RISK FACTORS FOR FATAL GENERAL AVIATION ACCIDENTS IN DEGRADED VISUAL CONDITIONS

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The prevalence of weather-related general aviation (GA) accidents has declined over the past two decades, yet the fatality rate of these accidents remains high. The goal of this study was to examine predictors of fatality within a set of weather-related GA accidents to determine if there are particular factors that contribute to excessively high fatality rates. 3,206 weather-related GA accidents from the National Transportation Safety Board (NTSB) Aviation Accident Database were analyzed using univariate chi-squares and binary logistic regression. A variety of pilot, aircraft, flight, and accident-related factors were evaluated to determine if they increased the odds of pilot fatality. Results suggest that the predictors of fatality in weather-related accidents are similar to those in the greater GA population; but that these factors are more prevalent within weather-related accidents.

Introduction

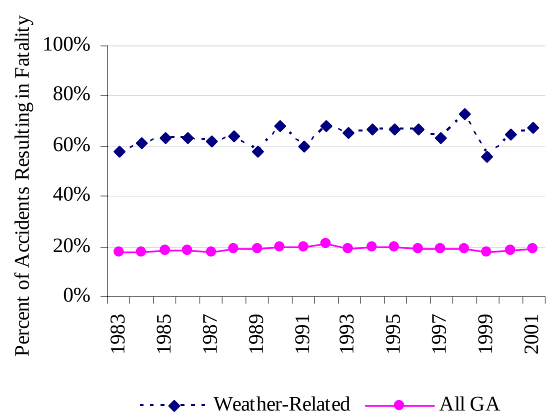
Adverse weather is an ongoing problem for safety in General Aviation (GA) operations, and one that has concerned the National Transportation Safety Board (NTSB) for many years. More than three decades ago, the NTSB published a study of GA accidents suggesting that certain types of weather including low ceiling, rain, and fog were particularly prevalent in fatal accidents involving weather (NTSB, 1968). A separate study found that weather factors such as unfavorable wind, updrafts and downdrafts were associated with nonfatal GA accidents (NTSB, 1976). These findings taken together suggest that degraded visibility is a common factor that separates fatal from nonfatal weather-related accidents.

The link between visibility-related weather and fatal outcomes is paralleled by the fact that accidents that occur in instrument meteorological conditions (IMC) are more likely to result in fatalities than those that occur in visual meteorological conditions (VMC). IMC is defined in the FAA Pilot/Controller Glossary as, "meteorological conditions expressed in terms of visibility, distance from clouds, and ceiling less than the minima specified for visual meteorological conditions." These minima vary by the type of airspace, altitude and light conditions, and are used as thresholds to determine when pilots must operate under instrument flight rules (IFR). While there is a substantial amount of overlap between weather-related accidents and those that occur in IMC, the two are not necessarily coupled; i.e., weather-related accidents may occur during conditions legally defined as VMC.

This study focused specifically on understanding the survivability of weather-related accidents where "weather-related" was operationally defined as those accidents citing visibility-related weather conditions such as fog, rain, snow or low ceilings. The involvement of various weather phenomena in an accident may be determined by reviewing the environmental conditions that were identified by the accident investigator as being a factor in the accident.

A review of NTSB accident data reveals that the proportion of weather-related GA accidents has declined over the years, from more than 11% of all GA accidents in 1983 to less than 6% in 2001. However, as shown in figure 1, the fatality rate for weather-related GA accidents is approximately three times higher than that for all GA accidents, and fatality rates for weather-related GA accidents have been consistently high over the years, ranging between 58% and 72%.

Figure 1. *Proportion of weather-related and all GA accidents that resulted in at least one fatality from 1983–2001*.



Because weather-related accidents are consistently more likely to result in fatality, it is important to search for factors associated with fatal outcomes and, when possible, take steps to mitigate those factors. Studies that have looked at risk factors for fatal injury in airplane accidents across all types of weather have consistently shown that certain variables such as off-airport locations and post-crash fire are strongly associated with higher fatality rates (Li & Baker, 1993; Li & Baker, 1999; O'Hare, Chalmers & Scuffham, 2003). "Off-airport" accidents likely occur when an airplane is at higher altitudes, resulting in crashes with higher speeds and angles of impact. A 1985 report on GA crashworthiness (NTSB, 1985) proposed a "survivable envelope" of impact defined by speeds of 45 knots at 90 degrees of impact angle, 60 knots at 45 degrees, and 75 knots at zero degrees.

Fatalities linked to post crash fire may be caused by burns and smoke inhalation associated with the fire itself, or because high impact crashes result in both fire and death due to deceleration forces. Other factors that have been associated with fatal outcomes in GA accidents include older pilot age, lack of restraint use, and nighttime conditions.

The goal of this study was to examine predictors of fatality within a set of weather-related GA accidents to determine if particular factors contribute to the excessively high fatality rate of those accidents. For example, light conditions may be associated with pilot fatality if the combination of darkness and inclement weather impedes search and rescue operations.

A second possibility is that fatal outcomes in all GA accidents are related to the same basic set of factors, and those factors are more common during flights in degraded visibility. For example, accidents involving multi engine airplanes may have higher fatality rates due to the impact forces associated with higher airspeeds relative to single engine aircraft. If multi-engine airplanes make up a larger proportion of the aircraft flown in inclement weather, it is likely that they would be more represented in weather-related accidents, contributing to their higher fatality rates.

Method

GA airplane accidents citing one or more visibility-related condition, for the period of 1983–2001, were extracted from the NTSB Aviation Accident Database. Independent variables were chosen based on hypothesized relationships between the variable and the likelihood of survival, though the selection of variables was limited to those that were well represented in the database.

Pilot-related independent variables included pilot age, highest certification (student, private, commercial or air transport), instrument rating (yes or no), total flight hours, seatbelt use (yes, no or unknown), and shoulder restraint use (yes, no or unknown). Aircraft-related variables included number of engines (single or multi-engine) and airplane construction (amateur-built or manufactured). Flight and accident related variables included light condition (light or dark), presence of fire (yes or no), presence of explosion (yes or no), collision as the first occurrence (yes or no), and phase of flight (standing/taxi, takeoff, climb, cruise, descent, maneuvering, approach, go-around or landing).

The dependent variable was the case-fatality rate, or the proportion of cases in which the pilot was fatally injured. Univariate chi square tests were used initially to assess the effect of each independent variable on the case fatality rate. Binary logistic regression was then used to evaluate the combined effect of the independent variables and to assess the significance of each predictor in the presence of all others. All data analyses were performed using the SPSS software.

Results

Of the 37,681 GA airplane accidents that occurred between 1983 and 2001, 3,206 or 8.5% were weather-related. Within this group, 71.5% occurred in IMC, 60.2% involved restrictions to visibility such as fog or haze, and 48.5% occurred during precipitation.

Univariate Analyses

The overall case fatality rate for the sample was 62.4%, and case fatality rates for all levels of each independent variable are shown in Tables 1 and 2. All of the pilot-related independent variables produced significant chi-square findings; a private pilot license, no instrument rating, fewer total flight hours, and older pilot age were associated with higher case fatality rates. Non-use of restraints such as seatbelts and shoulder harnesses was also associated with higher case fatality rates; however, due to the large number of cases where restraint use was missing or unknown, restraint use variables were not included in the multivariate analyses.

Neither of the aircraft-related variables (number of engines or aircraft construction) produced significant chi square findings, but all flight and accident-related factors significantly influenced case fatality rates. Darkness, presence of fire, presence of explosion, and collision as first occurrence were associated with higher case fatality rates.

Multivariate Analysis

Binary logistic regression incorporating pilot, aircraft, flight and accident-related variables resulted in a significant omnibus finding supporting the overall model. When controlling for all other variables, the individual pilot-related factors associated with a higher risk of fatality included older pilots and those holding a private pilot license, as compared to other types of pilot certificate. For example, pilots aged 34–43 were 1.38 times more likely to die in an accident than younger pilots, and the odds of fatality increased further for pilots older than 43. Also, pilots whose highest level of certification was the private license (OR = 1.81) were more likely to die compared to the reference group of those with air transport licenses.

Accidents involving multi-engine aircraft were 1.55 times more likely to result in a pilot fatality than those involving single-engine aircraft. Darkness (OR = 1.68), and the presence of fire (OR = 5.87) also significantly increased the odds of pilot fatality. For phase of flight, accidents that occurred during the standing/taxi and landing phases were least likely to result in a fatality. Accidents during the climb and cruise phases had the highest odds of fatality, each being greater than 30 times more likely to result in a pilot fatality than accidents that occurred during the standing/taxi phase.

Table 1. *Case fatality rates, odds ratios, and confidence intervals for pilot-related factors.*

Variable	Number of Pilots Involved	Number of Fatally Injured Pilots	Case Fatality Rate (%)	Odds Ratio	95% CI
Pilot Age					
16-33	651	337	51.8	Ref	--
34-43	706	430	60.9	1.38*	1.07, 1.79
44-53	883	575	65.1	1.90**	1.47, 2.46
>53	939	646	68.8	2.36**	1.79, 3.12
Highest Certification					
Student	98	47	48.0	0.87	0.45, 1.67
Private	1858	1259	67.8	1.81**	1.20, 2.72
Commercial	934	522	55.9	1.08	0.75, 1.56
ATP	293	156	53.2	Ref	--
Instrument Rated					
No	1419	928	65.4	Ref	--
Yes	1773	1068	60.2	1.14	0.90, 1.45
Total Flight Time					
0-247	568	351	61.8	1.42	0.97, 2.08
248-825	887	573	64.6	1.29	0.95, 1.75
826-2799	870	546	62.8	1.11	0.85, 1.46
>2799	771	444	57.6	Ref	--
Seatbelt Used					
No	30	28	93.3		
Yes	2569	1434	55.8		
Unknown	582	517	88.8		
Shoulder Harness Used					
No	781	483	61.8		
Yes	1297	625	48.5		
Unknown	1093	861	78.8		

* p < .05, ** p < .01

Table 2. *Case fatality rates, odds ratios, and confidence intervals for aircraft, flight, and accident-related factors.*

Variable	Number of Pilots Involved	Number of Fatally Injured Pilots	Case Fatality Rate (%)	Odds Ratio	95% CI
Number of Engines					
Single Engine	2536	1571	61.9	Ref	--
Multi Engine	662	425	64.2	1.55**	1.20, 2.00
Amateur-Built					
No	3124	1946	62.3	Ref	--
Yes	76	52	68.4	1.32	0.74, 2.35
Light Condition					
Light	2062	1209	58.6	Ref	--
Dark	1125	777	69.1	1.68**	1.39, 2.02
Presence of Fire					
No	2452	1332	54.3	Ref	--
Yes	726	645	88.8	5.87**	4.28, 8.05
Presence of Explosion					
No	2913	1733	59.5	Ref	--
Yes	242	220	90.9	1.49	0.86, 2.58
Collision as First Occurrence					
No	2515	1533	61.0	Ref	--
Yes	686	465	67.8	1.23	0.98, 1.54
Phase of Flight at First Occurrence					
Standing/Taxi	19	1	5.3	Ref	--
Takeoff	254	146	57.5	13.58*	1.74, 106.21
Climb	203	155	76.4	38.99**	4.93, 308.30
Cruise	1375	946	68.8	31.18**	4.05, 240.25
Descent	124	87	70.2	28.50**	3.56, 228.35
Maneuvering	348	234	67.2	27.49**	3.52, 214.70
Approach	560	323	57.7	12.08*	1.56, 93.53
Go-Around	86	60	69.8	20.86**	2.56, 170.25
Landing	194	8	4.1	0.56	0.06, 4.64

$* p < .05$, $** p < .01$

Discussion

Over the past two decades, weather-related GA accidents have been consistently more likely to result in fatalities than GA accidents overall. The goal of this research was to determine if particular factors within weather-related accidents are uniquely predictive of pilot fatality.

Similar to previous research (Li & Baker, 1999; O'Hare et al., 2003), some of the most predictive factors were related to the accident occurrence. For example, the climb and cruise phases of flight were associated with the highest odds of pilot fatality, similar to other research findings in which pilot fatality was linked to "off airport" accidents. In both cases, accidents that occurred mid-flight were linked to severe outcomes, presumably due to higher airspeeds. Accidents that occurred at night were also more likely to result in pilot fatality.

The presence of fire increased the risk of pilot fatality by nearly six times. The presence of explosion and collision were associated with higher case fatality rates, but did not significantly increase the odds of pilot fatality when controlling for all other predictors, possibly due to the correlation of these variables with the presence of fire.

Among pilot-related predictors, older pilots and those with a private license had increased odds of fatality. The finding that older pilots were more likely to die in weather-related crashes was consistent with previous research and was presumably due to increasing frailty with age.

Of the two airplane-related factors, only number of engines was significant in the multivariate analysis, with accidents involving multi-engine aircraft approximately 1.6 times more likely to result in pilot fatality. While this finding is difficult to explain without acknowledging pilot and operational differences, the association between aircraft size and pilot fatality was likely a consequence of the fact that multi-engine aircraft fly faster than single-engine aircraft, resulting in higher accident impact forces.

In sum, the majority of factors that were predictive of fatality among weather-related accidents, such as fire, dark conditions, intermediate phases of flight, multi-engine aircraft, and older pilot age, have also been linked to higher fatality rates among all GA accidents. These findings suggest that weather-related accidents are caused by the same underlying set of factors as non-weather accidents, but those factors are more prevalent in weather accident scenarios. Initial analysis of a corresponding set of non-weather accidents seems to support this idea. For example, more than 35% of the weather-related accidents in this study occurred at night, which is more than four times higher than the proportion of nighttime non-weather GA accidents (7.6%) over the same time period. Similarly, multi-engine airplanes made up 20.6% of weather-related accidents, but less than 9% of non-weather accidents.

There were, however, a few risk factors that uniquely predicted pilot fatality in weather-related accidents. Pilot-related factors, such as highest level of certification and flight hours, were specifically related to fatal accident outcomes. Among licensed pilots, private pilots and those with fewer flight hours were more likely to die than air transport pilots and those with more flight hours. These findings were not evident in research by Li and Baker (1999), who found few differences among pilots with private, commercial, and air transport certificates, and higher fatality rates among pilots with the greatest number of flight hours.

The relationship between pilot experience and accident outcomes is likely mediated by accident circumstances. For example, private pilots and/or those with fewer flight hours may be more susceptible to weather-induced problems, such as spatial disorientation or loss of control, which typically result in serious accidents. This finding points to a need to examine in greater detail the relationships between pilot characteristics and specific accident circumstances.

Previous laboratory- and survey-based studies of IMC or weather-related accidents have focused on factors such as pilots' ability to detect and evaluate deteriorating visibility conditions (Weigman, Goh, & O'Hare, 2002), their ability to make decisions regarding inclement weather (Burian, Orasanu & Hitt, 2000), and the availability of weather information during flight (Latorrella & Lane, 2002). Similar to the analysis presented here, these studies focused primarily on identifying commonalities among accident pilots rather than identifying those factors unique to accident involvement. To date, few field studies have investigated the factors that distinguish weather-related accident pilots from those pilots able to operate successfully in similar conditions—an area that would benefit from continued research.

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