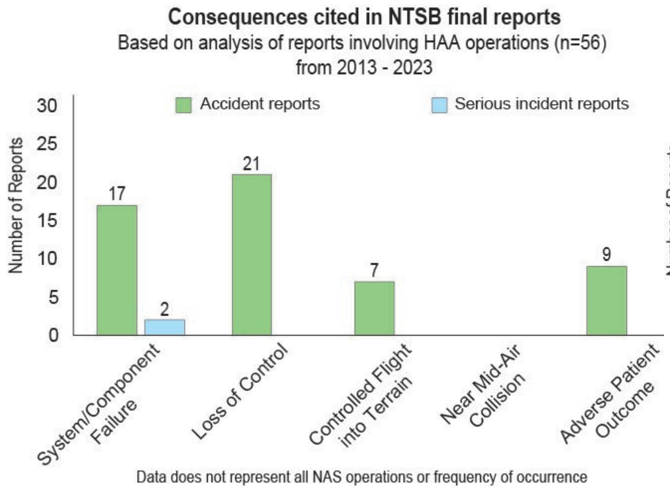

Figure 5. Consequences in NTSB Reports

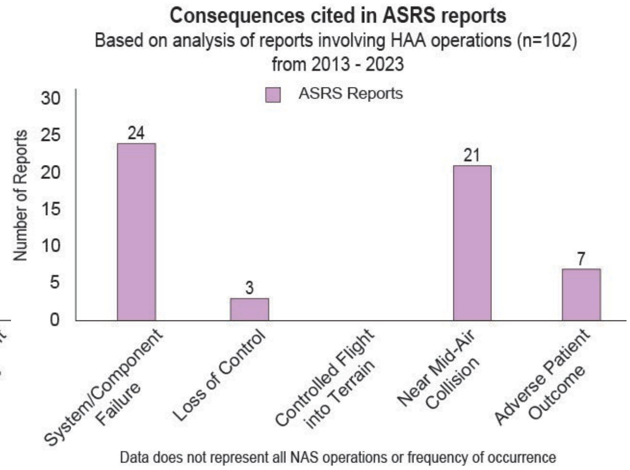

Figure 6. Consequences in ASRS Reports

Failure of System or Component

Among the HAA-related ASRS reports, the most common consequence identified was a system or component failure, as found in 24 (24%) reports (Figure 6). This involved failures or changes to some part of the aircraft system noted by the submitter. A malfunction may have occurred due to a Mx issue, an issue during flight, or other unidentified reasons. As one example, the attitude indicator on the primary flight display failed during flight and caused an ongoing audible alert, though the pilot was able to use the attitude indicator on the multifunction flight display (ASRS Report Number: ACN 1739476). Other examples of system or component failures that pilots were able to successfully navigate around included engine fires on approach, which required an engine shut down and diversion (ASRS Report Number: ACN 1727666), and the loss of tail rotor pitch control due to a Mx error for which a pilot successfully executed a precautionary landing (ASRS Report Number: ACN 1550746).

For NTSB accidents, failure of an aircraft system or component was identified in 17 of the 53 NTSB reports (32%; Figure 5). Among these 17 accidents, five occurred due to pilot lack of adherence to procedure, and seven occurred due to Mx-related errors. These accidents often occurred because the failure was hard to detect, often due to the pilot's lack of situation awareness, or because correcting the failure was challenging for the pilot, ultimately resulting in accidents. Specific examples of the types of components involved in these accidents include the failure of fuel control unit drive bearings, failure of power turbine thrust bearings, and a disconnection of an engine exhaust duct.

Loss of Control (LOC)

Loss of control (LOC) occurred in only three ASRS reports (3%), and all pilots were able to regain control of the aircraft (see Figure 6). LOC occurred in 21 NTSB accidents (40%), nine of which were fatal accidents (Figure 5). Within the NTSB accidents, LOC frequently happened during dark night conditions (n = 9) or was associated with other weather conditions, such as notable wind (n = 4) or IMC (n = 3). Of note, while all pilots for the LOCs that occurred during IMC conditions were instrument-rated, 2 out of 3 of these pilots had only minimum recent experience flying in instrument conditions in the 90 days before the accident (<3 hours). These LOCs frequently occurred during takeoff or landing portions of flights (n = 15). Finally, a smaller number of LOC-related accidents occurred due to bird strikes (*n* = 1) or pilot medical events (*n* = 2).

Controlled Flight into Terrain (CFIT)

Controlled flight into terrain (CFIT) was identified in seven (13%) NTSB accidents (see Figure 5). CFIT included unintentional collisions with terrain while the aircraft was under positive control, one of which was fatal. Of these, four accidents occurred in mountainous terrain, and three occurred due to collision with the ground while avoiding nearby obstacles. More of these collisions occurred during the landing portion of flights (*n* = 4) relative to the en route cruise phase (*n* = 2) or takeoff phase (*n* = 1). Notably, one of these accidents was also associated with inadvertent entry into IMC (IIMC). CFIT was not identified in any ASRS reports.

Near Mid-Air Collisions (NMAC)

Near mid-air collisions (NMACs) were identified in 21 (21%) ASRS reports (see Figure 6). These included incidents with potential collision risk due to reported proximity within 500 feet of another aircraft, frequently within the vicinity of helipads at hospitals or during flights with unmanned aerial vehicles. NTSB accidents and incidents did not include NMACs.

Adverse Patient Outcomes

Events that adversely impacted patient outcomes were identified in seven ASRS reports (7%) and in nine NTSB accident reports (17%). These included accident or incident reports that explicitly noted patient transportation being delayed or patient injury, regardless of the cause of the accident.

Summary of Human Factors Analysis Findings and Future Research Directions

Flightcrew Analysis Findings and Future Research Directions

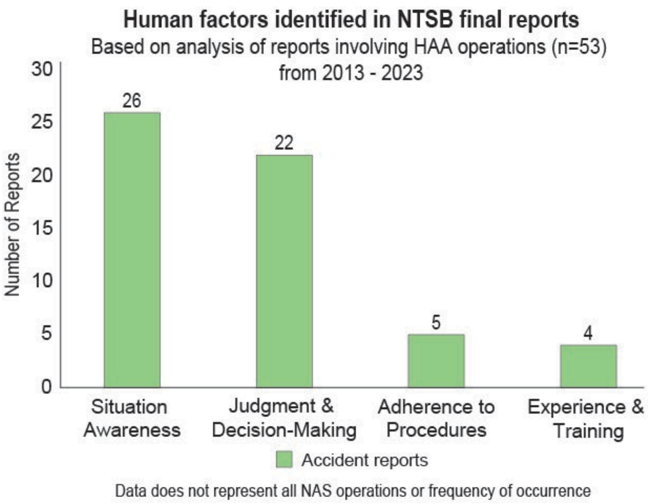

Figure 7. NTSB Reports with Human Factors Findings

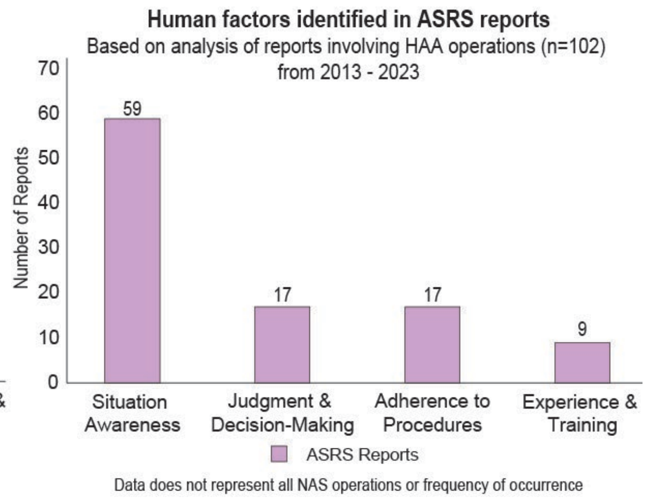

Figure 8. ASRS Reports with Human Factors Findings

Finding 1. Situation Awareness (SA)

SA was the most identified factor in NTSB accident reports (*n* = 26; 49%; Figure 7) and ASRS reports (*n* = 59; 58%; Figure 8). In these reports, pilots were found to have lacked awareness of conditions inside or outside of the flight deck. For example, lack of SA was observed in cases where pilots failed to notice external obstacles or other aircraft, and an example of lack of SA within the flightdeck occurred in one case where an iPad was inadvertently left in a location that restricted lateral movement of the cyclic (ASRS Report Number: 1514837). Within ASRS reports, a lack of SA led to deviations from planned routes, airspace violations, and NMACs near hospital helipads or involving unmanned aerial vehicles. Within NTSB accidents, a lack of SA often led to LOC.

For both NTSB accidents and ASRS incidents, lapses in SA most often occurred during the approach or landing phase of flight. For example, one NTSB accident report cited as probable cause "*The pilot's inability to identify the power line during the initial approach in night visual meteorological conditions and his subsequent failure to avoid the power line once he identified it on final approach.*" (NTSB Accident Number: CEN15LA066). Related to this stage of flight, 4 out of the 5 accidents that involved missed approaches also included errors in SA.

Issues with SA have previously been associated with accidents in HAA operations and, overall, are connected to errors made by pilots (Lee et al., 2007; Wickens et al., 2007). In the current analysis, several SA errors contributed to an LOC situation. Regaining SA in a LOC situation is critical, and possible countermeasures include Tactile Situational Awareness Systems (Rupert et al., 2016). Additional mitigations for SA issues include changes to visual scanning techniques (Yu et al., 2014), reducing pilots' mental workload to the extent possible (Lin & Lu, 2016), and using advanced visual technologies meant to assist in the identification of obstacles (Ernst et al., 2021).

While issues with SA often stemmed from not recognizing risks outside of the flight deck, certain reports in the current analysis also highlighted vulnerabilities in SA *within* the flight deck itself. For example, one ASRS incident report noted, "*A119 pilot reported that an iPad was inadvertently left between the center console and the cyclic temporarily restricted lateral movement of the cyclic*" (ASRS Report Number: ACN 1514837). Similarly, one NTSB accident report noted, "*Contributing to the accident was the pilot's improper decision to activate the annunciator panel's dimming function during dusk, which prevented him from seeing the illuminated fuel transfer pump caution light indicating that the pumps were off and the illuminated caution lights for low fuel in the supply tanks"* (NTSB Accident Number: CEN17FA252).

Research Opportunities

HAA Pilot Visual Scanning Baseline

Attention and where a pilot's attention is being directed is a key factor in maintaining SA while in flight (Wickens et al., 2007). Visual attention and associated visual scanning patterns within the flight deck are, therefore, integral aspects of supporting sustained SA (Yu et al., 2014). Indeed, eye movements, fixation rates, and pupil sizes are all metrics to evaluate SA during simulated operations (van der Merwe et al., 2012). Differences in visual scanning patterns may lead to different capacities for SA across pilots. For example, some research has indicated that experienced pilots demonstrate better SA than novice pilots (in terms of visual scanning) and spend more time looking within the cockpit (Yu et al., 2016). This could suggest that training for more novice pilots should focus on SA within the cockpit as well. However, without a full examination of the current techniques and visual scanning behaviors in HAA pilots, it is unclear what the most effective visual scanning techniques may be for maintaining SA.

Overall, there is a research opportunity to **investigate current visual scanning techniques and behaviors within HAA pilots**, which would provide a baseline of current effective techniques and potential vulnerabilities or deficiencies.

Emerging Head-Worn Display (HWD) Technologies

Given the complex and changing visual environment that pilots must be consistently scanning throughout flight, new technologies such as head-worn displays (HWDs) may offer relief to pilots in managing that attentional demand and, therefore, support better sustained SA. HWDs may be particularly useful in helping pilots identify potential obstacles in their environment (Ernst et al., 2021), a key component of effective visual scanning. Furthermore, head-up displays (HUDs) have been found to increase perceived SA and decrease perceived workload in civilian helicopter pilots when landing during degraded visual environments (Stanton et al., 2017).

Therefore, a research opportunity exists to **examine the usefulness of new assistive technologies, such as HWDs and HUDs, in maintaining SA in HAA operations** and the related effects on safety.

Finding 2. Judgment and Decision-Making (JDM) Errors

Judgment and decision-making (JDM) errors were identified in 22 NTSB accident reports (42%; Figure 7) and 17 ASRS reports (17%; Figure 8). These included unsafe actions due to a decision or known action of an HAA operator. Examples of a JDM error within ASRS reports included proceeding into flight without adequate communication with ATCs, flying without completing a required risk assessment, or overflying an aircraft due for Mx. Within NTSB reports, JDM-related accidents and serious incidents included errors with more immediate safety-related outcomes, and 6 out of the 7 accidents and serious incidents with CFIT as an outcome included JDM errors.

JDM errors frequently occurred while en route. For example, one NTSB accident report stated, "*The pilot's improper decision to review an aircraft logbook while en route, which resulted in controlled flight into terrain*" (NTSB Accident Number: ERA23LA147). Similarly, other JDM errors were also related to lack of experience or inadequate training: "*Contributing to the accident was the pilot's decision to perform low-level, high-speed maneuvers through mountainous terrain"* (NTSB Accident Number: WPR16FA040). Additionally, some of these JDM errors were also associated with adherence to approved procedures.

Several accidents and reports included JDM errors related to weather conditions. Experienced pilots have different tactics in making weather-related decisions in comparison to novice pilots (Wiggins & O'Hare, 1995), and HAA pilots with less than 6 years of experience are more likely to have fatal outcomes due to weather than pilots with more than 6 years of experience (Aherne et al., 2018). In previous research, JDM related to entering IMC conditions was found to be a particular risk factor for fatality in helicopter operations (de Voogt et al., 2020). This is notable because while pilots use a variety of tools to check weather when making go or no-go decisions, many pilots report a lack of accurate weather information to inform JDM during flight (Spiers et al., 2021).

Research Opportunities

Weather-Related Decision-Making

Given the observed relationship between JDM errors and weather conditions, weather-related resources and associated training to effectively use those resources is an important safety consideration in HAA operations. Further, while some errors in JDM involved go or no-go decisions, errors may also be made when deciding whether to continue a flight or deviate from plans due to changing circumstances. Resources such as up-to-date weather information should be available at all times of flight to make rapid decisions and changes to plans if necessary.

Therefore, a research opportunity exists to **examine operator and/or HAA pilot training on the identification and utilization of reliable, accurate, and authoritative weather sources**. This may inform the identification of vulnerabilities and potential mitigations.

Leadership and Command Training

In commercial fixed-wing operations, the FAA has Advisory Circular (AC) 121-42 Leadership and Command Training for Pilots in Command that includes specific guidance on decision-making. While the above guidance is noted to also be useful to part 135 operations, there is no such guidance specific to HAA operations.

Thus, a research opportunity exists to **examine the potential benefits of leadership and command training on JDM** in HAA operations.

Finding 3. Adherence to Procedures

Adherence to procedures was identified in 17 ASRS reports (17%; Figure 8) and 5 NTSB accident reports (9%; Figure 7). Within ASRS reports, issues with adherence to procedures often occurred due to failures in completing appropriate documentation and conducting pre-flight risk assessments. NTSB accident reports included similar issues with adherence to procedures, such as pilots failing to complete pre-flight duties. For example, one NTSB final accident report noted that "*Contributing to the accident were the pilot's failure to conduct preflight performance calculations*" (NTSB Accident Number: GAA18CA571). However, when procedures were not followed in HAA operations mentioned in NTSB reports, the outcomes were worse, often including instances of a failure of an aircraft system or component (n = 3), LOC (n = 1), and CFIT (n = 1).

Some cases revealed a practice of ignoring established procedures, suggesting broader problems with safety culture. For example, one ASRS report included: "*Helicopter Pilot reported misgivings due to suspected unapproved procedures used to return an aircraft to service*" (ACN 1756021). Previous safety culture research in HAA operations in the United Kingdom identified that bases were not fully complying with company policies and procedures, suggesting that this may be a risk in U.S. HAA operations as well (Chester et al., 2016).

Research Opportunity

Adherence to Procedures Vulnerabilities

Some reported cases of adherence to procedures may have been due to task saturation. Given the time constraints within HAA operations, completing pre-flight duties and risk assessments may increase the mental workload and stress on pilots. Depending on the patient and protocols, further paperwork is required, pre- or post-flight, to document patient status. Further, pre-flight risk assessments often involve coordination with an operator's Operational Control Center (OCC), which must approve an assessment before departure. Altogether, pilots may perceive time pressure to complete the pre-flight risk duties and takeoff as quickly as possible (see Safety Culture section below) or may feel overburdened by the requirements being asked of them before takeoff. Proper completion of these pre-flight steps is, therefore, a risk factor, as these time-sensitive processes are vital to ensuring flight safety.

Therefore, a research opportunity exists to **examine and identify potential vulnerabilities that may have an impact on adherence to procedures** in HAA operations. Examples may include workload, task management, task prioritization, and time pressure, particularly in regard to pre-flight duties and risk assessments for pilots.

Finding 4. Experience and Training

Issues with flightcrew experience and training were identified in nine ASRS reports (9%; Figure 8) and four NTSB accident reports (8%; Figure 7). Issues with experience and/or training were evaluated explicitly in cases where experience and/or training was identified either by the reporter within ASRS events or by the final report in NTSB accidents and serious incidents.

Within ASRS reports, issues with experience and training included pilots' failure to follow standard procedures due to lack of general experience (e.g., forgotten risk assessment on a training flight) and lack of experience or training in instrument flight rules (IFR) operations when encountering IMC. Specific areas of training or lack of experience identified in NTSB accident reports included helicopter differences training, lack of experience with high-density, high-altitude mountainous flying, and lack of experience in nighttime operations.

Research Opportunities

Helicopter Differences Training

Operators often make use of multiple aircraft, sometimes with very different configurations within the cockpit. Differences training is essential to ensure that pilots are accustomed to each individual helicopter that they may use during operations.

Therefore, a research opportunity exists to **examine the current state of training for helicopter differences** in HAA operations.

Training in Non-Normal Operating Conditions

Given that HAA operations may include a number of non-normal operating conditions, such as landing at unfamiliar sites and flying during nighttime or other low-visibility conditions, training for the various environments that pilots may encounter is critical. Current guidance for

HAA operations includes a number of these considerations, such as night training including NVG usage, IIMC avoidance and recovery, and familiarity with local flying areas (AC 135-14B).

Given the difficulty of these operational hazards and the relationship between the current accident and ASRS report findings and these non-normal operational conditions, a research opportunity exists to **examine the current state of training for unique/non-normal operating conditions** (e.g., high-density ops, nighttime, low visibility).

Organizational Analysis Findings and Future Research Directions

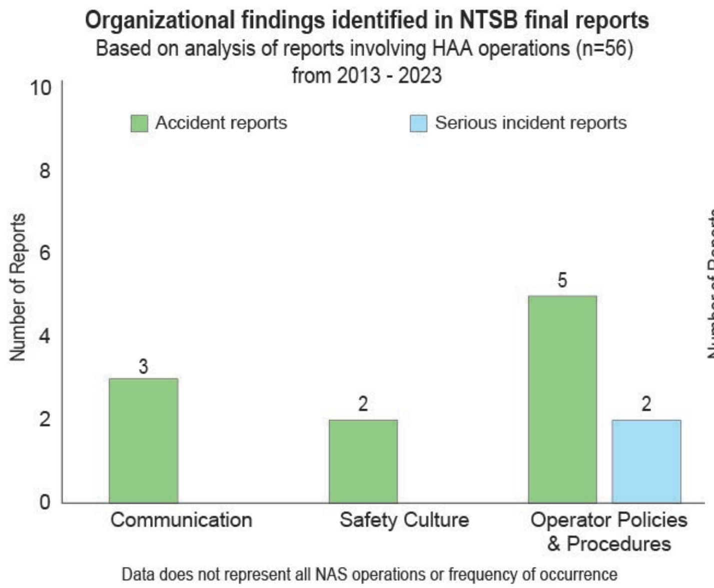

Figure 9. NTSB Reports with Organizational Findings

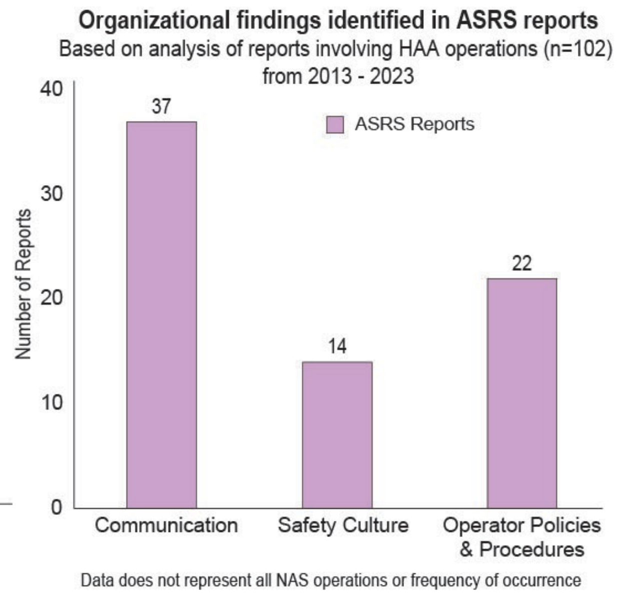

Figure 10. ASRS Reports with Organizational Findings

Finding 5. Communication

Communication issues were identified frequently in ASRS reports (n = 37; 36%; Figure 10), and less frequently identified in NTSB accident reports (n = 3; 6%; Figure 9). These communication issues included misunderstandings, incorrect communications, lack of communication, or difficulties in communication between pilots and other parties. Within ASRS reports, communication issues were observed between flightcrew and either ATC, Mx personnel, or other aircraft flightcrews. Communication risks often involved a lack of timely response or difficulty communicating due to equipment issues such as garbled radio transmissions. Other examples included communication breakdowns with company dispatch. For example, "*The reporter cited as contributing that dispatch had not notified the crew on the ground of the inbound helicopter*", which resulted in a helicopter attempting to land at an occupied hospital helipad before the departing crew took off (ASRS Report Number: ACN 1841860).

HAA pilots depend on adequate coordination and communication with OCCs to ensure they have all the information needed to choose whether to take a flight or determine whether a change of plan is needed during flight. Within NTSB accident reports, communication issues involved the pilot and oversight by the operator's OCC or other dispatch operators (for operations smaller than 10 aircraft). For example, one accident report cited as contributing to the accident: "*The operator's inadequate oversight of the flight by its operational control center*" (NTSB Accident Number: ERA16FA140). Another NTSB accident report noted that finding the helicopter post-accident was more difficult because "*The Operation Control Center mistakenly lost tracking of the helicopter about 2 hours and 10 minutes after the accident occurred"* (NTSB Accident Number: WPR16FA040).

Research Opportunity

<u>HAA Crew Resource Management Training</u>

Communication issues between pilots and medical crews and pilots and OCCs pose critical safety risks for HAA operators if not properly addressed (Rowley & Bryant, 2017). Communication with OCCs may be especially critical in emergency situations, such as cases of OCCs talking pilots through procedures for inadvertent entry into IMC events when not IFR-certified (ASRS Report Number: ACN 1244458). As such, federal regulations require that OCC specialists be trained in CRM and other communication topics (see 14 CFR § 135.619). Similarly, medical crews may take on flight-related tasks during emergency scenarios, such as assisting with spotting obstacles. As such, Advisory Circular 135-14B suggests that CRM training should include medical personnel to ensure proper communication techniques in emergency or certain non-emergency situations. However, the extent to which OCC specialists and medical crews receive training on in-flight communication and CRM across HAA operators and the effectiveness of that training is unclear.

Thus, a research opportunity exists to **examine the current state of CRM trainings for medical team members and OCC specialists in HAA operations**.

Finding 6. Safety Culture

Organizational findings related to safety culture perceptions that may have influenced the pilot were identified in 14 (14%) ASRS reports (Figure 10) and 2 (4%) NTSB accident reports (Figure 9). These typically involved time pressure (e.g., avoiding an oncoming storm), perceived pressure to accept the flight, and perceived pressure to keep the aircraft available for use. These performance pressures may have been external (e.g., perceived pressure from company) or internal, such as a pilot's desire to take a flight for fear of adverse patient outcomes.

One example that cited an undetermined internal pressure included that a contribution to the accident was "*the pilot's fixation on completing the mission probably motivated him to depart on the accident flight in IMC, even though significantly less risky alternatives existed, such as canceling the flight and transporting the patient by ground ambulance*" (NTSB Accident Number: ERA16FA140). In this instance, the pressure to complete the flight was known due to text correspondence between the pilot and a friend prior to takeoff. Other cases of pressure to perform may be harder to glean from accident reports, particularly in fatal accidents. Conversely, performance pressures in ASRS reports were found to be easier to identify, as they could be reported directly by pilots. In one example, a pilot held off from reporting an aircraft issue while the aircraft was offsite to keep it available, "*Honestly this was partly because of knowing that the company would probably not like for me to have written it up then*" (ASRS Report Number: ACN 1739476).

As demonstrated in the examples above, pilots may have felt pressure, either internal or external, to begin or complete a flight. External pressures may have included pressure from management to speed up response or lift-off times, and internal pressures may have included perceived pressure to fly when feeling fatigued or ill or pressure to get the aircraft back to base so that it is available for future flights. Pressures such as these have long been recognized as safety risks in HAA operations by both pilots and industry (Aalberg et al., 2020; Blumen et al., 2002; Chesters et al., 2016). The organizational culture that guides HAA operators should promote safety and, in doing so, minimize performance pressures.

Research Opportunity

Safety Culture

While it is well documented that a strong safety culture is key to promoting safety, actual evaluations of safety culture are less common (see Key et al., 2023 for review). Therefore, a research opportunity exists to **evaluate the attitudes, perceptions, and behaviors within HAA operations to identify potential influences on safety outcomes.**

This may include a targeted safety culture assessment of HAA operators. One such area would include pressures perceived by pilots that may impact decision-making. For example, much work has been done in recent years to combat pilot perceived pressures to take the flight irrespective of patient outcomes, such as not alerting the pilot to the status of the patient before flight decisions are made. However, many more performance pressures exist, such as perceived pressures to take flights due to economic issues with the company or explicit pressure from companies to minimize time to lift-off, which may impact safety. An investigation into the prevalence of current performance pressures from a safety culture lens would be beneficial.

Finding 7. Operator Policies and Procedures

Operator policy and procedure findings were identified in 22 (22%) ASRS reports (Figure 10), 5 NTSB accident reports (10%), and 2 NTSB incident reports (66%; Figure 9). These involved situations that (a) could not be handled properly according to standard procedures (e.g., existing operator policies or procedures did not exist or were not adequate for a particular situation); (b) included confusion about current operator policy and procedure; or (c) included suspected use of unapproved procedures at a systemic level. Some involved individuals who reported that there was an issue with operating policy or procedures but did not know how to correct for the issue. For example, one accident report concluded that a pilot was provided incorrect weather information by the OCC that led to an IIMC event due to an error in their weather checking system: "*Although the software formatting issues were known, there was no standard operating procedure to mitigate the problem*" (NTSB Accident Number: ERA16FA140).

Research Opportunity

Policy & Procedures Challenges

Policies and procedures will be unique to each HAA operator based on company size, location, types of services offered, and more. From an organizational standpoint, evaluating the effectiveness of company policies and procedures is important to ensuring that safety goals are being accomplished. With the new formalized adoption of Safety Management Systems (SMS) within Part 135 operations, continuous evaluation of company policies and procedures should be incorporated into practice.

Particularly with this current changing landscape and SMS adoption in mind, a research opportunity exists to **examine potential challenges operators face with the development, coordination, dissemination, and implementation of policies/procedures**. For example, are procedures clear and easy to follow? Are there missing procedures or steps? Are the policies/procedures up to date? Larger industry trends stemming from these types of questions may be addressed through this research opportunity.

Conclusion

Human factors and organizational findings were identified from HAA accidents, incidents, and events reported in ASRS and NTSB databases between 2013 and 2023. Findings suggest that situation awareness, judgment and decision-making, adherence to procedures, and experience and training were frequently identified flightcrew risks. In addition, communication, performance pressures, and operator policy and procedures were frequently identified organizational risks. Altogether, a number of research opportunities related to these findings were proposed, which could include future research projects or evaluation of HAA operators through targeted oversight efforts. These findings and research opportunities aim to inform potential mitigations to reduce future accidents and serious incidents within HAA operations.

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Appendix A. ASRS Search Criteria and Analysis

The NASA ASRS database was queried for reports meeting the following criteria:

- Occurring from 01/01/2013 to 11/02/2023,
- Involving operations regulated under Part 135,
- Involving air medical operations, and
- Involving accidents and incidents.

This initial query resulted in 163 ASRS reports. The researchers further excluded 61 reports that did not involve a rotorcraft, leaving 102 reports for analysis. The researchers then identified the standardized fields across all reports and logged findings in a Microsoft Excel spreadsheet, including:

- Date and Time,
- Light Conditions,
- Phase of Flight (e.g., takeoff, en route, landing),
- Flightcrew Size,
- Flight Conditions (e.g., Instrument Meteorological Conditions [IMC], Visual Meteorological Conditions [VMC], Instrument Flight Rules [IFR], Marginal, and Mixed), and
- Aircraft (helicopter) Manufacturer.

Next, the researchers evaluated and categorized the 102 ASRS reports for human factors safety risks. Narratives from ASRS reports were used to categorize human factors-related risks involving (a) personnel, (b) organization, (c) environment, and (d) consequences (e.g., of personnel actions). Reports were also categorized by the job role (e.g., flightcrew [e.g., pilots], air traffic controllers [ATCs], and maintenance [Mx]) that contributed to the event.

Each report was dummy coded (e.g., absent or present) for all human factors risks in a Microsoft Excel spreadsheet. The categorized human factors risks were distinct from the fields found in each event report. The categorized human factors risks from each risk category are provided below:

Personnel

- Situation Awareness (SA),
- Adherence to Procedures,
- Judgment and Decision-Making (JDM),
- Experience and Training,
- Flightcrew,
- ATC, and

- Mx.

Organization

- Communication,
- Operator Policy and Procedure, and
- Performance Pressure.

Environmental

- Weather.

Consequences

- Controlled Flight into Terrain (CFIT),
- Failure of System or Component,
- Loss of Control (LOC),
- Near Mid-air Collision (NMAC), and
- Adverse Patient Outcome.

The researchers completed their report classifications with all inconsistencies among the researchers' reviews discussed until a consensus was reached. Categorizations that could not be resolved within the group or that required additional guidance were resolved with the help of a subject matter expert. The Principal Investigator conducted a final review of the contributing human factors risks and verified that each ASRS report was correctly classified.

Appendix B. NTSB Search Criteria and Analysis

The NTSB Aviation Investigation Search database was queried for reports of accidents and serious incidents matching the following criteria:

- Occurred from 01/01/2013 to 11/02/2023,
- Included a final report,
- Involved a helicopter,
- Involved air medical operations,
- Involved an operation under 14 C.F.R. § 135, and
- Involved either an accident or incident.

This initial query resulted in 53 NTSB investigative reports. The researchers then identified fields from each report and logged findings in a Microsoft Excel (Microsoft Corporation, 2018) spreadsheet, including:

- Date and Time,
- Event Type (e.g., accident or incident),
- Location (e.g., state and city),
- Injury Type and Highest Injury Level (e.g., none, minor, serious, or fatal),
- Light Conditions (e.g., dawn, day, dusk, or night),
- Phase of Flight (e.g., takeoff, en route, landing),
- Flight Conditions (e.g., Visual Meteorological Conditions [VMC], Instrument Meteorological Conditions [IMC], Visual Flight Rules [VFR], Instrument Flight Rules [IFR]),
- Aircraft (helicopter) Manufacturer,
- Findings from each NTSB investigative report, and
- Defining event associated with the accident or serious incident (e.g., loss of control [LOC] in flight, hard landing, ground collision).

Next, the 53 NTSB investigative reports were classified for safety risks that contributed to HAA accidents and incidents. Narratives from NTSB reports were used to classify human factors-related risks involving (a) personnel, (b) organization, and (c) environmental factors. NTSB reports were also categorized by the consequences of each accident or incident, including controlled flight into terrain (CFIT), failure of system or component, LOC, and whether the patient's outcome was adversely impacted. Investigations were also classified by the job role (e.g., flightcrew [pilots], air traffic controllers [ATCs], and maintenance [Mx]) that contributed to the accident or incident. NTSB reports contain a parameter of the single defining event that led to the accident or incident (e.g., LOC in flight, hard landing, ground collision, bird strike).

Each report was dummy coded (e.g., absent or present) for all human factors risks in a Microsoft Excel spreadsheet (Microsoft Corporation, 2018). The categorized human factors risks were distinct from the fields found in each event report. The human factors risks identified within each risk category are provided below:

Personnel

- Situation Awareness (SA),
- Adherence to Procedure,
- Judgment and Decision-Making (JDM),
- Experience and Training,
- Flightcrew,
- ATC, and
- Mx.

Organization

- Communication,
- Operator Policy and Procedure, and
- Performance Pressure.

Environment

- Weather.

Consequences

- Controlled Flight into Terrain (CFIT),
- Failure of System or Component,
- Loss of Control (LOC), and
- Adverse Patient Outcome.

The researchers completed their report classifications with all inconsistencies among the researchers' reviews discussed until a consensus agreement was reached. The Principal Investigator conducted a final review of the contributing human factors risks and verified that each NTSB report was correctly classified.

Appendix C. ASRS Supplemental Figures

Supplemental figures from the analysis of ASRS reports in HAA operations from 2013 to 2023 are shown below. Figure 11 displays the number of ASRS reports submitted across years of analysis. There is a relatively consistent submission of reports across the 11-year span, with a peak of 15 reports submitted in 2016 and a minimum of 5 reports submitted in 2023. The reported meteorological conditions within ASRS reports are displayed in Figure 12. For reports that included the meteorological conditions (*n* = 83), visual meteorological conditions (VMC) were most commonly reported (*n* = 67), followed by marginal conditions (*n* = 6), instrument meteorological conditions (IMC; *n* = 5), mixed (*n* = 3), and instrument flight rules (IFR; *n* = 2). Lighting conditions that were included within ASRS reports are displayed in Figure 13. For all reports that included lighting conditions (*n* = 89), daytime conditions were the most commonly reported (*n* = 53), followed by night (*n* = 28), dusk (*n* = 6), and finally, dawn (*n* = 2).

Figure 11.
ASRS Reports by Year of Incident

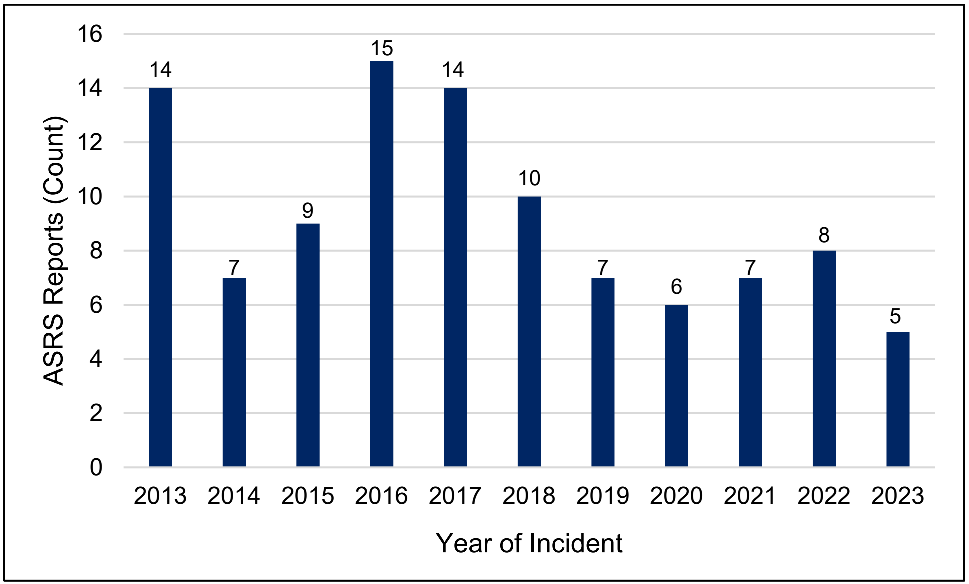
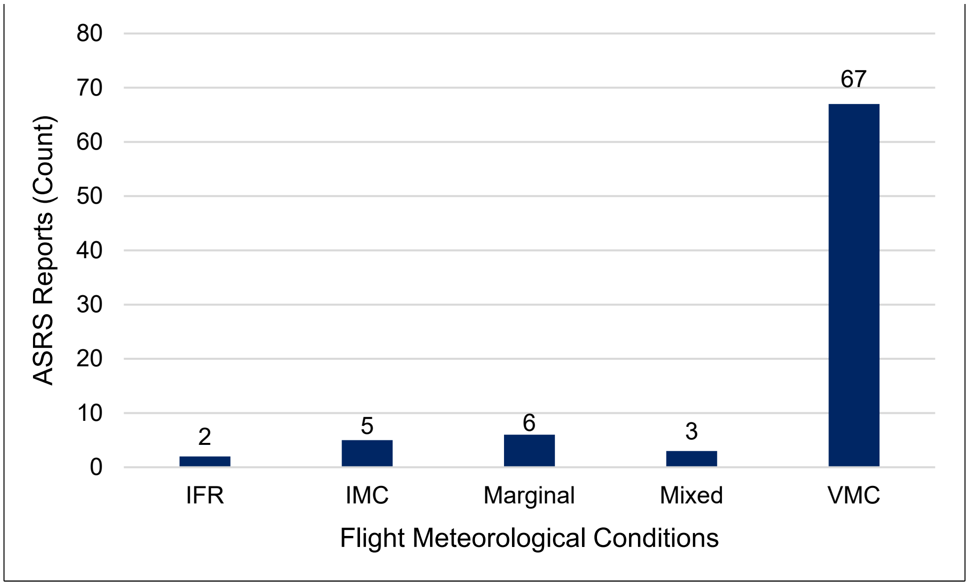
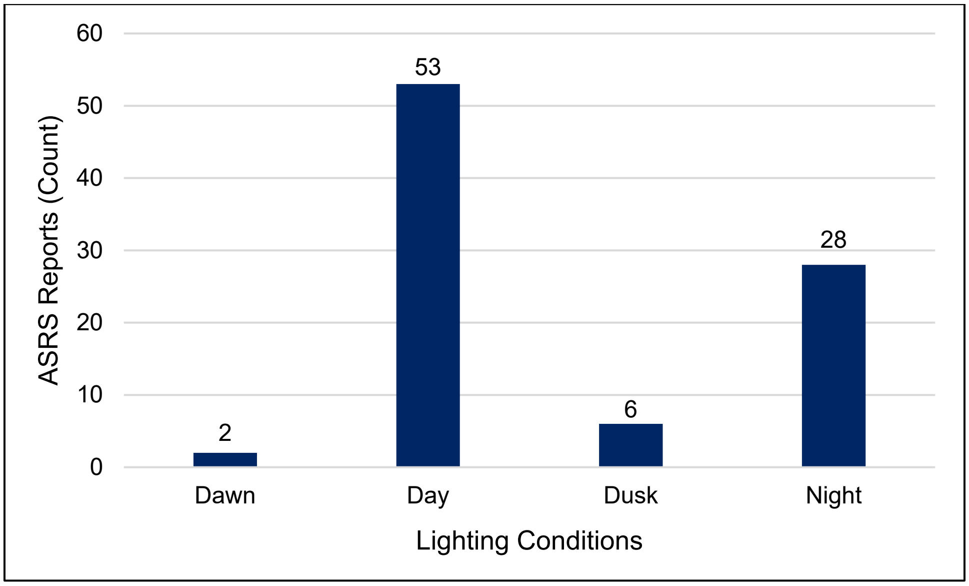


Figure 12.
ASRS Reports by Meteorological Conditions



* IFR - Instrument Flight Rules; IMC - Instrument Meteorological Conditions; VMC - Visual Meteorological Conditions.

Figure 13.
ASRS Reports by Lighting Conditions



Appendix D. NTSB Supplemental Figures

Supplemental figures from the analysis of NTSB final accident and incident reports are included in the below figures. Figure 14 displays the number of accident/incident reports over the 11-year span, with a peak of eight reports in 2016 and a minimum of one final report for both 2020 and 2023. The meteorological conditions at the scene of the accident/incident for each NTSB report are included in Figure 15. The most commonly reported conditions were VMC (n = 41) versus IMC (n = 5). Night was the most commonly reported lighting condition in these reports (n = 21), followed by day (n = 13) and dusk (n = 3; Figure 16).

Figure 14.
NTSB Reports by Year of Accident or Incident

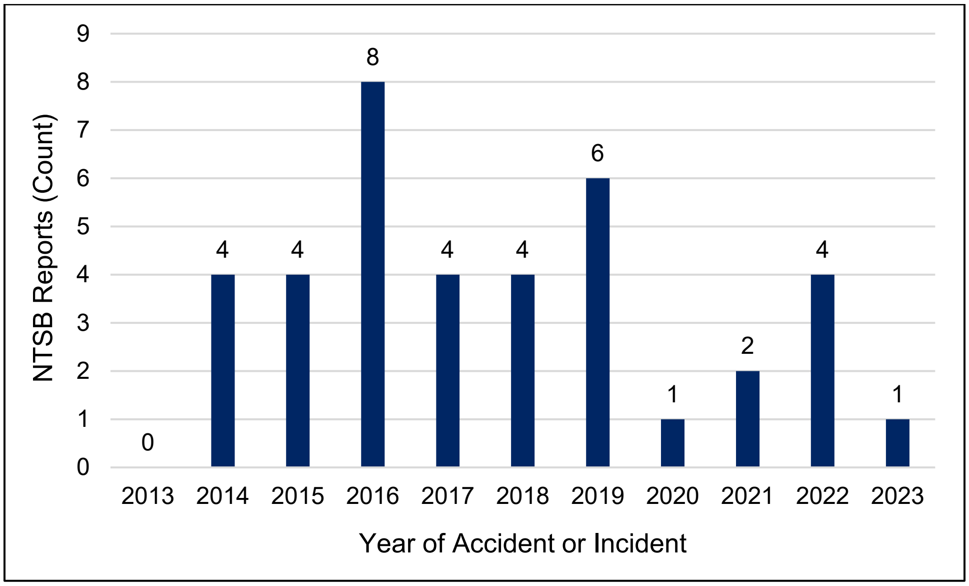
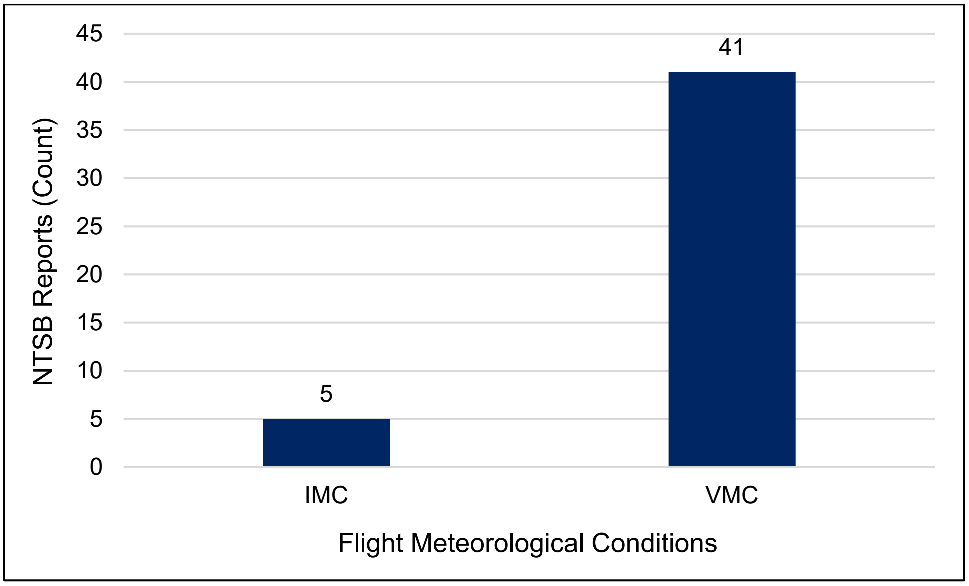


Figure 15.
NTSB Reports by Meteorological Conditions



* IMC - Instrument Meteorological Conditions; VMC - Visual Meteorological Conditions.

Figure 16.
NTSB Reports by Lighting Conditions