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Low-Level Helicopter Flights: Safety and Operational Specificity

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Abstract

Low-level flight or maneuvering defines a flight phase that is particularly common and, in some cases, central to helicopter operations, but brings several safety concerns. At low altitude, helicopters are more susceptible to collisions with objects, while there is also limited time and space in which to perform an emergency landing. A total of 403 helicopter accidents in the low-level flight phase that occurred between 1 January 2009 and 31 December 2022 in the US were analyzed for their most common causes and differentiated based on the type of flight operation to gain insight into low-level flight accidents. It is shown that, for low-level flights, the proportion of fatal accidents in flights conducted under Federal Aviation Regulations Part 91, General Aviation, is 30%, but in flights conducted under Part 137, aerial application or agricultural flights, only 12%. Logistic regression analysis shows that while controlling for other factors, the proportion of fatal accidents was significantly higher in Part 91 operations. Flight experience measured as total flight hours was not a significant factor for estimating fatality. It is recommended that low-level helicopter training includes low-altitude autorotations in simulators to optimize the mitigating effect of this emergency procedure in this flight phase with a specific focus on Part 91 operations.

Keywords: flight phase; wire strike; autorotation; fatality; Federal Aviation Regulations

1. Introduction

An analysis of accident rates and trends in 2018 has shown little progress in accident prevention for helicopters [1]. In the history of helicopter safety, it is said that: “Prevention of accidents from material failure causes is a fairly mature process, whereas the ability to identify and correct specific human error in helicopters is still in its infancy” [2]. A dataset of over five thousand accidents from the National Transportation Safety Board (NTSB) was used in 2015 to identify the most frequent occurrences in helicopter accidents, which included loss of control in-flight and engine failure, but did not distinguish between different flight operations [3]. A dataset of a few hundred accidents related to European helicopter operations listed the most common causes and distinguished between General Aviation, Commercial Air Transport operations, State Flights, and “Aerial work.” The latter is defined by ICAO as “an aircraft operation in which an aircraft is used for specialised services such as agriculture, construction, photography, surveying, observation and patrol, search and rescue, aerial advertisement, etc.” [4]. The limited numbers of this latter study did not allow for analyses of each of the specialized services that Aerial work includes.

Off-shore and helicopter emergency medical services with helicopters (HEMS) stand out as specialized operations that have received extensive attention in the accident analysis

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literature. Comprehensive reviews include accidents of the United Kingdom [5], United States [6,7], Australia [8], and, specifically, Germany [9] where HEMS has the longest history. The specificity of the operation has highlighted night [10,11] and weather-related accidents [12] on the one hand, and fatigue and shift length on the other to be of particular concern [13,14]. Similarly, in off-shore accident analysis, night-time operations feature prominently [15].

A study across all helicopter operations but focusing on night flights concluded that a combination of night operations and reduced visibility due to weather is especially dangerous [16]. Weather has been studied across helicopter operations [17]. For instance, helicopter accidents that occurred when encountering fog were fatal in 67% of the cases [18]. These findings, however, are not specific to a particular flight phase or aircraft operation. Indeed, causes related to light and visibility that are frequently associated with fatalities in helicopter operations are also the main causes found in General Aviation studies that mostly focus on fixed-wing aircraft [19,20].

Other specific operations have received only cursory attention but share some of the particulars found in, for instance, HEMS. Aerial application and agricultural flights [21], external load operations [21,22], helicopter emergency medical services, and aerial observation flights are four types of operations that make extensive use of the low-level flying capabilities of helicopters, while other activities, such as sightseeing, may enter regularly into the same flight phase. This aspect of helicopter operations may have safety issues not easily identified in the general datasets used in the studies mentioned above. Moreover, differences between operations, as opposed to the study of one specific operation, are rarely identified in the accident analysis literature.

Federal Aviation Regulations (FAR) stipulate additional training for agricultural and external load operations. Flight training and experience are often highlighted as the main mitigating strategy for accident prevention, and a comparison between flights conducted under different regulations may confirm this point [23]. However, a better understanding of the causes of accidents in low-level flight phases is required to identify which parts of training are of primary concern.

Low-altitude/aerobatic flight operations are a phase of flight that includes the following subphase as defined by the National Transportation Safety Board (NTSB): "Intentional low-altitude flight not connected with a landing or takeoff, usually in preparation for or during observation work, demonstration, photography work, aerial application, training, sight seeing, ostentatious display, or other similar activity. For rotorcraft, this also includes hovering (not associated with landing or takeoff) and handling external loads" [24]. This flight phase is termed low-altitude/maneuvering in the NTSB accident database.

Low-level or low-altitude flight or maneuvering is a flight phase that is particularly common and, in some cases, central to helicopter operations. Although the NTSB does not specify the altitude, helicopters are uniquely suited for low-level flight, due to their maneuverability and low-speed capabilities, but it brings several safety concerns. The National Transportation Safety Board (NTSB) has included this flight phase as a separate category in its accident database to facilitate investigations.

It is posited that at least two aspects of low-level flight affect its safety compared to other flight phases. First, there is an increased risk of collisions with objects. Take-off and landings occur in air space clear of such dangers but low-level flights may occur outside airfields. Second, recovery during an emergency is impaired at low levels if a certain combination of forward speed and altitude is not maintained and if the pilot has no experience recovering from low-level flight situations.

1.1. Collisions with Objects at Low Altitude

At low altitude, aircraft are more susceptible to collisions with objects. These can include collisions with trees and poles but typically concern power lines since wires cannot always be detected visually [25]. More importantly, pilots have little recourse after a wire strike, making such collisions especially dangerous. NTSB reports may include collisions with objects but do not necessarily specify the object in the summary of their findings. Instead, only an examination of the narrative statement in each report will reveal the type of object, such as power lines, and may support the statement that wire strikes are a relatively frequent occurrence in low-level flight accidents and should be of primary concern.

1.2. Autorotations at Low Altitude

An additional safety concern, and in the case of collisions also a confounding problem, is the limited time and space in which to perform an emergency landing. An autorotation, a helicopter landing procedure in which the power of the engine is decoupled from the rotor system, allows for a safe landing in case of engine or tail rotor malfunctions. Autorotations are practiced at length during helicopter pilot training but are rarely practiced below 500 ft altitude [26]. In some cases, autorotations are also not practiced towards a full-stop landing on the ground due to manufacturer restrictions in the flight manual [23].

Autorotations at low level need to take place within the limits defined by the height–velocity diagram, which is specific for each type of helicopter, sometimes referred to as the dead-man's curve [26]. Only with a certain combination of forward speed and altitude is an autorotation possibly successful. A total or partial loss of engine power typically triggers a pilot to enter an autorotation to attempt a safe landing of the helicopter. The presence of an autorotation is not necessarily mentioned in the findings of NTSB accident reports but can still be found in the narrative statement and may support the suggestion that accidents where pilots attempted an autorotation less often led to a fatality.

1.3. Flight Rules

Aerial application and external load operations are conducted under different flight rules: Code of Federal Regulation, Title 14, Chapter 1, Subchapter G, Part 137 and Part 133, respectively [27]. Other operations in this study are either conducted under Part 91, General Aviation, or concern Public Aircraft, which are aircraft operated by government agencies. Additional flight rules and the special training required under these regulations would suggest that low-level flying accidents under Parts 137 and 133 are perhaps less common. But since in these cases almost the entire operation may be conducted at a low level, this is not likely. Instead, accidents at low level could be less often fatal. Also, autorotations may be more often attempted, leading to damage but to less injury, particularly if pilots are more often exposed and trained to deal with low-level emergencies. A comparison of flight operations may support this idea.

In the following analysis, accidents that occurred during low-level flight are compared based on the different types of flight operations, using, where possible, a five-way distinction between Part 137, Part 133, Public Aircraft, Part 91 General Aviation (Aerial observation) and Part 91 General Aviation (other) (see Table 1). In addition, the frequency of wire strikes and the presence of (un)successful autorotations are given additional attention to identify specific dangers as well as possible procedures that may mitigate the frequency or seriousness of an accident. A previous study [21] compared Part 137 and Part 133 helicopter accidents, and also identified wire strikes and autorotations, but only included an analysis of the flight phase in the case of Part 137. The current study builds upon this work by extending the comparison to other operations and, in contrast, by using the low-level flight phase as a basis for comparison.

Table 1. Aircraft operations.

Code of Federal Regulations (FAA)	Type of Operation	Additional Pilot Requirements
Part 91	General Aviation	
Part 91 (Aerial observation)	General Aviation	
Public Aircraft	Aircraft fulfilling a government function	
Part 133	Rotorcraft external-load operations	Knowledge and skill tests
Part 137	Agricultural aircraft operations	Knowledge and skill tests

The NTSB identifies one occurrence as the defining event of an accident. When comparing different outcomes for helicopter operations in accidents occurring during the low-level/maneuvering flight phase, the defining event as defined by the NTSB is not necessarily "low-level flying". A separate analysis of the defining event as well as the most common causes of the accidents for each of the operations is added to obtain a more fine-grained analysis.

The main objective of this study is to conduct a detailed analysis of helicopter accidents that occurred during low-level flight or maneuvering at low altitude with a separate analysis of the defining event as well as the most common causes of accidents for each type of operation. In line with the main objective, the following two hypotheses were formulated:

Hypothesis 1 (H1): *Different types of helicopter flight operations show a variation in the relative number of fatal accidents based on pilot experience.*

Hypothesis 2 (H2): *Causes related to weather and visibility are equally common in low-level helicopter operations compared to General Aviation, but wire interference increases the relative number of fatalities while autorotations decrease the relative number of fatal accidents during low-level flight.*

2. Materials and Methods

Member States of the International Civil Aviation Organization (ICAO) are mandated to investigate accidents and incidents (ICAO Annex 19). The NTSB is the US authority to do so. In this study, a total of 403 helicopter accidents from 1 January 2009 to 31 December 2022 that took place during the low-altitude/maneuvering flight phase were extracted from the US NTSB online database using the Case Analysis and Reporting Online (CAROL) query tool [28]. Only accidents that took place in the United States with completed reports were included.

The accident reports include standardized items of information about the pilot(s), aircraft, airport, weather and wreckage. Each report also includes a narrative statement about the history of the flight, the defining event, a list of findings and a conclusion about the causes of the accident.

Key variables used in the analysis were obtained from the following standard NTSB coded fields: Phase of Operation (i.e., flight phase), Flight Time (i.e., pilot's total flight hours), Flight Conducted Under (i.e., operational category), and Injuries. Wire involvement and autorotation attempt were reconstructed from the narrative statement. Other coded fields, including Engines (i.e., the number and type of engine), Condition of Light (e.g., day or night), and Conditions at Accident Site (i.e., Visual Conditions or Instrument Meteorological Conditions) were collected and noted in the descriptive statistics. Accidents with one or more fatalities were coded as fatal accidents.

The key response variable is whether or not the accident was fatal. To test whether fatality rate is dependent on a specific (typically binary) factor, we use Fisher's exact test. Relations were considered significant if p-values were below 0.05. In addition, we fit a main effect logistic regression model to simultaneously test for the effect of different factors on fatality.

2.1. Denominator Data and the Proportion of Fatal Accidents

There are no denominator data available that could measure to what extent pilots have been exposed to the risks of low-level flight. As a proxy for risk, the proportion of fatal accidents is used since this metric can be compared between different operations [29]. However, the differences in exposure, mission frequency, or, in some cases, reporting practices will not be reflected in this way. It is noted that any causal or risk-based conclusions cannot be supported. Instead, the conclusions are based on comparisons of accident outcomes and not on differences in risk.

2.2. Low-Level Flight

The NTSB category "low altitude/maneuvering" is categorical and investigator-assigned. The NTSB does not provide a specific altitude range to this definition. While it is reasonable to assume that these low altitudes are generally within 500 ft above ground level, this information could not be operationalized in the analysis as it was not provided or not consistently provided in the accident reports.

In the case of helicopters, low-level flight may introduce additional risk when the aircraft operates outside its height–velocity diagram and may not have enough speed or altitude to recover with an autorotation. Such an observation would not only require the NTSB to report the exact height of the helicopter at the time of accident but also its forward speed, neither of which are available in most if not all of the accident reports. While important as a theoretical consideration, this element of low-level flight could not be empirically tested in this dataset.

2.3. Pilot Experience

The number of total flight hours is used as a metric for pilot experience. Other metrics that are sometimes available in the accident reports include total flight hours in the make and model of the aircraft that was present in the accident, Pilot in Command in all aircraft, and flight hours in the last 90 days, 30 days, and 24 h in all aircraft, all of which would provide more pertinent or additional data for analysis. Unfortunately, these categories are infrequently and not consistently reported. Pilot experience could be further informed by the certificates, aircraft ratings, and instrument and instructor ratings. For the purposes of this study, experience with low-level flying and mission-specific hours would be especially helpful but remains unavailable. Despite these limitations, the availability of the metric of total flight hours continues to be used in General Aviation accident analysis but needs to be interpreted with caution.

2.4. Wire Strikes and Autorotations

Autorotations are included in the analysis if they were reported in the narrative of the accident report. Data from the narrative statements create a potential bias since the presence of autorotations is not a mandatory or consistent category that is reported by each NTSB investigator. In addition, autorotations are usually attempted when conditions allow. The quality of the attempt, the timing, and the altitude at which the attempt took place are rarely reported. Furthermore, an attempted autorotation may be an indication that the accident was already in a scenario that could be survived by way of an autorotation.

The type of helicopter, in particular the number of engines, affects the kind of situation in which an autorotation is safe to conduct. The dataset does not allow the many types of helicopters to be distinguished in a way that allows for statistical analysis. However, the number and type of engine is consistently reported and may assist the analysis.

Similar to autorotations, wire strikes are only reported if they were mentioned in the narrative statement. Details about such a strike, such as the speed of impact, the location, and any aircraft control after the strike, are not or not consistently reported and could not be made part of the dataset in this study.

In short, the presence of wire strikes and autorotations were included in this study but have important reporting limitations.

3. Results

Out of the 403 low-level accidents, 91 (22.6%) reported a fatality. Only 17 accidents occurred at night and 7 were in IMC conditions, suggesting that these conditions do not explain the relatively high percentage of fatal accidents in low-level flight compared to General Aviation. These numbers can be made more insightful by distinguishing between different flight operations and specific causes of accidents.

3.1. Operational Specificity and Relative Number of Fatalities

Low-altitude accidents occurred mostly under Part 91 (N = 183), which pertains to General Aviation (GA), and those occurring under Part 137 (N = 164), which governs operations for agriculture or aerial application. A smaller set concerned Public Aircraft (N = 25) and external load operations, the latter of which take place under Part 133 (N = 31).

Flight operations to a large extent determine the presence of low-altitude maneuvering. This is at least in part reflected by the percentage of accidents that occur in low-altitude flight phases in each flight operations category. For instance, in Part 137 (agriculture or aerial application), 65% (164 out of 251) of all accidents (i.e., including all flight phases) in the NTSB database of the selected time period occurred during low-level maneuvering, among which, more strikingly, 87% (20 out of 23) of the fatal accidents concern those that were in a low-level flight phase. Table 2 compares the number of low-altitude accidents to the number of all accidents, separately for each flight operation category. Fisher's exact test is used to test the proportional differences in fatality between low-altitude and not-low-altitude accidents, with p-values reported in Table 2. This information is visualized in Figure 1.

Table 2. Number of fatal accidents as part of the total number of accidents for each operation.

2009–2022	All Accidents	All Accidents, Fatal	Low-Alt Accidents	Low-Alt Accidents, Fatal	Fisher Exact
Part 91	1204	191 (15.9%)	183	55 (30.1%)	$p < 0.001$
Public	119	19 (16.0%)	25	9 (36.0%)	$p = 0.005$
Part 133	97	25 (25.8%)	31	7 (22.6%)	$p > 0.05$
Part 137	251	23 (9.2%)	164	20 (12.2%)	$p = 0.022$
Total	1671	258 (15.4%)	403	91 (22.6%)	$p < 0.001$

The percentage of fatal accidents among all accidents in the same time period can be used as an indication of risk in lieu of denominator data, such as low-level flight movements [29]. In Table 2, this metric shows that, among all Part 137 (Agriculture or Aerial Application) accidents, 9.2% are fatal, which is low compared to the other three types of operation. In addition, while relatively many accidents in Part 137 were in the low-altitude flight phase, a much smaller percentage of 12.2% turned out to be fatal compared to the other three operations.

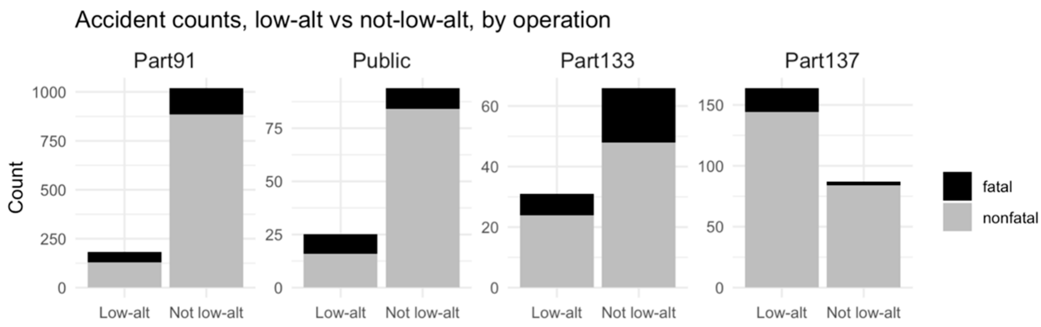

Figure 1. Proportional differences in fatality between low-altitude and not-low-altitude accidents.

Fisher's exact test was used to determine if the fatality rate depends on being low-altitude (p-values reported in Table 2). We see that the percentage of fatal accidents is significantly higher when there is a low-altitude flight phase then when there is none, among Part 91, Public, and Part 137 operations.

When low-altitude flying is also the defining event in the accident report according to the NTSB investigators, the percentages show a similar pattern (i.e., higher fatality rate for Part 91 and Public Aircraft compared to Part 137) (see Table 3).

Table 3. Low-level flying as a defining event compared for different operations.

2009–2022	Low-Alt Defining Event Total Accidents	Low-Alt Defining Event Fatal Accidents
Part 91	44	12 (27.3%)
Public	3	2 (66.7%)
Part 133	7	2 (28.6%)
Part 137	39	6 (15.4%)

3.2. *Analysis of Causes*

The most common causes in this dataset were loss of engine power, fuel-related causes, and collisions with terrain or objects (see Table 4). It is noted that multiple causes may be listed for one accident. The ratio of fatal and non-fatal fuel-related causes was significantly higher for Part 91 accidents than for the other operations combined (Fisher exact = 0.0142, $p < 0.05$).

Table 4. Main causes per operation excluding wire or power line strikes.

	Fuel (Non-Fatal)	Fuel (Fatal)	Partial Engine Power (Non-Fatal)	Partial Engine Power (Fatal)	Total Engine Power (Non-Fatal)	Total Engine Power (Fatal)
Part 133	2	0	3	0	2	0
Part 137	12	0	8	0	19	2
Part 91	5	4	12	1	11	5
Public Aircraft	0	0	2	0	2	1
Total	19	4	25	1	34	8

While the ratio of fatal and non-fatal accidents differed per operation, this ratio was not significantly different between operations when the cause was a loss of engine power ($p > 0.05$).

The seriousness of both fuel-related and engine-power-related accidents may be mitigated by emergency landings using an autorotation procedure, which we investigated separately.

Other causes specific to helicopter flight, such as loss of tail rotor effectiveness, which occurred 15 times, of which 3 (20%) were fatal, were too few to allow for a meaningful comparison between the different operations.

3.3. The Role of Autorotations in Low-Level Flight Accidents

Autorotations occurred during 104 (25.8%) of the accidents and these accidents were fatal in 16 (15.4%) cases but these numbers differed significantly between the different types of operations (see Table 5). Note that the two dimensions of the Fisher exact test are listed in the same row.

Table 5. Presence of autorotations during low-level helicopter flight accidents.

	Without Autorotation, Non-Fatal	Without Autorotation, Fatal	Autorotation Included, Non-Fatal	Autorotation Included, Fatal	Fisher Exact
Part 133	19	6	5	1	$p > 0.05$
Part 137	106	18	38	2	$p > 0.05$
Public Aircraft	9	7	7	2	$p > 0.05$
All Part 91	69	36	26	7	$p > 0.05$
Total	224	75	88	16	$p = 0.0421$
Part 91 without Aerial Observation	48	28	14	3	$p > 0.05$
Part 91 Aerial observation only	21	8	12	4	$p > 0.05$

In all cases, the percentage of fatal accidents during flights where an autorotation was attempted was substantially lower than the overall percentage of fatal flights per operation.

3.4. Analysis of Wire Strikes

Wire or power line strikes occurred in 137 accidents, of which 24 (17.5%) were fatal (see Table 6). Note that the two dimensions of the Fisher exact test are listed in the same row. Although there are differences per operation in the percentage of fatal wire or power line strike accidents, these differences are not significant. In addition, differences within each operation showed that the percentage of fatal accidents after a wire or power line strike is not significantly different from the percentage of fatal accidents more generally.

Table 6. Presence of wire or power line strikes during low-level helicopter flight accidents.

	Without Wire/Power Line Strikes, Non-Fatal	Without Wire/Power Line Strikes, Fatal	Wire/Power Line Strikes, Non-Fatal	Wire/Power Line Strikes, Fatal	Fisher Exact
Part 133	8	2	16	5	$p > 0.05$
Part 137	55	6	89	14	$p > 0.05$
Public aircraft	8	4	8	5	$p > 0.05$
All Part 91	95	43	0	0	$p > 0.05$
Total	199	67	113	24	$p > 0.05$

3.5. Analysis of Pilot Experience

The pilots varied considerably with regard to total flight experience as measured by total flight hours accrued; the hours that were reported ranged from a few to 38,000 h, with a mean of 6500 h and a median of 3914 h.

We made four categories of flight experience based on numbers often used in the industry. A total of 500 h is often a minimum for commercial pilots while 1500 h is equivalent to the minimum for an air transport license, and 5000 h was chosen to allow for a meaningful comparison between operations (see Table 7). No significant differences were found (see Section 3.6). In 15 accidents, pilot experience was not reported.

Table 7. Pilot experience and low-level helicopter flight accidents per operation.

Flight Experience	≤500, Non-Fatal	≤500, Fatal	>500 and ≤1500 Non-Fatal	>500 and ≤1500 Fatal	>1500 and ≤5000, Non-Fatal	>1500 and ≤5000, Fatal	>5000, Non-Fatal	>5000, Fatal
Part 133	0	0	3	0	6	2	14	4
Part 137	7	0	24	4	49	6	60	10
Public aircraft	0	0	0	1	10	2	6	6
All Part 91	18	6	31	10	33	20	36	19
Total all operations	25	6	58	15	98	30	116	39

3.6. Logistic Regression

We fit a main-effect logistic regression model with 'fatal' versus 'non-fatal' as the response variable. The model was fitted using R version 4.2.2 and the standard *glm* function from the base stats package. Results are reported in Table 8. We included the two variables that were of main interest (wire strike and autorotations), light conditions, as they are a prominent factor in previous literature, and added the number of engines as a possible confounding variable for autorotations. We also included the total flight hours of the pilot as a proxy for flight experience. The variable is categorized based on the cutoffs described in Section 3.5 and Table 7. The type of helicopter, in particular the number of engines, affects the kind of situation in which an autorotation can be safely conducted. The dataset does not allow the many types of helicopters to be distinguished in a way that allows for statistical analysis. For flight operations, Part 137 (agriculture or aerial application) is used as the baseline category as it is the least fatal.

We determined that Part 91 flights (compared to Part 137) are significantly more associated with fatality; the odds of fatality are increased by 3.7 fold. Flights in dark conditions are significantly more often associated with fatality, with the odds of fatality increasing by 4.14 fold.

A total of seven predictors were considered in building the logistic regression model: apart from the six included in the reported model in Table 8, we have omitted the engine type (reciprocating or turbine). The likelihood-based Akaike Information Criterion (AIC) was used to inform model selection. The "best" model (i.e., lowest value of AIC, 400) is the one with engine type and wire strike both omitted, whereas we included wire strike as a variable of interest. The reported model is similar to the best AIC model in terms of coefficient significance and has an AIC value of 402. We note that the full main effect model is also similar, with an AIC value of 404.

Furthermore, we did not detect serious multicolinearity issues among the predictors. Pairs of variables with a correlation coefficient greater than 0.1 in maginitude are reported in Table 9 (Spearman correlation was used for the categorized flight hour variable; other cases involve only dichotomous variables, so Spearman and Pearson correlation coefficients are equivalent). Engine type is weakly correlated with a few other predictors (for instance, pilots of turbine engines tend to have more flight hours than pilots of reciprocating engines, on average). This supports the omission of engine type from the model. The interaction terms between flight operation categories and dark/light conditions are not significant. This is not surprising due to the small cell counts (only 17 dark accidents in total).

Table 8. Coefficient estimates of logistic regression model. Exponentiated coefficient estimates (i.e., odds ratio) and the corresponding 95% confidence intervals are also reported. Significant coefficients are highlighted in bold.

Predictor	Reference	Coef. Estimate	Odds Ratio	95% CI of Odds Ratio	*p*-Value
Public	Part 137	0.99	2.69	0.89–7.63	>0.05
Part 91		**1.31**	**3.70**	**1.69–8.79**	**0.002**
Part 133		0.46	1.58	0.52–4.27	>0.05
Wire strike	No wire strike	0.19	1.21	0.54–2.83	>0.05
Two engines	One engine	0.74	2.10	0.56–8.10	>0.05
Autorotation	No autorotation	−0.61	0.55	0.28–1.01	>0.05
Flight hours between 500 and 1500	Flight hours < 500	0.29	1.34	0.46–4.28	>0.05
Flight hours between 1500 and 5000		0.53	1.70	0.63–5.15	>0.05
Flight hours > 5000		0.67	1.96	0.74–5.89	>0.05
Dark	Light	**1.42**	**4.14**	**1.36–13.44**	**0.013**

Table 9. Correlation coefficient between predictors.

Variable 1	Variable 2	Correlation Coefficient
Engine type	Flight hours	0.257
Engine type	Wire strike	0.207
Engine type	Number of Engines	0.175
Engine type	Dark	0.143
Number of Engines	Dark	0.122
Number of Engines	Autorotation	−0.1

4. Discussion

The dangers of low-altitude flying with helicopters are confirmed by the high proportion of fatal accidents compared to General Aviation. This proportion, however, is shown to be different per operation. The proportion of fatal accidents in flights conducted under FAR Part 91, General Aviation, is 30%, or even 36% during Aerial Observation flights, which is particularly disconcerting given that the proportion of fatal accidents for General Aviation more broadly is 20% [20]. In contrast, the proportion of fatal accidents for low-level flights conducted under FAR Part 137, aerial application or agricultural flights, and Part 133, sling-load operations, is 12% and 22% respectively.

While we hypothesized differences existed between the various operations in terms of fatality rate, this difference was not explained by the number of flight hours, a common proxy for flight experience. However, conclusions regarding pilot experience apply to survivability once an accident has occurred in the low-level flight phase and do not pertain to accident prevention or overall operational safety. In addition, other factors determining flight experience could be more meaningful.

Also, with only 17 accidents occurring at night and 7 in IMC conditions, the most common conditions known to affect the number of fatal helicopter accidents more generally were largely absent [16,17].

One specific concern for low-level flights, autorotations, showed that the ratio of fatal accidents to non-fatal ones was lower in low-level flight accidents where an autorotation had taken place, but this was no longer significant in the logistic regression model. It is important to note that factors enabling an autorotation attempt, such as the altitude margin, may co-vary with survivability, even if not directly measurable in the dataset. Furthermore, the analysis identifies an association between an attempted autorotation and lower fatality odds, but cannot demonstrate a causal effect. Furthermore, it is possible that these accidents already had favorable circumstances that then also allowed an autorotation. Still, a low-level flight phase makes any autorotation challenging. Training autorotations outside or barely within the height–velocity diagram of a helicopter's manual should only be attempted in simulators and are not part of mandatory training curricula. The mitigating effect of such autorotations even if they are only partially successful would require additional research, but the frequency of accidents in low-level operations suggests that such a benefit could exist.

The second concern, wire or power line strikes, led to fatal accidents but in lower percentages. In other words, wire and power line strikes do not contribute significantly to the percentage of fatal accidents in low-level flight and do not help to explain the relatively high percentage of fatal accidents in this flight phase. This does not imply that wire strikes are less dangerous. Reporting biases and limitations are likely to have affected the statistical outcome. The NTSB data on wire strikes, however, do not assist in explaining the high proportion of fatal accidents during the low-level flight phase.

Experience in terms of flight hours did not affect the ratio of fatal and non-fatal accidents in the low-level flight phase. This is surprising as it was hypothesized that flight experience would mitigate the percentage of fatal accidents. This result may expose the limitations of total flight hours as a proxy for flight experience. This problem is amplified in this study, as experience in low-level flying is neither represented well by total flight hours nor by the other flight hour categories offered by the NTSB reports. It is possible or even likely that experience mitigated the total number of low-level flight accidents, but in the absence of denominator data for low-level flying, this cannot be ascertained with the current dataset.

5. Conclusions

This research indicates that the differences between helicopter and General Aviation operations are significant, both in terms of cause types and the relative number of fatalities, and that these differences cannot be fully explained by pilot experience as measured by total flight hours. This finding is partially supported by previous studies on aerial application and external load operations [21], which also found that flight hours were not a major factor. Therefore, we can conclude that hypothesis H1 is not confirmed. In addition, it was hypothesized (H2) that causes related to weather and visibility are as common in low-level helicopter operations as in General Aviation, but this is also not supported. On the contrary, few such causes are identified. This aligns with prior research on HEMS, where light conditions are only slightly overrepresented [7]. Additionally, it cannot be confirmed that wire-strike accidents at least partly explain the relative number of fatal accidents. Thus, hypothesis H2 is also rejected.

Implications

Our findings point to specific concerns in relation to low-level helicopter flights. Operational differences, however, suggest that flights conducted under General Aviation flight rules require the most attention. Experience with emergencies in low-level flying circumstances commonly occurs only in the advanced stages of training. Indeed, the dangers of wire strikes and low-level engine failures are probably best taught and trained in a simulator environment, which have been employed for several high-risk operations [30].

The literature suggests that low-level autorotations are the main element that could mitigate fatalities. Although this is not a proven intervention outcome, simulator training of an autorotation at low levels may add to this advantage, possibly as part of scenario-based training already developed by the FAA [31,32]. Low-level autorotations outside the prescribed height–velocity diagram may still be effective and future research may provide more detail about this effectiveness and the viability of training. Pilots in this study's sample ranged from inexperienced to very experienced; therefore, the dangers of low-level flying need to be part of ongoing training of pilots as opposed to their initial training only.

Additional flight rules for low-level flight for operations under Part 91 may be opportune in light of the significant differences between operations in the dataset. In particular, pilots involved in aerial observations at low levels could benefit from additional training, which could range from awareness training to simulator hours. The relative high percentage of fatal accidents, even if compared to General Aviation generally, suggests that an intervention of this sort has much to gain in helicopter safety.

Some environmental aspects of flights operated under Part 137, agricultural flights, stand out when it concerns low-level flight. Pilots typically visit the same fields over time. In contrast, sling-load, EMS, and aerial observations are rarely in the same location, so any experience with a particular geography is less likely. In addition, Part 137 low-level operations almost exclusively take place outside built-up areas. Future research may show if those aspects explain some of the positive differences that this flight operation shows in this dataset.

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References

1. Churchwell, J.S.; Zhang, K.S.; Saleh, J.H. Epidemiology of helicopter accidents: Trends, rates, and covariates. *Reliab. Eng. Syst. Saf.* **2018**, *180*, 373–384. [CrossRef]
2. Fox, R.G. The History of Helicopter Safety. In *Proceedings of the International Helicopter Safety Symposium, Montréal, QC, Canada, 26–29 September 2005*; American Helicopter Society International: Fairfax, VA, USA, 2005; pp. 26–29. [CrossRef]
3. Rao, A.H.; Marais, K. Identifying high-risk occurrence chains in helicopter operations from accident data. In *Proceedings of the 15th AIAA Aviation Technology, Integration, and Operations Conference, Dallas, TX, USA, 22–26 June 2015*; American Institute of Aeronautics and Astronautics: Reston, VA, USA, 2015.

4. Van Hijum, M.; Masson, M. *Final Report—EHEST Analysis of 2000–2005 European Helicopter Accidents*; European Helicopter Safety Team: Cologne, Germany, 2010. Available online: www.easa.europa.eu/document-library/general-publications/ehsat-safety-analysis-reports-former-ehest (accessed on 15 February 2026).
5. Chesters, A.; Grieve, P.H.; Hodgetts, T.J. A 26-year comparative review of United Kingdom helicopter emergency medical services crashes and serious incidents. *J. Trauma Acute Care Surg.* **2014**, *76*, 1055–1060. [CrossRef]
6. Baker, S.P.; Grabowski, J.G.; Dodd, R.S.; Shanahan, D.F.; Lamb, M.W.; Li, G.H. EMS helicopter crashes: What influences fatal outcome? *Ann. Emerg. Med.* **2006**, *47*, 351–356. [CrossRef]
7. Boyd, D.D.; Macchiarella, N.D. Occupant injury severity and accident causes in helicopter emergency medical services (1983–2014). *Aerosp. Med. Hum. Perform.* **2016**, *87*, 26–31. [CrossRef] [PubMed]
8. Holland, J.; Cooksley, D.G. Safety of helicopter aeromedical transport in Australia: A retrospective study. *Med. J. Aust.* **2005**, *182*, 17–19. [CrossRef]
9. Hinkelbein, J.; Schwalbe, M.; Neuhaus, C.; Wetsch, W.A.; Genzwürker, H.V. Incidents, accidents and fatalities in 40 years of German helicopter emergency medical system operations. *Eur. J. Anaesthesiol.* **2011**, *28*, 766–773. [CrossRef]
10. Aherne, B.B.; Zhang, C.; Newman, D.G. Pilot domain task experience in night fatal helicopter emergency medical service accidents. *Aerosp. Med. Hum. Perform.* **2016**, *87*, 550–556. [CrossRef]
11. Peters, J.H.; van Wageningen, B.; Hoogerwerf, N.; Biert, J. Helicopter emergency medical patient transport safety at night? *Air Med. J.* **2014**, *33*, 296–298. [CrossRef]
12. Aherne, B.B.; Zhang, C.; Chen, W.S.; Newman, D.G. Pilot decision making in weather-related night fatal helicopter emergency medical service accidents. *Aerosp. Med. Hum. Perform.* **2018**, *89*, 830–836. [CrossRef] [PubMed]
13. Nix, S.; Gossett, K.; Shepherd, A.D. An investigation of pilot fatigue in helicopter emergency medical services. *Air Med. J.* **2013**, *32*, 275–279. [CrossRef] [PubMed]
14. Frakes, M.A.; Kelly, J.G. Shift length and on-duty rest patterns in rotor-wing air medical programs. *Air Med. J.* **2004**, *23*, 34–39. [CrossRef]
15. Nascimento, F.A.C.; Majumdara, A.; Jarvis, S. Night-time approaches to offshore installations in Brazil: Safety shortcomings experienced by helicopter pilots. *Accid. Anal. Prev.* **2012**, *47*, 64–74. [CrossRef]
16. de Voogt, A. Helicopter accidents at night: Causes and contributing factors. *Aerosp. Psychol. Appl. Hum. Factors* **2011**, *1*, 99–102. [CrossRef]
17. Crognale, M.A.; Krebs, W.K. Performance of helicopter pilots during inadvertent flight into instrument meteorological conditions. *Int. J. Aviat. Psychol.* **2011**, *21*, 235–253. [CrossRef]
18. de Voogt, A.; Kalagher, H.; Diamond, A. Helicopter pilots encountering fog: An analysis of 109 accidents from 1992 to 2016. *Atmosphere* **2020**, *11*, 994. [CrossRef]
19. Ayiei, A.; Murray, J.; Wild, G. Visual flight into instrument meteorological condition: A post-accident analysis. *Safety* **2020**, *6*, 19. [CrossRef]
20. Boyd, D.D. A Review of General Aviation Safety (1984–2017). *Aerosp. Med. Hum. Perform.* **2017**, *88*, 657–664. [CrossRef] [PubMed]
21. de Voogt, A.; Uitdewilligen, S.; Eremenko, N. Safety in high-risk helicopter operations: The role of added crew in accident prevention. *Saf. Sci.* **2009**, *47*, 717–721. [CrossRef]
22. Manwaring, J.C.; Conway, G.A.; Garrett, L.C. Epidemiology and prevention of helicopter external load accidents. *J. Saf. Res.* **1998**, *29*, 107–121. [CrossRef]
23. de Voogt, A.; van Doorn, R.R.A. The paradox of helicopter emergency training. *Int. J. Aviat. Psychol.* **2007**, *17*, 265–274. [CrossRef]
24. National Transportation Safety Board, NTSB. Phase of Flight: Definitions and Usage Notes. 2013. Available online: https://www.ntsb.gov/safety/data/Documents/datafiles/PhaseofFlightDefinitions.pdf (accessed on 12 August 2025).
25. Farr, W.D.; Ruehle, C.J.; Posey, D.M.; Wagner, G.N. Injury pattern analysis of helicopter wire strike accidents (-Gz load). *Aviat. Space Environ. Med.* **1985**, *56*, 1216–1219.
26. Federal Aviation Administration. Rotorcraft Flying Handbook. 2000; FAA-H-8083-21. Available online: https://www.faa.gov/sites/faa.gov/files/regulations_policies/handbooks_manuals/aviation/faa-h-8083-21.pdf (accessed on 12 August 2025).
27. Federal Aviation Administration. Licenses and Certificates. Available online: https://www.faa.gov/licenses_certificates/airline_certification/ (accessed on 12 August 2025).
28. National Transportation Safety Board. Available online: https://data.ntsb.gov/carol-main-public/basic-search (accessed on 1 March 2025).
29. de Voogt, A. Lack of Denominator Data in Aviation Accident Analysis Response. *Aviat. Space Environ. Med.* **2010**, *81*, 77–78.
30. Petri, M.; Friedrich, L.; Hildebrand, F.; Mommsen, P.; Brand, S.; Hubrich, V.; Middeke, S.; Krettek, C.; Zeckey, C. Simulator training: Reducing risk in helicopter rescue. *Air Med. J.* **2012**, *31*, 117–123. [CrossRef] [PubMed]

31. Craig, P.A. Evaluating pilots using a scenario-based methodology: A guide for instructors and examiners. *Int. J. Appl. Aviat. Stud.* **2009**, *9*, 155–170.
32. Halleran, M.S.; Wiggins, M.E. Changing general aviation flight training by implementing FAA industry training standards. *Int. J. Appl. Aviat. Stud.* **2010**, *10*, 117–130.