Air Medical Journal 43 (2024) 499–507

Contents lists available at ScienceDirect

Air Medical Journal

journal homepage: http://www.airmedicaljournal.com/

Original Research

# Analysis of Helicopter Air Ambulance Accidents in the United States From 2010 to 2021

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*Keywords:*
Helicopter Air Ambulance
HAA accidents
HEMS accidents

A B S T R A C T

*Objective:* Helicopter air ambulance (HAA) services are essential to air medical transport in the United States. However, HAA accidents, incidents, and fatalities have been a reason for concern for HAA operations. This article analyzes the numbers, proportions, contributing or causal factors, and defining events of HAA accidents in the United States from 2010 to 2021.

*Methods:* The National Transportation Safety Board final investigation reports, defining events, findings, and summary data were analyzed for 83 HAA accidents in the United States from 2010 to 2021. The 2 proportions test was used to compare the proportions of fatal HAA accidents between 2010-2015 and 2016-2021.

*Results:* The data show that 21/47 (45%) of HAA accidents in 2010-2015 and 6/36 (17%) in 2016-2021 were fatal, representing a significant ($P < .01$) reduction in the proportion of fatal accidents in 2016-2021 from 2010-2015 time period. VFR encounter IMC events accounted for 9/47 (19%) of HAA accidents in 2010-2015 and 1/36 (3%) accident in 2016-2021, representing a significant ($P < .05$) reduction in VFR encounter IMC accidents.

*Conclusion:* There was a statistically significant decrease in the proportion of fatal HAA accidents from 2010-2015 to 2016-2021, which may be attributable to the changes in the regulatory framework, training protocols, safety awareness initiatives, and technological advancements to address HAA safety.

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Air medical transport (AMT) plays a critical role in the health care system in the United States. Within AMT, helicopters provide specialized airborne emergency response services to patients in remote areas or during time-sensitive situations.[1] Helicopter air ambulances (HAAs) are a component of the Emergency Medical Services (EMS) system, bridging the gap between traditional ground-based ambulances and hospital facilities.[2] With rotary wing AMT's ability to expeditiously transport medical professionals and equipment to the site of accidents and medical emergencies, HAA services have proven vital in administering prompt and specialized care, significantly enhancing survival rates and overall patient outcomes.[3,4] The HAA industry is expanding.[5] From 2010 to 2020, the HAA fleet has grown at an average of 6.6% per year.[6] However, HAA accidents and incidents have concerned the aviation community regarding the safety of HAA operations.[7-9]

In this article, the authors use the term HAA instead of helicopter emergency medical services (HEMS), following the recommended phraseology by the Federal Aviation Administration (FAA) for rotary wing air medical services.[5] This research uses the term HAA operation as defined in the FAA Advisory Circular (AC) 135-14B,'.[5]

> "A flight, or sequence of flights, with a patient or medical personnel on board, for the purpose of medical transportation, by a Part 135 certificate holder authorized by the Administrator to conduct helicopter air ambulance operations. A helicopter air ambulance operation includes, but is not limited to:
> (1) Flights conducted to position the helicopter at the site at which a patient or donor organ will be picked up.
> (2) Flights conducted to reposition the helicopter after completing the patient, or donor organ transport.
> (3) Flights initiated for the transport of a patient or donor organ that are terminated due to weather or other reasons."(p3-4)

The number of helicopters dedicated exclusively to AMT in the HAA industry has more than doubled from 545 in 2003 to 1,115 in

*Abbreviations:* AMT, Aeromedical transport; CFIT, Controlled Flight into Terrain; EMS, Emergency Medical Service; HAA, Helicopter Air Ambulance; HTAWS, Helicopter Terrain Awareness and Warning System; IFR, Instrument Flight Rules; IMC, Instrument Meteorological Conditions; LOC-I, Loss of Control in Flight; NVIS, Night-Vision Imaging System; OCC, Operations Control Center; VFR, Visual Flight Rules; VMC, Visual Meteorological Conditions

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1067-991X/$36.00
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2019.[6,10] Even though the number of aviation accidents during HAA operations has decreased over the years, previous studies have found that the proportions of fatal HAA accidents have remained high.[7,11,12] The proportion of fatal accidents and fatal accident rates were found to be higher for HAA accidents than those for non-HAA accidents between 1999 and 2018.[7] A study of 239 fatalities from 87 fixed wing and helicopter AMT accidents found that more than 70% of fatalities occurred during helicopter AMT operations.[13] Researchers have studied multiple factors that impact the safety of HAA operations and have been identified as contributing and/or causal factors to HAA accidents. These factors include marginal weather conditions,[14-20] nighttime/darkness or reduced illumination,[14-16,18,19,21,22] poor visual references,[15,16,18,19] sparse and sometimes inaccurate weather information,[23,24] pilot experience,[17,25-27] and human factors.[8,28] A combination of these factors may lead to Inadvertent Instrument Meteorological Conditions (IIMC) encounters,[8] spatial disorientation,[15,16,19] and/or fatalities due to loss of control in flight and Controlled Flight Into Terrain (CFIT).[29] The aviation safety literature widely recognizes pilot experience as a protective factor against general aviation accidents.[29-31] One study analyzed HAA accidents conducted under Title 14 CFR Part 135 operations during night flying conditions from 1995 to 2013 and found that HAA pilots with over 10 years of HEMS experience have significantly fewer accidents, whereas those with less than 4 years of experience have significantly higher accident rates.[16] Furthermore, the FAA's Risk Management Handbook evidences the importance of flying experience, concluding that the accident rates during night visual flight rules (VFR) decrease approximately 50% after the pilot logs the first 100 flight hours (FHs) and continue decreasing until the pilot reaches 1,000 FHs.[32] The FAA's Risk Management Handbook, the Pilot's Handbook of Aeronautical Knowledge, and the Helicopter Flying Handbook recommend that pilots with less than 500 hours, flying at night under VFR, should "establish higher personal limitations than are required by the regulations and, if applicable, apply instrument flying skills in this environment."[32-34]

Three recent studies of HAA accidents compared fatal and nonfatal accidents in different time periods ranging from 1983 to 2018. Researchers have studied 274 HAA accidents from 1983 to 2014 and found that although the overall accident rate (per million FHs) had decreased, the proportion of fatal accidents was consistently between 36% and 50%.[12] A study of 59 AMT accidents (52 HAA and 7 fixed wing) between 2003 and 2015 reported approximately 70% of accidents included fatalities, with no significant change in the number of fatal AMT accidents per year for pre-2003 (7 fatal accidents/y) and post-2003 (8 fatal accidents/y).[13] A study of 206 HAA accidents from 1999 to 2018 reported that, on average, 33% of HAA accidents per year were fatal.[7] These 3 studies indicate that the overall number of HAA accidents has decreased; however, the proportions of fatal HAA accidents have not declined over time.[7,12,13] These safety concerns have prompted regulators, aviation organizations, and researchers to develop a regulatory framework, training protocols, safety awareness initiatives, and technological advancements to address HAA safety.

## Safety Initiatives and Regulation Changes in HAA Operations

After experiencing an increase in the number of fatal HAA accidents, changes to the operational regulatory framework for HAA services were proposed. In 2006, the National Transportation Safety Board (NTSB) presented recommendations in technology, training, and regulations to increase safety levels during HAA operations.[35] In October 2010, the FAA published a Notice of Proposed Rulemaking (NPRM) to address safety concerns in air ambulance and commercial helicopter operations.[36] The NPRM included requirements for Part 91 helicopter operations, Part 135 aircraft-load manifest, and additional equipment on board HAAs.[36] The FAA received support and feedback on the NPRM from 32 operators, 11 manufacturers, and 13 associations (eg, the NTSB, National EMS Pilots Association, Air Medical Operators Association, and Association of Critical Care Transport).[37]

In 2012, the FAA Modernization and Reform Act (Public Law 112-95) was passed, which aimed to modernize and reform the FAA's functions and responsibilities related to aviation safety and air traffic control.[38] Its purpose was to improve the aviation industry's efficiency, reliability, and safety in the United States by updating the FAA's systems and procedures. Section 306 of this law directed the FAA to improve the HAA regulations, dispatching procedures, pilot training, and equipment required for Title 14 CFR Part 135 HAA operators. In April 2014, the FAA issued *Final Rule RIN 2120-AJ53* entitled *Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations.*[37] The regulations in this rule were issued in response to an increasing number of fatal accidents involving helicopter air medical transportation after analyzing the recommendations from the aviation safety investigations and incorporating the best practices regarding HAA operations. The revised regulations in this final rule aim to enhance safety in Part 135 and 91 helicopter operations by setting new standards for training and stringent weather minimums, requiring the installation of new equipment, and increasing mission support personnel required during HAA services.[37] This new regulation also included additional requirements for flight data monitoring and safety management systems for air medical transportation companies in the United States. Table 1 provides a summary of changes that affect helicopter operators under Title 14 CFR parts 91, 120, and 135.

In addition to the regulatory changes, in 2015, the FAA published AC 135-14B,[5] which highlighted the best practices and recommended procedures to conduct HAA operations in the United States. AC 135-14B contains the challenges faced during HAA operations and explores the best practices that can address these issues. By tailoring these practices to the unique characteristics of each organization, HAA operators can ensure compliance with the regulatory framework and maintain safety standards.[5] In 2016, the FAA published AC 120-96A[39] to assist HAA operators in incorporating the operations control center (OCC) into HAA services.[39] This AC clarified the OCC's regulatory requirements, structure, and procedures and explained the responsibilities and functions of operations control specialists during HAA operations. In 2017, responding to a joint request from the Flight Standards Division of the FAA (AFS-800) and the Air Transportation Division (AFS-200), the FAA published the DOT/FAA/AM-17/13 Crew Resource Management in Helicopter Air Ambulance Operations[40] report. This report summarizes the literature on helicopter crew resource management for Part 91 and Part 135 operators, focusing on the human factors approach to prevent accidents.[40]

After identifying the changes in the HAA regulatory framework, pilot training, and modern on-board equipment and technology that occurred between 2006 and 2018, the researchers hypothesize that the proportion of fatal HAA accidents may have decreased during the 2016-2021 time period. In this article, the number, proportions, contributing or causal factors, and defining events to HAA accidents in the United States are analyzed and compared between 2010-2015 and 2016-2021 time periods. The NTSB accident investigation reports provide a description of the accident, a review of the investigative analysis, and a determination of the probable cause.[41] The term "probable causes" is used to describe the factors that are most likely to have contributed to the occurrence of an accident. In addition, from the probable cause analysis, the NTSB provides a coded categorization of the contributing or causal factors in NTSB findings. As a part of the accident categorization process, the NTSB identifies a "defining event" from the sequence of events that led to the accident.[42] The implementation of common taxonomies and definitions for aviation accident investigations and reporting is aimed at augmenting the aviation community's proficiency in discerning and

**Table 1**
*Final Rule RIN 2120-AJ53*[37]: A Summary of the Changes That Affect the Helicopter Operations Under Title 14 CFR Parts 91, 120, and 135

| Area | Description | Effective Date |
|---|---|---|
| Helicopter equipment | Reduced VFR minimums for night vision imaging systems (NVIS) operators | Apr 2014 |
| | *Use of NVIS not made mandatory by the final rule | |
| | Reduced VFR minimums for helicopter terrain awareness and warning systems (HTAWS) operators | Apr 2017 |
| | *Installing HTAWS made mandatory by the final rule | |
| | Radio altimeter | Apr 2017 |
| | Safety equipment for overwater operations | Apr 2017 |
| | Flight data monitoring | Apr 2018 |
| Pilot training and ratings | Inadvertent IMC and decision-making training | Apr 2014 |
| | Medical personnel—aviation safety training | Apr 2014 |
| | Flat light, whiteout, and brownout training | Apr 2015 |
| | Pilot in command—airline transport pilot certificate or instrument rating | Apr 2017 |
| Operations | HAA flight with medical personnel on board—operating under Title 14 CFR Part 135 | Apr 2014 |
| | Preflight risks assessment | Apr 2014 |
| | Identify and document highest obstacle on the planned route of flight | Apr 2014 |
| | Operations control specialist—training | Apr 2014 |
| | Safety briefings—include medical personnel | Apr 2014 |
| | Mandatory for certificate holders of 10 or more helicopters | Apr 2016 |
| Ceiling and visibility | Stringent VFR minimums for class G airspace | Apr 2014 |
| | Procedures for IFR to VFR transitions | Apr 2014 |

IFR = instrument flight rules; IMC = instrument meteorological condition; VFR = visual flight rules.

addressing shared safety issues.[43] Although NTSB-reported probable causes are studied widely, defining events and NTSB findings codes are not usually analyzed and compared over time. Defining events may provide insights about categories and events that lead to fatal HAA accidents (eg, historically, VFR encounter IMC events are associated with fatal accidents). A comprehensive analysis and understanding of defining events and NTSB findings may help in devising effective safety measures to prevent future occurrence of such events and improve the safety of HAA operations. Therefore, in this article, numbers, proportions, defining events, and contributing/causal factors to HAA accidents are explored across 2 time periods. Specifically, the research questions in this study are as follows:

Research question 1: Did the proportion of fatal HAA accidents in the United States decrease in 2016-2021 from 2010-2015 by 1) time of day, 2) number of aircraft engines, 3) pilot flight hours, and 4) phase of flight?
Research question 2: What were the defining events and NTSB findings (categories/codes) for the HAA accidents in the United States in 2010-2015 and 2016-2021?

## Methodology

*Data Sources and Collection*

In this retrospective study, the researchers selected data from the NTSB CAROL (Case Analysis and Reporting Online)[44] for HAA accidents from 2010 to 2021. A custom search was conducted with the following 6 query parameters: 1) aircraft category is helicopter, 2) air medical is true, 3) event type is accident, 4) event date is on or after January 1, 2010, 5) event date is on or before December 31, 2021, and 6) country is the United States. All HAA accident investigations in the selected time frame of 2010 to 2021 were completed and had a published NTSB accident investigation final report.

There were 83 HAA accidents (47 accidents in 2010-2015 and 36 accidents in 2016-2021) retrieved for analysis. These accidents happened during HAA operations conducted under Title 14 CFR Part 91 and Title 14 CFR Part 135. As per Title 49 CFR Part 830.2, accidents are defined as any incident that results in 1) aircraft substantial damage, 2) loss of life, and/or 3) serious injuries and occur from the time an individual boards the aircraft with the intent of flying until all passengers have disembarked the aircraft.[45] Fatal injuries are defined as "any injury which results in death within 30 days of the accident" (49 CFR §830.2).[45] Public dockets, final investigation reports, and summary data from the 83 accidents were analyzed to answer the research questions. Rotorcraft air medical FHs were obtained from the FAA Aviation Data and Statistics, General Aviation and Part 135 Activity Surveys, "Chapter III: Primary and Actual Use," from 2010 to 2021.[46] The sum of Part 135 rotorcraft air medical hours and GA rotorcraft air medical hours flown by actual use was used in calculating the HAA accident rate. Researchers have used a threshold of 500 FHs to categorize pilot experience in general aviation studies.[47-49] In this study, the number of hours in the specific aircraft make and model involved in the accident were used as a measure of the pilot's experience, and a threshold of 500 FHs was used to create 2 categories: HAA pilots with less than or equal to 500 FHs and pilots with greater than 500 FHs.

*Data Analysis*

To answer research question 1 and its subparts, counts of total accidents and fatal HAA accidents in 2010-2015 and 2016-2021 were recorded by time of day, number of aircraft engines, number of FHs in the aircraft make and model, and phase of flight (refer to Table 2). The 2 proportions test (Fisher exact and normal approximation) was used to compare the proportions of fatal accidents between the 2 time periods. In general, the null hypothesis for the proportions test was as follows: the difference between the population proportions ($P_{2010\text{-}2015} - P_{2016\text{-}2021}$) of the accidents between 2010-2015 and 2016-2021 equals the hypothesized difference of 0. The alternate hypothesis was as follows: the difference between the population proportions ($P_{2010\text{-}2015} - P_{2016\text{-}2021}$) was greater than 0 (because we wanted to check if the fatal accidents have reduced in 2016-2021). The proportions of fatal accidents in the null and alternate hypotheses were specific to each subpart of research questions 1, and a 1-sided 2 proportions test (alpha = 0.05) was used to compare the proportions. Minitab® Statistical Software Version 21 was used for descriptive and inferential statistics (https://www.minitab.com/en-us/legal/author-permissions-guidelines/).

To answer research question 2, the defining events and findings, as identified and reported by the NTSB, were obtained from the NTSB accident data summary of the 83 HAA accidents. The NTSB lists a single defining event of an accident in the defining events column within the NTSB data summary. These defining events were tabulated by frequency and proportions for the accidents in 2010-2015 and

2016-2021 (Table 3). The NTSB categorized the contributing or causal factors to an accident in the findings column within the NTSB data summary. The general structure of categorizing and reporting factors in these findings is category-subcategory-section-subsection-modifier.[7] In this research, the category, subcategory, and the NTSB codes were recorded for each finding in each of the accidents (an accident may have more than 1 finding). The findings were tabulated by frequency of instances in the 47 accidents in 2010-2015 and the 36 accidents in 2016-2021. The percentage of accidents that listed a particular finding was also reported (Table 4).

## Results

The researchers studied 83 HAA accidents from 2010 to 2021. There were 47 HAA accidents in 2010-2015 and 36 HAA accidents in 2016-2021. Figure 1 shows the number of fatal and nonfatal HAA accidents per year and the fatal and nonfatal HAA accident rates per 100,000 FHs from 2010 to 2021. The number of fatal accidents and the fatal accident rate appear to be decreasing between 2010 and 2021. In 2010-2015, 14% to 75% (mean of 43%) of the HAA accidents per year resulted in fatalities, whereas in 2016-2021, 0% to 38% (mean of 14%) of the HAA accidents per year resulted in fatalities, with 0 fatal accidents in 2018, 2020, and 2021.

*Research Question 1*

The numbers and proportions of HAA accidents in 2010-2015 and 2016-2021 were recorded by time of day, aircraft engines, number of FHs in aircraft, and phase of flight. Table 2 presents these results for fatal and nonfatal HAA accidents. Of the 47 HAA accidents in 2010-2015, 21 (45%) were fatal. Of the 36 accidents in 2016-2021, 6 (17%) were fatal. There was a statistically significant ($P < .01$) reduction in the proportion of fatal accidents in 2016-2021 from 2010-2015.

*Fatal Accidents by Time of Day*

More than 50% of the total HAA accidents in 2010-2015 and 2016-2021 happened during the nighttime. During the daytime, there were 6/47 (13%) fatal HAA accidents in 2010-2015 and 3/36 (8%) in 2016-2021, with no statistically significant reduction in the proportions of fatal accidents ($P > .05$). However, during the nighttime, there were 15/47 (32%) fatal HAA accidents in 2010-2015 and 3/36 (8%) in 2016-2021, representing a statistically significant reduction ($P < .01$) in the proportions of fatal accidents at night.

*Fatal Accidents by Aircraft Engines*

There were 32/47 (68%) HAA accidents in 2010-2015 and 14/36 (47%) HAA accidents in 2016-2021 that occurred in a single-engine aircraft. There were 16/47 (34%) fatal single-engine HAA accidents in 2010-2015 and 3/36 (8%) in 2016-2021, which was a statistically significant reduction in the proportion of fatal single-engine helicopters ($P < .05$). For twin-engine helicopters, there were 5/47 (11%) fatal accidents in 2010-2015 and 3/36 (8%) in 2016-2021, with no statistically significant reduction in the proportions ($P > .05$).

*Fatal Accidents by Pilot FHs in Aircraft Make and Model*

From the 83 HAA accident data, more than 50% of the total HAA accidents in 2010-2015 (57%) and 2016-2021 (53%) were associated with pilots with less than 500 FHs in aircraft make and model. For pilots with FHs ≤ 500, there were 13/47 (28%) fatal HAA accidents in 2010-2015 and 4/36 (11%) in 2016-2021, which was a statistically significant reduction ($P < .05$). For pilots with FHs > 500, there were 8/47 (17%) fatal HAA accidents in 2010-2015 and 2/36 (5%) in 2016-2021, representing a statistically significant reduction ($P < .05$) in the proportion of fatal accidents. In addition, of the fatal accidents, 13/21 (62%) in 2010-2015 and 4/6 (67%) in 2016-2021 were associated with pilots with less than 500 FHs in aircraft model.

*Fatal Accidents by Phase of Flight*

A majority of the total HAA accidents in 2010-2015 (74%) and 2016-2021 (69%) were associated with the cruise or landing phase of flight. In 2010-2015, there were 4/47 (9%) fatal HAA accidents during landing, 2/47 (4%) during takeoffs, and 1/47 (2%) during hover and ground. In 2016-2021, there were 2/36 (6%) fatal accidents during landing and 0 during takeoffs or hover and ground. There was no statistically significant reduction ($P > .05$) in landing, takeoff, or hover and ground fatal accidents. However, during cruise, there was a statistically significant reduction ($P < .05$) in the proportion of fatal HAA accidents in 2016-2021 (with 4/36 (11%) being fatal) from 2010-2015 (with 14/47 (30%) being fatal).

*Research Question 2*

The NTSB identifies a defining event from the sequence of events that led to the accident.[36] Table 3 presents the defining events, as reported by the NTSB, of the 83 HAA accidents studied in this article. The researchers grouped similar types of defining events into 7 categories (refer to Table 3 and the associated notes). Table 3 includes the number and proportion of HAA accidents with defining events in each category for 2010-2015 and 2016-2021. The defining event category VFR encounter IMC was associated with 9/47 (19%) HAA accidents in 2010-2015 and 1/36 (3%) accidents in 2016-2021, which was a statistically significant ($P < .05$) reduction (89%) in VFR encounter IMC accidents. The powerplant mal/fail category includes powerplant sys/com mal/fail, loss of engine power (total), and loss of engine power (partial) defining events. in this category, there were 9/47 (19%) HAA accidents in 2010-2015 and 5/36 (14%) in 2016-2021, which represents a reduction of 44%. The loss of control category includes the loss of control in flight and loss of tail rotor effectiveness defining events. This category was associated with 7/47 (15%) HAA accidents in 2010-2015 and 8/36 (22%) in 2016-2021, representing an increase of 14% in the number of HAA accidents associated with this category.

The NTSB findings section categorizes the contributing or causal factors to an accident. The analysis of these contributing or causal factors for 83 HAA accidents is listed in Table 4, which includes the NTSB categories and subcategories, codes, frequency of instances, and proportion of the number of HAA accidents that occurred within each period. Because 1 accident may be associated with more than 1 causal or contributing factor, the total frequency of each category is greater than the number of accidents for each period. The aircraft category was identified as a causal or contributing factor in 35/47 (74%) HAA accidents during 2010-2015 and in 25/36 (69%) accidents during 2016-2021. Within the personnel issues category, the task performance subcategory was present in 25/47 (53%) accidents during 2010-2015 and 19/36 (53%) during 2016-2021. Under the environmental issues category, the physical environment or conditions/weather/phenomena subcategories were present in 27/47 (58%) accidents in 2010-2015 and 26/36 (72%) accidents in 2016-2021.

## Discussion

This article studied 83 HAA accidents in the United States to better understand and compare the numbers, proportions, contributing or causal factors, and defining events of HAA accidents between 2010-2015 and 2016-2021 as collected from the NTSB final investigation reports and summary data. The major results of this study are as follows:

1. There was a significant decrease in the proportion of fatal HAA accidents from 2010-2015 (21/47 [45%] being fatal) to 2016-2021 (6/36 [17%] being fatal).

**Table 2**
Helicopter Air Ambulance (HAA) Accident Frequency and Percentage in 2010-2015 and 2016-2021

| Condition/Event Type | | Number of Accidents | | | | | | | Proportions of Fatal Accidents 2010-2015 $P_{2010-2015}$ | Proportions of Fatal Accidents 2016-2021 $P_{2016-2021}$ | Two Proportions Test (Alpha = 0.05) $H_0$: $P_{2010-2015} - P_{2016-2021} = 0$ $H_1$: $P_{2010-2015} - P_{2016-2021} > 0$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010-2015 | | | 2016-2021 | | | Total | | | | | |
| Total Number of HAA Accidents | | By Highest Injury Level | | Total | By Highest Injury Level | | Total | | | | | | |
| | | Fatal | Nonfatal | | Fatal | Nonfatal | | | | | $P_{2010-2015} - P_{2016-2021}$ | 95% Lower Bound | P Value |
| | | 21 | 26 | 47 | 6 | 30 | 36 | 83 | 21/47<br>0.4468 | 6/36<br>0.1667 | 0.2801 | 0.1231 | Fisher exact: 0.006[a]<br>Normal approximation: 0.002[a] |
| By time of day | Day | 6 | 16 | 22 | 3 | 14 | 17 | 39 | 6/47<br>0.1276 | 3/36<br>0.0833 | 0.0443 | −0.0659 | Fisher exact: 0.392<br>Normal approximation: 0.254 |
| | Night | 15 | 10 | 25 | 3 | 16 | 19 | 44 | 15/47<br>0.3192 | 3/36<br>0.0833 | 0.2358 | 0.1007 | Fisher exact: 0.009[a]<br>Normal approximation: 0.002[a] |
| By aircraft engines | Single engine | 16 | 16 | 32 | 3 | 14 | 17 | 49 | 16/47<br>0.3404 | 3/36<br>0.0833 | 0.2571 | 0.1205 | Fisher exact: 0.005[a]<br>Normal approximation: 0.001[a] |
| | Twin engine | 5 | 10 | 15 | 3 | 16 | 19 | 34 | 5/47<br>0.1064 | 3/36<br>0.0833 | 0.0231 | −0.0828 | Fisher exact: 0.515<br>Normal approximation: 0.360 |
| By number of FHs in aircraft make and model | FHs ≤ 500 hours | 13 | 14 | 27 | 4 | 15 | 19 | 46 | 13/47<br>0.2766 | 4/36<br>0.1111 | 0.1655 | 0.0276 | Fisher exact: 0.055<br>Normal approximation: 0.024[a] |
| | FHs > 500 hours | 8 | 12 | 20 | 2 | 15 | 17 | 37 | 8/47<br>0.1702 | 2/36<br>0.0556 | 0.1147 | 0.0048 | Fisher exact: 0.104<br>Normal approximation: 0.043[a] |
| By phase of flight | Hover & ground | 1 | 5 | 6 | 0 | 5 | 5 | 11 | 1/47<br>0.0213 | 0/36<br>0 | 0.0213 | −0.0133 | Fisher exact: 0.566<br>Normal approximation: 0.156 |
| | Takeoff | 2 | 4 | 6 | 0 | 6 | 6 | 12 | 2/47<br>0.0426 | 0/36<br>0 | 0.0426 | −0.0059 | Fisher exact: 0.318<br>Normal approximation: 0.074 |
| | Cruise | 14 | 8 | 22 | 4 | 6 | 10 | 32 | 14/47<br>0.2979 | 4/36<br>0.1111 | 0.1868 | 0.0473 | Fisher exact: 0.036[a]<br>Normal approximation: 0.014[a] |
| | Landing | 4 | 9 | 13 | 2 | 13 | 15 | 28 | 4/47<br>0.0851 | 2/36<br>0.0556 | 0.0296 | −0.0622 | Fisher exact: 0.472<br>Normal approximation: 0.298 |

FH = flight hour.
Note: The proportions of fatal HAA accidents are calculated out of the total number of HAA accidents in each time period and by each condition. The proportions are not calculated out of the total number of HAA operations. Also, the number of flight hours are pilot's hours in the specific aircraft make and model involved in the accident and not the pilot's total flight hours.
[a] Significant result.

**Table 3**
Defining Events for Helicopter Air Ambulance (HAA) Accidents in 2010-2015 and 2016-2021

| HAA Accidents Grouped by NTSB Defining Events | Number of Accidents, n (%) | | | Percentage Change in Number of Accidents |
|---|---|---|---|---|
| | 2010-2015 | 2016-2021 | Total 2010-2021 | 2010-2015 vs 2016-2021 |
| Total Number of Accidents | 47 (100) | 36 (100)[h] | 83 (100) | −23% |
| Collisions (non-CFIT)[a] | 5 (11) | 6 (17) | 11 (13) | 20 |
| Loss of control in flight (LOC-I)[b] | 7 (15) | 8 (22) | 15 (18) | 14 |
| Controlled flight into terrain (CFIT) | 0 (0) | 1 (3) | 1 (1) | 100 |
| Powerplant mal/fail[c] | 9 (19) | 5 (14) | 14 (17) | −44 |
| Nonpowerplant mal/fail[d] | 1 (2) | 2 (6) | 3 (4) | 100 |
| VFR encounter IMC[e] | 9 (19) | 1 (3) | 10 (12) | −89 |
| Settling with power/hard landing[f] | 7 (15) | 4 (11) | 11 (13) | −43 |
| Miscellaneous/other categories[g] | 9 (19) | 9 (25) | 18 (22) | 0 |

NTSB = National Transportation Safety Board.
[a] Collisions/non-CFIT group includes collision during takeoff/landing−terrain (5), collision with terrain/object/non-CFIT (4), and ground collisions (2) defining events.
[b] Loss of control group includes loss of control in flight (14) and loss of tail rotor effectiveness (1) defining events.
[c] Powerplant mal/fail group includes powerplant sys/com mal/fail (3), loss of engine power (total) (5), and loss of engine power (partial) (6) defining events.
[d] Nonpowerplant mal/fail group includes aircraft structural failures (1), flight control malfunctions (1), and sys/comp mal/fail (nonpower) (1) defining events.
[e] VFR encounter IMC group includes VFR encounter IMC (9) and wind shear (1) defining events.
[f] Settling with power/hard landing group includes settling with power and hard landing (3), abrupt maneuver (2), abnormal runway contact (2), hard landing (3), and low altitude operation event defining events (1).
[g] Other categories include bird strike (2), fuel starvation (2), parts separation from aircraft (2), external load event (1), fire/no impact (1), inflight upset (1), medical event (1), and midair collision (1).
[h] The sum of this column may not be 100 because of rounding.

2. The fatal HAA accident rate per 100,000 FHs appeared to be decreasing between 2010 and 2021, with 0 fatal HAA accidents recorded in 2018, 2020, and 2021.
3. There was a statistically significant reduction in the proportion of nighttime fatal HAA accidents from 2010-2015 (with 15/47 [32%] being fatal) to 2016-2021 (with 3/36 [8%] being fatal).
4. From the collected 83 HAA accident data, more than half of the total HAA accidents in 2010-2015 (57%) and 2016-2021 (53%) were associated with pilots with less than or equal to 500 FHs in the aircraft make and model involved in the accident.
5. Of the fatal HAA accidents, 62% (13/21) in 2010-2015 and 67% (4/6) in 2016-2021 were associated with pilots with less than or equal to 500 FHs in the aircraft make and model involved in the accident.
6. There was a significant decrease in the HAA accidents associated with VFR encounter IMC events from 2010-2015 (19%) to 2016-2021 (3%).

**Table 4**
National Transportation Safety Board (NTSB) Categorization of Contributing or Causal Factors for Helicopter Air Ambulance Accidents in 2010-2015 and 2016-2021

| NTSB Categorization of Contributing or Causal Factors | | 2010-2015 | | 2016-2021 | |
|---|---|---|---|---|---|
| Category Subcategory | Code | Frequency of Instances, n[a] | Percent of Accidents[b] (Out of 47), n (%) | Frequency of Instances, n[a] | Percent of Accidents[b] (Out of 36), n (%) |
| ***Aircraft*** | **01** | **55** | **35 (74)** | **31** | **25 (69)** |
| Aircraft handling/service | 01-01 | — | — | 1 | 1 (3) |
| Aircraft systems | 01-02 | 11 | 8 (17) | 5 | 3 (8) |
| Aircraft structures | 01-03 | 6 | 3 (6) | 2 | 2 (6) |
| Aircraft propeller/rotor | 01-04 | 9 | 6 (13) | 1 | 2 (6) |
| Aircraft powerplant | 01-05 | 9 | 6 (13) | 5 | 5 (14) |
| Aircraft oper/perf/capability | 01-06 | 18 | 15 (32) | 16 | 13 (36) |
| Fluids/misc hardware | 01-07 | 2 | 2 (4) | 1 | 1 (3) |
| ***Personnel issues*** | **02** | **73** | **30 (64)** | **49** | **29 (81)** |
| Physical | 02-01 | 5 | 3 (6) | 2 | 2 (6) |
| Psychological | 02-02 | 10 | 9 (19) | 8 | 6 (17) |
| Experience/knowledge | 02-03 | 4 | 2 (4) | 3 | 3 (8) |
| Action/decision | 02-04 | 23 | 11 (23) | 13 | 12 (33) |
| Task performance | 02-06 | 31 | 25 (53) | 23 | 19 (53) |
| ***Environmental issues*** | **03** | **42** | **25 (53)** | **44** | **21 (58)** |
| Operating environment | 03-01 | — | — | 1 | 1 (3) |
| Physical environment | 03-02 | 15 | 12 (26) | 16 | 14 (39) |
| Conditions/weather/phenomena | 03-03 | 27 | 15 (32) | 26 | 12 (33) |
| Task environment | 03-04 | — | — | 1 | 1 (3) |
| ***Organizational issues*** | **04** | **12** | **6 (13)** | **10** | **4 (11)** |
| Development | 04-01 | 2 | 1 (2) | — | — |
| Management | 04-02 | 2 | 1 (2) | 3 | 1 (3) |
| Support/oversight/monitoring | 04-03 | 8 | 4 (8) | 7 | 4 (11) |
| ***Not determined*** | **05** | **5** | **5 (11)** | **2** | **2 (6)** |

[a] Frequency of instances columns present how many times a specific category and subcategory was listed as contributing or causal factor in the findings in the 47 accidents in 2010-2015 and 36 accidents in 2016-2021. An accident may be associated with more than 1 category and subcategory in findings.
[b] Percent of accidents columns present the number and percent of accidents that had listed a specific category and subcategory in findings. For example, aircraft structures were listed as contributing or causal factor in the findings in 3 (6%) of the 47 accidents in 2010-2015 and 2 (6%) of the 36 accidents in 2016-2021.

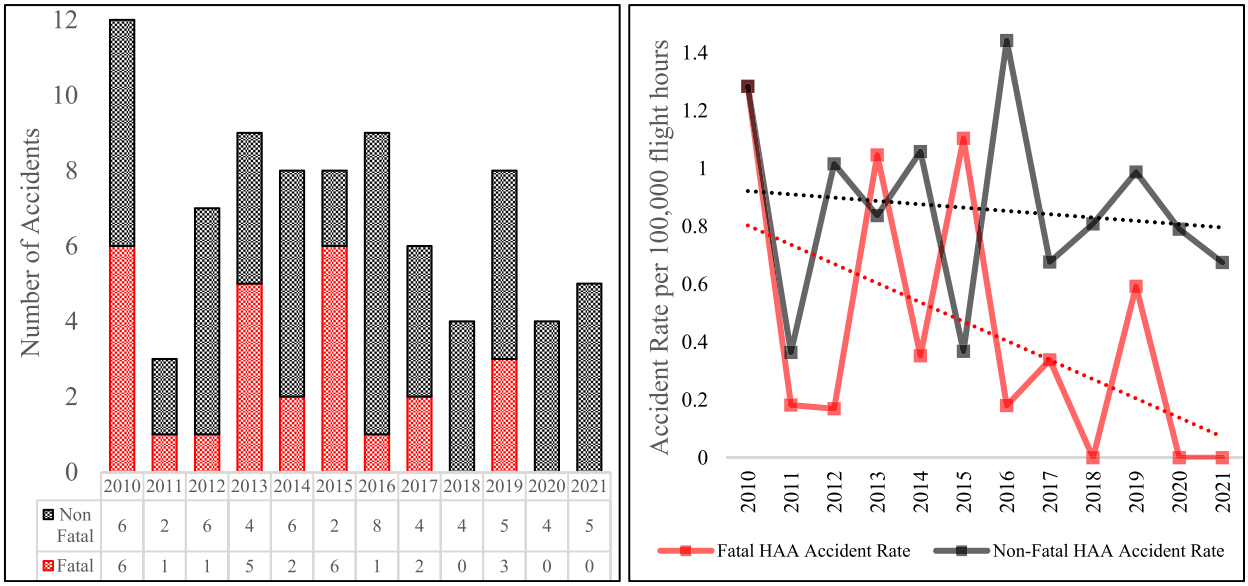


**Figure 1.** Fatal and nonfatal HAA accidents and accident rates in 2010-2015 and 2016-2021.

Note: The accident rates were calculated by dividing the number of accidents by the total rotorcraft air medical (Part 135 and GA) FHs flown by actual use and multiplying by 100,000. The FAA did not publish GA and Part 135 Activity Survey for 2011. In this research, the average of Part 135 and GA rotorcraft air medical hours in 2010 to 2021 was used to obtain the total rotorcraft air medical flight hours for 2011.

7. There was a significant decrease in the fatal HAA accidents associated with the cruise phase of flight from 2010-2015 (30%) to 2016-2021 (11%).
8. Landing, hover and ground, and takeoff accounted for a majority of the HAA accidents in 2010-2015 (53%) and 2016-2021 (72%).

In line with previous studies,[7,11,12] the data in this study indicated a reduction in the accident rate of HAA operations between 2010 and 2021. However, in contrast to these studies,[7,11,12] this research article found that there was a statistically significant decrease in the proportion of fatal HAA accidents from 2010-2015 (21/47 [45%] being fatal) to 2016-2021 (6/36 [17%] being fatal). The decrease in the proportion of fatal HAA accidents from 2010-2015 to 2016-2021 may be attributable to several changes in the HAA operational framework, regulations, safety initiatives, technological advancements, and training improvements, among other reasons. Night flying,[22,50] marginal weather,[21] loss of control in flight,[29] CFIT,[29,51] and IIMC[20] are categories that have been associated with a higher number of fatal accidents in rotary wing operations.

In previous studies, pilots with lower experience were found to be associated with a higher likelihood of HAA nighttime accidents.[16] The results in this article are consistent with previous research[7,16] (ie, pilots with fewer FHs in aircraft make and model [FHs ≤ 500] were associated with a higher proportion of HAA accidents). Further in-depth research is needed to understand the root cause and contributing factors of HAA accidents related to pilots with lower HAA experience (HAA FHs, commercial vs. airline transport pilot certificate, and so on) that may explain the higher proportion of HAA accidents associated with them.

The changes established by the FAA *Final Rule RIN 2120-AJ53*[37] in terms of new regulations, stringent weather minimums, training requirements, and mandatory pilot-in-command instrument type rating (airline transport pilot or instrument flight rules rating) may have contributed to the lower proportion of fatal HAA accidents. The flight simulator training in IMC has been associated with a reduction of spatial disorientation events during marginal weather conditions.[52] The mandated use of on-board equipment, such as a radio altimeter and a helicopter terrain awareness and warning system,[35] may assist pilots in obstacle clearance[53,54] and avoid CFIT accidents. Furthermore, weather information availability and management during HAA operations are critical,[14] and pilots have fewer sources of weather information after takeoff.[23] OCCs[39] may help to provide accurate and reliable weather data to HAA pilots and assist them in making informed decisions during marginal weather conditions. There may be other reasons for the reductions noted in HAA accidents. Future research may seek to determine causal relationships.

The retrospective nature of this study brings limitations. As in any database or report, the data are assumed to be accurate, but they are susceptible to misclassification, typographical errors, or incomplete information. Calculating HAA accidental rates using data from the FAA voluntary survey[46] carries inherent limitations, including the risk of response bias,[55] because participants' self-reporting might not accurately represent the number of HAA FHs per year. These limitations underscore the necessity for a balanced interpretation of results and emphasize the need for further studies to mitigate these constraints. In this study, the proportions are conditional, meaning that the number of fatal accidents is a proportion from the total number of HAA accidents and not from the number of HAA operations (eg, the total annual number of HAA flights or HAA FHs). More research and data collection are needed to find the total number of HAA operations so that the proportions of HAA accidents (and fatal HAA accidents) to HAA operations can be estimated. One major limitation of this article is the lack of the total number of HAA operations to serve as a grand denominator; therefore, the results must be interpreted very cautiously,[55] and readers must understand that the proportions in this article are of fatal HAA accidents to total HAA accidents and not to total HAA operations. The focus of this study has been on comparing the proportions of fatal HAA accidents between 2 time periods that involved changes in HAA regulatory framework, training procedures, and technological advancements. The findings and limitations of this research also highlight the need for future research to develop methods to accurately estimate the number of HAA operations, the number of patients transported, and/or FHs.

## Conclusions

In regard to HAA accidents and their association with flight experience, this article found that lower flight experience (FHs ≤ 500) in aircraft make and model was associated with higher proportions of fatal HAA accidents; however, there may be other factors such as flight experience in a specific geographic area/terrain, improper supervision, poor risk assessment, inaccurate weather interpretation, or poor decision making that may also contribute to HAA accidents, especially with less experienced pilots. Therefore, based on the findings of this study, HAA operators may need to consider establishing or modifying training and supervision programs for pilots with fewer than 500 hours on the aircraft operated by the company. Regulators and HAA operators may need to strengthen regulations and procedures for unprepared landing zones and heliports to address HAA accidents during landing, takeoff, and hover and ground operations. Technological advancements in modern HAA fleets and state-of-the-art onboard equipment (eg, night vision goggles, avionics, and 4-axis autopilot) may assist pilots during high workload situations such as night operations, marginal weather conditions, and unprepared landing areas. Further research is needed to understand the root causes and/or contributing factors to HAA accidents and to study the number of accidents per number of HAA operations.

## Declaration of Competing Interest

The author(s) have no relevant disclosures. There was no grant funding or financial support for this manuscript.

## CRediT authorship contribution statement

Gustavo Sanchez: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Resources; Validation; Visualization; Writing—Original draft preparation; Writing—Reviewing, Editing. Shantanu Gupta: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Writing—Original draft preparation; Writing—Reviewing, Editing. Mary E. Johnson: Conceptualization; Methodology; Project administration; Supervision; Visualization; Writing—Reviewing, Editing.

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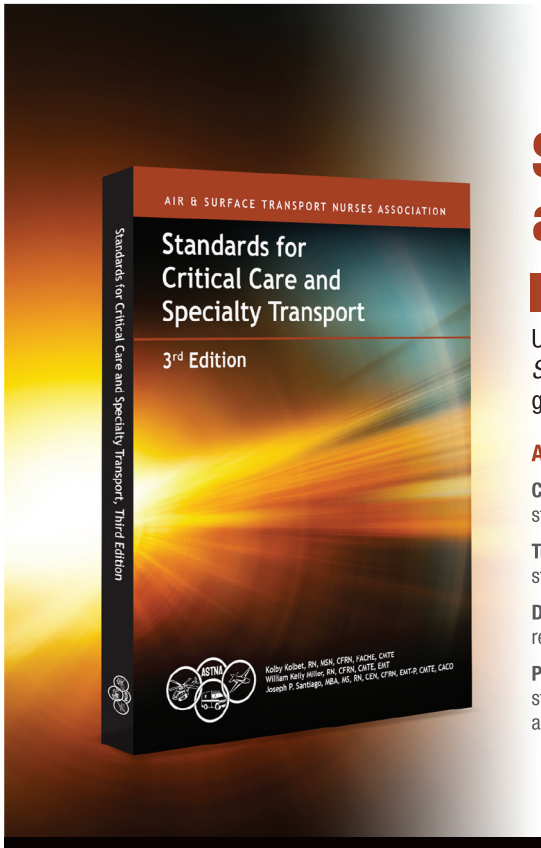


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