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Technical Failures in Helicopters: Non-Powerplant-Related Accidents

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Abstract: Technical failures in helicopters are a main concern for helicopter safety. The prominence of mechanical failures differs for specific helicopter operations. This analysis used 151 General Aviation accident reports from the National Transportation Safety Board online database from an 11-year time period. The information in each report was collated, including the list of findings for each accident. Possible relations between causes and specific flight operations were analyzed by looking at significant differences between expected and actual values within the dataset of categorical data. It is found that the proportion of fatal accidents in this category of accidents is low (16.6%) compared with the percentage of fatal helicopter accidents in general, as well as those of specific helicopter operations. Instructional flights appear significantly more likely to be associated with maintenance-related causes. Causes related to fatigue of aircraft parts are more often associated with ferry and positional flights, as well as helicopters with turbo-shaft engines. Future research is recommended for these specific associations to further mitigate the number of accidents with non-powerplant failures.

Keywords: non-powerplant failures; helicopter; instructional; fatigue; maintenance

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1. Introduction

In the study of helicopter safety, "most of the reviewed studies viewed pilot error and technical failure as the most important risk factors" [1]. Previous research has shown that accidents with helicopters in maintenance-related accidents include failures of main rotors, tail rotors, transmission systems, and engines of rotorcraft [2,3]. They are considered the most critical and the most exposed components to maintenance errors. Improper maintenance, however, is only one possible cause of a technical failure. For instance, in a study on sling load operations, 88 (38%) accidents were attributed to mechanical failures of all types, but only 23 (10%) were cited for inadequate maintenance as a probable cause [4]. Furthermore, the role of technical failures in helicopter accidents is confounded by the diversity of helicopter designs and by the variety of helicopter operations.

A comparison of twin- and single-engine Part 135 helicopter operations for the period between 2005 and 2015 showed 20.1% fatal accidents for twin- and 28% for single-engine helicopters. It was found that twin-engine helicopters were more often exposed to night and instrument meteorological conditions (IMC), even though their fatality rate was not affected [5]. The comparison between twin- and single-engine helicopters was inspired by the suggestion that the increased complexity of the twin-engine aircraft would contribute to the risk of technical failures, but the evidence did not support that idea [6]. A previous study showed that the type and number of engines, as well as the number of blades, were relevant covariates in predicting helicopter accidents but did not significantly relate to technical failures.

In contrast, specific types of helicopter operations have shown differing proportionate numbers of fatalities, as well as a varying prominence of "mechanical failures of all types" (see Table 1) [4,7]. These studies suggest that specific technical failures of helicopters are more likely associated with particular operations than with the number or kind of engines.

Table 1. Previous research on operations, fatalities, and mechanical failures.

Operation	Years	Fatal [1]	Mechanical
Aerial application [7]	1998 thru 2005	9% (N = 12)	23% (N = 32)
Sling load [7]	1995 thru 2005	22.5% (N = 27)	40% (N = 48)
Sling load [4]	1980 thru 1995	25% (N = 57)	38% (N = 88)

[1] N indicates the number of fatal accidents; the number of fatalities may be higher.

The following study analyzes U.S. helicopter accidents that suffered technical failures. The data are limited to non-powerplant failures, since emergencies in helicopters have historically concentrated on engine failures for which autorotations provide the necessary recovery procedure. Emergency procedures for non-powerplant technical failures are less commonly practiced and the frequency and severity of their occurrence are less understood [8].

The aim of this study is to determine if types of technical failures can be associated with particular helicopter operations and to suggest strategies for mitigating future accidents. A better understanding of the significance of technical failures that do not affect the engine may also help to guide training priorities of helicopter pilots.

2. Materials and Methods

A total of 151 accidents from an 11-year period from January 2009 to December 2019 were extracted from the U.S. National Transportation Safety Board (NTSB) online database using the Case Analysis and Reporting Online (CAROL) query tool [9]. CAROL allows database users to select "non-powerplant failures" in their search menu, a term which follows the coding of NTSB investigators.

Each accident report consists of a factual report and a probable cause statement. The factual reports include a series of standardized items of information about the pilot(s), aircraft, weather, and wreckage, as well as an autopsy summary in cases of fatal accidents. In addition, the reports include a narrative statement with the history of the flight. The probable cause statement has a list of findings and a conclusion about the causes of the accident. The reports were selected using the category "non-powerplant failures", "General Aviation", as well as the aircraft category "helicopters", and only included accidents that occurred in the specific time period, in the region of the United States, and that were classified as accidents. Additionally, only accident reports that were completed before 2021 were included.

The categorical information provided in each report was collated, including the list of findings for each accident. The findings consist of causes, (contributing) factors and occurrences, and make up additional columns in the final dataset. From these standardized sections of the reports, organized information pertaining to pilot characteristics (e.g., total flight hours accrued), meteorological information (e.g., visibility and light conditions), and impact information (e.g., number of fatalities and damage to the aircraft) were listed. Additionally, the narrative statement in each report was coded for the presence of autorotations.

Significant differences between expected and actual values within the dataset of categorical data were determined using Pearson's chi-squared analysis using one degree of freedom, a 0.05 significance level, and a Fisher's exact test when cell counts fell below 5.

3. Results

Out of the 151 accidents, 25 (16.6%) were fatal, with 44 people sustaining fatal injuries and 16 additional accidents reporting serious injuries. Sixteen aircraft were destroyed (10.6%), of which only four reported a fatal injury. There appears no significant relationship between injury severity and damage to the aircraft ($p < 0.05$) in this dataset (see Table 2).

The average age of the pilot was 49.9 years old. Three female pilots were involved in accidents. More than half (N = 64 have less, 77 more 51%, 10 unknown) of the pilots had more than 3000 h of total flight experience. This flight experience was not significantly related to fatality ($p > 0.05$).

Table 2. Injury severity compared with damage to the helicopter (# accidents).

Damage/Injury	Fatal	Serious	Minor	None
Destroyed	4	2	3	8
Substantial	21	14	26	73
Minor	0	0	0	0
None	0	0	0	0

All accidents in this dataset occurred in visual meteorological conditions (VMC), with the exception of one fatal accident with seven casualties where a helicopter continued into IMC conditions. There were eight accidents at night, three at dawn, and two at dusk, none of which were fatal.

Causes that pertain to non-powerplant accidents include failures to the navigation systems (N = 1), flight instruments (N = 2), flight control systems (N = 3), electrical systems (N = 1), communication systems (N =2), and pressure/environmental pressure system (N = 4), but few of these are commonly attested. The main technical failures are mechanical and include part separation (N = 23), system component failure (N = 9), failures pertaining to fluids (N = 10), fatigue (N = 35), tail rotor (N = 36), and main rotor failure (N = 33). Several of these are attributed to maintenance causes (N = 36). Causes were specified by the NTSB investigators, and in several cases multiple causes were attributed to the same accident.

The relation of specific causes identified by the NTSB investigators and injury severity was only in some cases proportionally higher or lower, but rarely significantly so. For instance, maintenance-related causes led to fatal and/or serious injury in 14 out of 36 cases, and this proportion is higher than the 27 fatal or serious injuries in the 115 remaining accidents (χ^2 = 3.2919, df = 1, p = 0.0696), but only significantly so at the $p < 0.10$ level. The only significant relation to fatality was found when causes related to main rotor and tail rotors were combined. Only 5 out of 69 accidents with tail or main rotors were fatal, while 20 out of 82 were fatal in all other accidents combined (χ^2 = 7.9716, df = 1, p = 0.004752).

Autorotations were reported in 13 cases since they can also be initiated in cases other than powerplant failures. For instance, one pilot encountered a cyclic-input problem and entered a 180-degree autorotation to lose altitude, but landed near trees and rolled over after landing, which substantially damaged the helicopter. Accidents with autorotations included two fatalities.

Out of 151 accidents, 12 reported a helicopter with twin engines, and 68 with turboshaft versus 83 with reciprocating engines. Specific operations included 23 instructional flights, nine external load, 19 agricultural (aerial application as well as landscaping), 12 ferry or positioning flights, six test flights, and eight aerial observation flights. It is noted that all accidents with external load included helicopters with turboshaft engines. Significant relations between specific operations/aircraft and types of causes are listed in Table 3.

Table 3. Significant relations between specific operations/aircraft and types of causes.

	Fatigue	Other	Significance (df =1)
Turbo-shaft	21	47	χ^2 = 4.123
Reciprocating	14	69	p = 0.042303
Positioning/ferry	8	4	χ^2 = 13.8455
Non-positioning/ferry	27	112	p = 0.000198
	Maintenance	Other	Fisher-exact: $p < 0.05$
Instructional	10	12	χ^2 = 6.254
Non-instructional	26	103	p = 0.010053

4. Discussion

Fatality was not strongly related to any specific cause with the exception of problems with the main or tail rotor, which showed a significantly lower proportion of fatal accidents.

This result confirms the premise that training on the emergency procedures for main and tail rotor failures, which includes autorotations, may prevent fatalities [8].

Pilots that were part of non-powerplant failures did not show a lack of experience and did not fall within a certain age group. It is noted that there was no significant relation between injury severity and damage to the aircraft, an absence that is uncommon and thus far only attested for accidents with ballooning and accidents with helicopters standing [10,11]. The absence of this relation may be partially explained by the highly diverse nature of non-powerplant failure accidents.

This study of accidents concerning non-powerplant failures has a relatively low proportionate number of fatal accidents (16.6%) compared with, for instance, twin engine (23.7%) or sling load (22.5%) accidents. While mechanical failures contribute to the overall number of accidents in helicopter operations, they appear to be less often fatal and were infrequently associated with low visibility conditions, which in recent studies has been identified as the main concern in helicopter accidents in general [12–15].

Specific causes were related to instructional flights and the combination of positioning and ferry flights, which showed significantly higher proportions of maintenance and fatigue-related causes, respectively. In addition, twin-engine helicopters were proportionally more often associated with fatigue-related causes, a result that may help mitigate twin-engine helicopter accidents, which otherwise have fewer accidents than single-engine helicopters and for which little explanation is present in the literature [5].

5. Conclusions

In view of a low proportion of fatalities for non-powerplant accidents, as well as the significantly lower proportion of fatal accidents in case of main or tail rotor failures, the assertion that "pilot error and technical failure as the most important risk factors" for helicopter accidents may be interpreted differently [1]. Risk factors may affect accidents, but not necessarily fatal ones, while non-powerplant technical failures are likely less important. Instead, as recent research on helicopter accidents has suggested, weather and light conditions, especially instrument meteorological conditions, are an increasing cause of concern [12–15].

This study emphasizes that a fine-grained analysis of aviation accidents is necessary to identify which combination of operations, causes, and aircraft need most attention in future aviation accident analysis studies. Non-powerplant failures in helicopters are particularly diverse. Despite the fragmented nature of the data, this study found that fatigue-related failures and maintenance-related causes were specific to certain operations. This study focuses on General Aviation accidents only, and maintenance is less regulated in operations following Part 91 flight rules. Instructional flights as well as ferry flights may benefit from stricter maintenance procedures to mitigate the number of accidents. Fatigue and maintenance, as well as different flight rules, form starting points for future studies, which may assist in identifying operations where the above findings need to be communicated.

Future studies that compare helicopters and other aircraft, including the associations of type of accident and operation, may further assist in our understanding of helicopter safety. The training of autorotations for other than just engine failures remains of primary importance despite the variety of possible technical failures.

Although the NTSB data allow insight in non-powerplant-related accidents of helicopters, they do not contain information about the organization behind helicopter operations. Therefore, it remains unclear what organizational factors may affect, for instance, the presence of fatigue-related accidents and for which additional measures may mitigate future accidents. Technical failures are not always identified as a cause of an accident but were reported and part of the accident description. Despite this limitation of the data, the results identify areas where further research may be directed.

It is also noted that the current dataset does not have a sufficient number of accidents related to specific types of failures or operations to conduct a statistical analysis for each of them or draw more detailed conclusions. While this limitation may be addressed by including more years of accidents, a longer time-span may introduce other factors, such as technological developments over time, that complicate interpretations. Alternatively, international comparative studies as well as the inclusion of incidents may assist in more detailed analysis in future studies, of which only few examples have been published [16,17]. Finally, while denominator data for each type of helicopter operation are not available, the proportionate number of failures allows for initial comparisons in the absence of such data [18].

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Conflicts of Interest: The authors declare no conflict of interest.

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