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Fatality and Injury Rates for Two Types of Rotorcraft Accidents

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16. Abstract

An analysis of the frequency of four different types of rotorcraft accidents was conducted to determine if the number of fatalities and injuries between accident conditions was different. Accidents involving rollover, no rollover, fire, and no fire were studied to determine if accidents with a rollover or fire might be creating evacuation delays that contribute to the fatality and injury rates.

A search of the FAA Accident Incident Data System from January1986 to March 1997 produced 2704 accident records for this analysis. A Chi-Square test for independence was used to determine the difference between the rollover and no rollover and fire and no fire accident categories. Further analysis were performed on combinations of the two main categories to determine if an event such as a rollover and fire produced more fatalities or injuries than a rollover without a fire.

There were more fatalities in the no rollover category (P=.0001) and more injuries in the rollover group (P=.001). Accidents with a fire produced more fatalities than accidents without a fire, (P=.0001). Rollover accidents without a fire produced more fatalities (P=.0001) than no rollovers without a fire, and more injuries were produced in the rollover no fire group (P=.0001) than the no rollover no fire category. The group of accidents where the rotorcraft rolled and caught fire lead to more fatalities (P=.0001), and the no rollover group with fire generated more fatalities (P=.0001).

Rollover accidents injure more pople, and accidents with no rollover kill more occupants. It appears as if the no rollover condition produces greater impact forces, preventing the rotorcraft from bouncing and rolling; consequently, the higher fatality rate. Fires produce more fatalities but not more injuries. Autopsy data might explain this, but smoke inhallation during the evacuation and the speed of the evacuation warrent more attention, since it may be a contributing factor in the number of fatalities.

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Fatality and Injury Rates for Two Types of Rotorcraft Accidents

INTRODUCTION

Rotorcraft Operations are not routinely associated with high passenger loads, but it is an area that accounts for a significant part of general aviation activity. Statistics show rotorcraft generally transport fewer than four passengers (2), thus, rotorcraft accidents do not generally get the kind of attention afforded large commercial aircraft where the potential for a large number of injuries and fatalities is greater. Ensuring that all rotorcraft occupants have a rapid means of escape is, however, of importance.

Airworthiness standards for normal and transport category rotorcraft operations are governed by the Code of Federal Regulations (CFR), Title 14, Aeronautics and Space, Parts 27 and 29, respectively. Normal category rotorcraft have a maximum weight of 7,000 lbs with 9 or less passenger seats and must have at least 1 emergency exit on the opposite side of the cabin from the main door. This emergency exit must consist of a movable window, panel, or additional external door, to provide an unobstructed opening that will accept a 19-by-26 inch ellipse, be readily accessible, require no exceptional agility of the person using it, and be located so as to allow ready use without crowding in any probable attitude that may result from a crash (3). Transport category rotorcraft have a maximum weight greater than 20,000 lbs with 10 or more passenger seats. The number of emergency exits located on the opposite side of the main door is based on seating capacity; however, CFR Title 14 Part 29.807(c) specifies a requirement for exits on the top, bottom, or ends of the rotorcraft. Specifically, there must be enough exit openings in the top, bottom, or ends of the fuselage to allow evacuation with the rotorcraft on its side, or the probability of the rotorcraft coming to rest on its side in a crash landing must be extremely remote (4). The intent of these regulations is to provide occupants with a viable means of escape in any type of rotorcraft accident.

With the large number of passengers traveling on commercial fixed wing aircraft, it is imperative that evacuations are efficient, expeditious, and can be executed without injury. CFR Title 14 Part 29.803 requires manufacturers of transport category rotorcraft to demonstrate that a full load of passengers can exit the aircraft in 90 seconds or less, in darkness, using half the emergency exits, and with only emergency lights illuminating the cabin (1). Requiring these evacuations to be completed within 90 seconds has significantly reduced the effects of post-crash fires and toxic smoke on evacuating passengers. Although commercial aviation accidents are capable of producing the highest number of fatalities per accident in the aviation industry and warrant strict regulatory oversight, general aviation accidents also produce post-crash fires that may exacerbate the injuries and increase the number of fatalities.

The large volume of highly combustible fuel carried by commercial and general aviation aircraft increases the threat of an in-flight or post-crash fire in a survivable accident. The National Transportation Safety Board (NTSB) defines a survivable accident as one in which the fuselage remains basically intact, the impact forces are within human tolerance limits, and the seat belts restrain the passengers during impact. Using this definition, fatalities in survivable accidents are caused by events that occur after the initial impact. That is, the crash impact forces do not kill the occupants, but rather the post-crash fire and toxic smoke routinely cited in the autopsy reports are the primary cause of death. For this reason, government and industry have continually sought ways to not only prevent the threat of aircraft fires but to expedite the evacuation of the occupants once a fire has developed.

This study analyzes the frequency of rotorcraft accidents involving fatalities and injuries to determine if certain types of accidents are inherently more dangerous in relation to rapid evacuation capability. Four categories of accidents were analyzed: those involving a fire, those without a fire, those in which the rotorcraft rolled over, and those without a rollover. It was hypothesized that rollover accidents create evacuation delays that produce more fatalities, particularly in situations involving a rollover and post-crash fire, where evacuation delays may expose occupants to toxic fumes longer than they would be if the rotorcraft remained upright and the evacuation only required occupants to quickly step out of the rotorcraft.

DATA SOURCE

The Federal Aviation Administration (FAA) maintains a database of every accident investigated over the last 25 years. This database (approximately 140,000 accidents dating back to 1973), the Accident Incident Data System (AIDS), has become the comprehensive source of information for all accidents investigated by the FAA. Aircraft make and model, phase of flight, weather conditions, accident location, date of the accident, primary and secondary causes, a narrative describing the accident, and the number of fatalities and injuries comprise a small portion of the information collected from each event. In this study, the narratives for each accident were analyzed to identify accidents where a rotorcraft rolled over and/or caught fire. Statistical analysis of the data was then conducted to show if one type of accident consistently produced more fatalities or injuries than another.

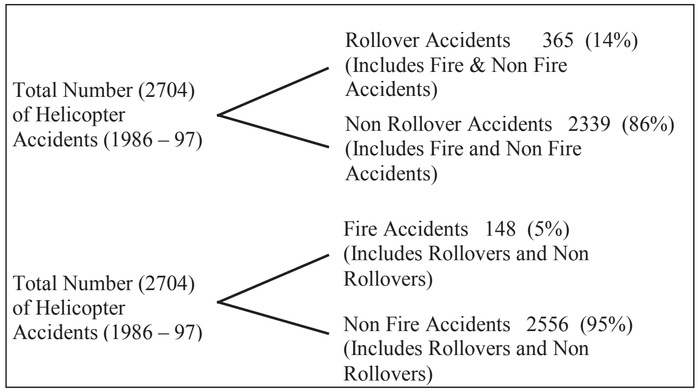

Figure 1. A Comparison of Accidents by Rollover and Fire Status.

METHODS

There are 181 fields used to describe an accident or incident in the AIDS database. Most of these fields are coded with letters or numbers specifying a particular condition, action, or consequence associated with the event. Even though the database contains a large amount of information, unique questions concerning the cause of injuries and fatalities associated with fires and rollovers are not easily answered.

The two factors in rotorcraft accidents thought to be the most likely reasons occupants are not able to rapidly egress a rotorcraft are rollover and fire. However, no fields in the database specifically allow accidents to be identified by rollover and fire. Descriptions (e.g. in-flight fire, engine fire, post-crash fire, and cockpit fire) are routinely used to explain the primary or contributing cause(s) of an accident. Consequently, multiple searches must be used to identify those situations where a fire has occurred. In addition to the coded fields in the database, a narrative text field is available that briefly describes the accident. By conducting word searches on this narrative field, it is possible to categorize accidents by rollover and fire.

A search of the AIDS database for accidents occurring between January 1, 1986, and March 4, 1997, showed there were 2870 rotorcraft accidents or incidents reported. Screening of these accidents revealed 166 that did not accurately report the number of injuries or fatalities and were excluded from the population sample. The remaining 2704 records became the dataset on which all other queries were based. Using the fire codes: *in-flight fire*, *post crash fire*, and *engine fire*, as well as word searches for *rollover*, a total of 148 accidents involving *fire*, and 365 accidents involving *rollover*, were identified. A comparison of the accidents by rollover and fire status is shown in Figure 1.

In addition to the descriptive accident information in the database, a count of the number of injuries and fatalities associated with each event is available. Two statistical tests were used to compare the number of fatalities and injuries for each accident type to determine if one type of accident significantly produced more fatalities or injuries than another. The first test analyzed the frequency of fatality and injury accidents for the different groups, while the second test compared the fatality and injury rates of the subsets of accidents that had at least one fatality or injury.

The Chi Square (χ^2) Test of Independence for Frequencies is used when data are arranged in categories. Comparisons are made between the observed and expected frequency to determine dependence or independence (5). Accidents involving rollovers and fires make up the different categories of information, while the number of accidents with fatalities and injuries represents the frequency of occurrence in each category. The analysis focused on the difference between rollovers/non-rollovers and fire/no-fire accidents. Further analysis was also performed on combinations of these two categories to determine if an event such as a rollover with fire produced more fatalities or injuries than a rollover without fire. Table 1 shows the four main categories, as well as the combinations of these categories that were analyzed using the $\chi 2$ statistic.

Table 1. Analytical Design for Each Accident Category

	Fire	No Fire
Rollover	Rollover & Fire	Rollover & No Fire
No Rollover	No Rollover & Fire	No Rollover & No Fire

The second statistical test performed on the data compared the fatality and injury rates for the different accident groups. The mean number of fatalities and injuries were calculated and a comparison of means was performed using the *t* statistic (6).

RESULTS

Figure 2 shows the total number of accidents, accidents with fatalities, and accidents with injuries for each category.

The χ^2 analysis for accidents with fatalities and accidents with injuries was initially run on the two main categories: rollover *vs.* non-rollover and fire *vs.* no-fire. These were then divided into the subcategories shown in Figure 3. Using the data in Table 2, separate χ^2 values were also calculated on the number of fatal and injury accidents in each of the remaining four categories.

Table 2 shows the number of fatality and injury accidents for all categories.

The χ^2 results for the rollover and fire categories are listed in Tables 3 and 5, respectively.

Comparisons of accidents involving rollovers versus those without rollover showed a significant difference between the two groups; fatal accidents occurred more often without rollover while injury accidents occurred more often with rollover (Table 3).

The χ^2 values for the rollover accidents with fire *vs* rollover accidents with no fire showed there was a greater number of fatal accidents in the rollover with fire category. In contrast, no difference was found in the number of injury accidents in these groups. A greater number of fatal accidents with fire but not rollover was found relative to those with neither fire nor rollover; again, there was no difference in the number of injury accidents for the two (Table 4).

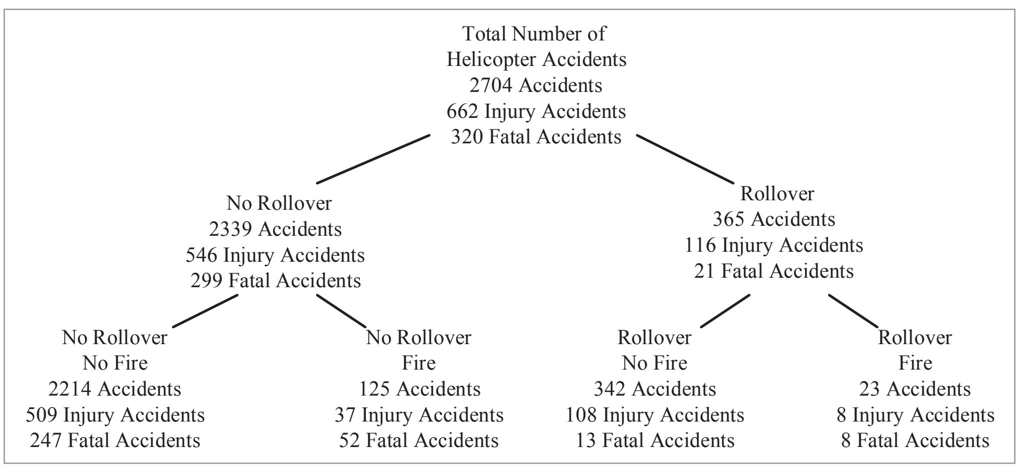

Figure 2. Total Number of Accidents, Accidents With Fatalities, and Accidents With Injuries for Each Category.

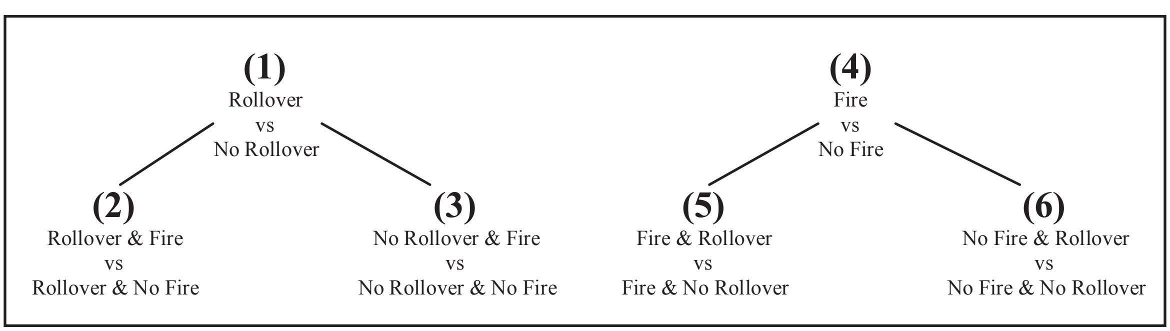

Figure 3. Subcategories of Accidents.

Table 2. The Number of Fatality and Injury Rates for All Categories.

	Accidents with no Fatalities	Accidents with at Least 1 Fatality	Accidents with no Injuries	Accidents with at Least 1 Injury
Rollover (365)	344 (94%)	21 (6%)	249 (68%)	116 (32%)
No Rollover (2339)	2038(87%)	299 (13%)	1791(77%)	546 (23%)
Fire (148)	88 (59%)	60 (41%)	103 (70%)	45 (30%)
No Fire (2556)	2294(90%)	260 (10%)	1939(76%)	617 (24%)
Rollover Fire (23)	15 (65%)	8 (35%)	15 (65%)	8 (35%)
Rollover No Fire (342)	329 (96%)	13 (4%)	234 (68%)	108 (32%)
No Rollover Fire (125)	73 (58%)	52 (42%)	88 (70%)	37 (30%)
No Rollover No Fire (2214)	1965(89%)	247 (11%)	1703(77%)	509 (23%)

Table 3. $\chi 2$ Results for the Rollover Category.

Accident Type	Fatal Accidents	Injury Accidents
Rollover *(1)*	$\chi 2$ (1, N =2702)=14.98, p = .0001*	$\chi 2$ (1, N =2702)=12.09, p = .001*
No Rollover		

Table 4. Results of the Rollover and Fire Categories.

Accident Type	Fatal Accidents	Injury Accidents
Rollover Fire *(2)* **Rollover No Fire**	$\chi 2$ (1, N=365)=38.15, p < .0001*	$\chi 2$ (1, N=365)=0.10, p=.749
No Rollover Fire *(3)* **No Rollover No Fire**	$\chi 2$ (1, N=2337)=98.22, p < .0001*	$\chi 2$ (1, N=2337)=2.87, p = .09

Table 5. $\chi 2$ Results for the Fire Category.

Accident Type	Fatal Accidents	Injury Accidents
Fire *(4)* **No Fire**	$\chi 2$ (1, N =2702)=123.5, p < .0001*	$\chi 2$ (1, N =2702)=2.95, p = .086

* Significance greater than or equal to .001

The χ^2 results for the fire category are listed in Table 5.

Comparison of the accidents with fire versus those without fire showed there were more fatality accidents involving fire than without. There was no difference in the number of injury accidents based on fire condition (Table 5).

Comparing *accidents with fire and rollover* with *accidents with fire* but not *rollover* revealed no difference for either the fatality or injury groups. Accidents with rollover but not fire, and accidents with neither, produced χ^2 values for fatalities and injuries that were consistent with the main rollover categories (Table 6).

Determining a difference among various accident types does not mean there is an analogous difference in the total number of fatalities or injuries. For example, an equal number of *fire* versus *non-fire* fatal accidents does not mean the total number of fatalities for the two categories will be the same. Since the objective was to look at the difference between the total number of fatalities and injuries for the different accident types, we decided to analyze accidents involving at least 1 fatality or injury. A comparison of the mean number of fatalities and injuries for the subsets of accidents with at least 1 fatality or injury made it possible to determine if one accident type, on average, produced more fatalities or injuries than another. (See Table 7 for a breakdown of accidents, fatalities, and injuries.)

Toward this end, a comparison of the means was run using a *t* test (5). The results are listed in Table 8.

In most cases, the τ statistic showed little difference in the average number of fatalities or injuries for the different accident categories. The results in Table 8 did reveal, however, that accidents without rollover produced more fatalities than those with rollover. This indicates that not only is the frequency of fatal accidents in the non-rollover group higher, but more people on average are killed in accidents when the rotorcraft does not roll over. There also were more injuries in the *rollover no-fire* group than the *rollover fire* category. Among accidents with a fire, it was the *non-rollover* category that produced the most injuries.

Table 6. Comparison of Accidents With Fire Versus Those Without Fire.

Accident Type	Fatality Accidents	Injury Accidents
Fire Rollover*(5)* **Fire No Rollover**	χ^2 (1, N=148)=.38, p = .54	χ^2 (1, N=148)=.25, p = .62
No Fire Rollover (6) **No Fire No Rollover**	χ^2 (1, N=2554)=17.57, p < .0001*	χ^2 (1, N=2554)=11.87 p = .001*

Table 7. Breakdown of Accidents, Fatalities, and Injuries.

	Accidents 1 or More Fatalities	Total Number Fatal	Mean	Accidents 1 or More Injury	Total Number Injured	Mean
Rollover	21	26	1.238	116	178	1.534
No Rollover	299	527	1.763	546	927	1.698
Fire	60	109	1.817	45	72	1.600
No Fire	260	444	1.708	617	1033	1.674
Rollover Fire	8	12	1.500	8	9	1.125
Rollover No Fire	13	14	1.077	108	169	1.565
No Rollover Fire	52	97	1.865	37	63	1.703
No Rollover No Fire	247	430	1.741	509	864	1.697

Table 8. Results of *t*-test of Means Comparison.

	Fatal	Injured
(1) Roll *vs* No Roll	t (34) = 3.36 $p = 0.002$*	t (187) = 1.5 $p = 0.135$
(2) Fire *vs* No Fire	t (66) = 0.41 $p = 0.687$	t (50) = 0.40 $p = 0.689$
(3) Roll Fire *vs* Roll No Fire	t (8) = 1.26 $p = 0.245$	t (19) = 2.73 $p = 0.013$*
(4) No Roll Fire *vs* No Roll No Fire	t (56) = 0.41 $p = 0.684$	t (41) = 0.02 $p = 0.981$
(5) Roll Fire *vs* No Roll Fire	t (21) = 0.83 $p = 0.418$	t (40) = 2.35 $p = 0.024$*
(6) Roll No Fire *vs* No Roll No Fire	t (37) = 6.47 $p < 0.001$*	t (170) = 1.15 $p = 0.251$

[*] Significance greater than .05

DISCUSSION

The effects on passenger evacuation related to *rollover and fire* generally met expectations. For example, there were more injury accidents with rollover than without, as would be expected when considering the crash dynamics related to occupants being thrown around the cabin during rollover. In contrast, there were unexpected results, such as the greater number of fatal accidents attributable to the non-rollover condition. A likely explanation for this circumstance could be that the impact forces that cause a rotorcraft to roll are less severe than those encountered in a non-rollover situation, where the rotorcraft hits the ground with such direct force that it embeds firmly. These extreme forces would also explain the relatively greater number of fatalities in accidents that do not involve rollover. Comparison of these two situations suggests that the impact, and not the rollover, is the more important consideration for passenger evacuation.

Evaluation of the effects of fire in rotorcraft accidents also produced mixed results. There were more fatal accidents with fire than without; however, there was no difference in the number of injury accidents for the two conditions. The reason fire produced more fatalities, but not injuries, is not immediately obvious, although a likely explanation would be that the impact/rollover forces primarily injured occupants, while accidents involving post-crash fires included the effects of both crash dynamics and the heat/toxic byproducts produced by the fire. This would also explain the larger proportion of injuries in rollover accidents without fire, as compared with those having fire; i.e., the presence of fire makes the relative number of injuries appear lower, since many initially injured passengers may be killed by smoke or fire. The inaccessibility of autopsy data precludes the ability to draw appropriate conclusions regarding such a speculation, although the combination of crash and fire effects would disable occupants more than would the crash alone, exacerbating difficulties with evacuation and increasing the likelihood that passengers would succumb to the worsening environment. Thus, the effects of rotorcraft fire on passenger evacuation warrants particular attention, especially in situations in which the rotorcraft has rolled over.

CONCLUSION

Of the 2,704 crashed rotorcraft included in the analysis, approximately 14% rolled over and 5% caught fire. These percentages, while small, are not insignificant; that is to say, there is more than a remote possibility that a rotorcraft will roll over and/or catch fire in an accident. The demonstrated results of these crash factors makes the provision of emergency exits in appropriate numbers and locations a necessity.

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