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Causes and Risk Factors for Fatal Accidents in Non-Commercial Twin Engine Piston General Aviation Aircraft

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ABSTRACT

Accidents in twin-engine aircraft carry a higher risk of fatality compared with single engine aircraft and constitute 9% of all general aviation accidents. The different flight profile (higher airspeed, service ceiling, increased fuel load, and aircraft yaw in engine failure) may make comparable studies on single-engine aircraft accident causes less relevant. The objective of this study was to identify the accident causes for non-commercial operations in twin engine aircraft.

A NTSB accident database query for accidents in twin piston engine airplanes of 4-8 seat capacity with a maximum certified weight of 3,000-8000 lbs. operating under 14CFR Part 91 for the period spanning 2002 and 2012 returned 376 accidents. Accident causes and contributing factors were as per the NTSB final report categories. Total annual flight hour data for the twin engine piston aircraft fleet were obtained from the FAA. Statistical analyses employed Chi Square, Fisher’s Exact and logistic regression analysis.

Neither the combined fatal/non-fatal accident nor the fatal accident rate declined over the period spanning 2002-2012. Under visual weather conditions, the largest number, n=27, (27%) of fatal accidents was attributed to malfunction with a failure to follow single engine procedures representing the most common contributing factor. In degraded visibility, poor instrument approach procedures resulted in the greatest proportion of fatal crashes. Encountering thunderstorms was the most lethal of all accident causes with all occupants sustaining fatal injuries. At night, a failure to maintain obstacle/terrain clearance was the most common accident cause leading to 36% of fatal crashes. The results of logistic regression showed that operations at night (OR 3.7), off airport landings (OR 14.8) and post-impact fire (OR 7.2) all carried an excess risk of a fatal flight.

This study indicates training areas that should receive increased emphasis for twin-engine training/recency. First, increased training should be provided on single engine procedures in the event of an engine failure. Second, more focus should be placed on instrument approaches and recovery from unusual aircraft attitude where visibility is degraded. Third, pilots should be made aware of appropriate speed selection for inadvertent flights in convective weather. Finally, emphasizing the importance of conducting night operations under instrument flight rules with its altitude restrictions should lead to a diminished proportion of accidents attributed to failure to maintain obstacle/terrain clearance.

Highlights

- THE FATAL ACCIDENT RATE IN GA TWIN-ENGINE AIRPLANES IS UNCHANGED FOR 2002-2012.
- A MALFUNCTION WAS ONE OF THE MOST FREQUENT CAUSES OF A FATAL ACCIDENT.
- IMPROPER SINGLE ENGINE PROCEDURES UPON POWER LOSS OFTEN LED TO FATAL ACCIDENTS.
- ALL NIGHT OPERATIONS SHOULD BE CONDUCTED UNDER INSTRUMENT FLIGHT RULES.

Keywords: aviation accidents, general aviation, fatal accidents, multi-engine aircraft.

1.0 INTRODUCTION

General aviation (14CFR Part 91) includes all civilian aviation with the exception of operations involving paid passenger transport the latter covered under 14CFR Part 121 and 135. 14CFR Part 91 refers to a set of FAA regulations that govern the operation of small, non-commercial aircraft within the United States (http://www.ecfr.gov/cgi-bin/text-idx?node=14:2.0.1.3.10) whereas 14CFR Part 121 and 135 are the comparable but more stringent rules applying to airlines and air-taxi operations respectively. Although accidents for the airlines have dramatically declined over the last decade [15], such a decrease has not been witnessed in general aviation. In fact, general aviation accounts for the overwhelming majority (94%) of civil aviation fatalities in the United States [13,15] and represents one of the last unresolved safety challenges for aviation. Furthermore general aviation accidents carry an associated annual cost of $1.6-4.6 billion to individuals and institutions affected (e.g. family and non-family incurring injury and/or loss of life, insurance companies, accident investigation costs) when taking into account hospital costs, loss of pay with a fatal accident and loss of the aircraft [27]. In all likelihood these costs would be even higher were litigation costs assessed as well.

Approximately 7% of the general aviation fleet is comprised of multi-engine piston aircraft. Moreover, of all general aviation accidents 9% occur in twin-engine, piston-powered aircraft [13]. General aviation accidents in these aircraft carry a higher risk of fatality compared with single engine aircraft [13]. Although the reason for the higher fatality rate is unknown several factors may contribute. First, these aircraft typically have a higher airspeed, service ceiling and carry an increased fuel load (and therefore increased potential for a post-impact fire). Second, unlike a single engine aircraft, an engine failure in a twin-engine airplane (with the exception of aircraft with centerline thrust twin engines) creates a yawing tendency due to the asymmetrical thrust a characteristic which may enhance the chance of an aerodynamic stall. Conversely, multi-engine aviators are likely to have more aviation experience than pilots flying single engine aircraft. These differences may make prior studies on single-engine aircraft accident causes less relevant.

Although there are several published studies on general aviation fatal crashes [3,6,9,15], to the knowledge of the author, none have specifically focused on the causes and temporal changes for twin-engine piston aircraft operating under the 14CFR Part 91 umbrella. With few exceptions [24,25], research on aviation accidents typically aggregate single and multiple engine-powered aircraft [10,14,19,29]. In addition, there is also the tendency of studies to cite general (e.g. pilot error, pilot-related) [6,16,26] rather than specific causes. Where specific accident causes are provided, studies often fail to distinguish between single and multi-engine aircraft. The Joseph T. Nall report (hereafter referred to as the Nall report) compiled by *The Air Safety Institute* (http://www.aopa.org/Pilot-Resources/Safety-and-Technique/Accident-Analysis/Joseph-T-Nall-Report) is a biennial report on general aviation accidents. While extremely comprehensive, the Nall report documents several accident causes (e.g. fuel mismanagement, aerodynamic stalls, failure to maintain obstacle/terrain clearance, thunderstorms, instrument approach deficiencies, failure to maintain control and spatial disorientation) across the entire general aviation fixed-wing fleet with little distinction between single and multi-engine aircraft. Additionally, this report fails to identify risk factors that may also contribute to fatal crashes. The objective of the current study was to determine the causes of fatal and non-fatal accidents in twin-piston engine powered airplanes operating under 14CFR Part 91 as well as to identify risk factors for fatal crashes for the period spanning 2002-2012.

2.0 METHODS

The NTSB (2014 Aug release) Access database was downloaded (http://www.ntsb.gov/avdata/Access/) and queried for accidents occurring for the period spanning 2002 and 2012 in twin piston engine aircraft (airplane category) of 4-8 seat capacity with a maximum certified weight of 3,000-8000 lbs. To be included in the current study aircraft operating under 14CFR Part 91 also fulfilled the following criteria: (a) engine horsepower of 150-499 engine) (b) exclusion of homebuilt aircraft (c) flights restricted to the purpose of business or personal use. Data were exported to Excel and, where applicable, de-duplicated in that program. This strategy returned 376 accidents comprised of 150 and 226 fatal and non-fatal accidents respectively. A fatal accident was defined as any in which one, or more, occupants perished within 30 days of the accident (Code of Federal Regulations-49CFR830.2).

Visual conditions were operationally defined as a vertical visibility (above the airport) equal to, or greater than, 3000 feet and a horizontal visibility of 3 statute miles or more. Conversely, instrument flight conditions (also referred to herein as degraded or reduced visibility) constituted weather where the vertical visibility value was less than 3000 feet or horizontal visibility was lower than 3 statute miles. Lethality of accidents was defined as the percentage of occupants sustaining fatal injuries.

Accident causes and contributing factors categories used a classification scheme identical to the NTSB final report. Abbreviations were as follows: Convective WX, thunderstorms; FMC/SD, failure to maintain control/spatial disorientation; FMOTC, failure to maintain obstacle/terrain clearance; Fuel, fuel exhaustion/contamination/mismanagement; landing/takeoff- errors in the landing/takeoff phase. The planned accident flight distance was computed point to point using the AOPA FlyQ Web tool (http://www.aopa.org/flightplanning/flyqweb/index.cfm). Denominator data (total annual flight hour data for the twin engine piston aircraft fleet designated for personal/business purpose) for determining accident rate was obtained from the FAA (http://www.faa.gov/data_research/aviation_data_statistics/general_aviation/). The methodology used for collection of data for the FAA survey has been described in a previous study [1].

2.1 Statistics

All statistical analyses were performed using the SPSS (version 22) software package. Chi Square and Fishers Exact (the latter test used when expected frequencies were ≤ 5 [7]) methods were employed to determine if a difference in fatal accident proportions comparing the initial time period and a subsequent period was statistically significant. For a test of trend for fatal accident proportions across all time periods, a Chi-Square linear-by-linear association output was used for trend assessment [2]. Chi square analysis was also employed to determine if the percentage of the various accident causes under visual and instrument weather conditions were statistically significantly different.

Logistic regression was used to identify risk factors for fatal accidents using 95% confidence intervals. However, the analysis was hindered by the problem of missing data for several parameters. For this reason and since independent variables are often associated with each other, a two-step approach as advocated prior [12] was performed. First, a uni-variable analysis was undertaken on parameters related to airman demographics [4,14], flight experience [14,17] and certification [10], aircraft characteristics [8], weather and lighting conditions [3,10,14] and accident flight distance [10]. Second, a multi-variable analysis was performed to statistically adjust the estimated effect of each variable in the model for differences in the distributions of and association among the other independent variables [12]. Risk factors identified from the bi-variable analysis and showing a Wald significance (which assesses the contribution of each predictor [7]) of $p<0.05$ were advanced into the multi-variable model building. Here a "block entry" method was used where each covariable was added sequentially. If the change in the Chi square value between models was statistically significant ($p<0.05$) then the corresponding parameter was deemed as improving the strength of the model.

3.0 RESULTS

3.1 Accident Rate and Temporal Change over a Decade.

For the 2002-2004 period, there were 11.3 accidents per 100,000 flight hours (Figure 1-bar graph). There was little evidence of change over the subsequent time periods with an accident rate of 10.9 for the most recent (2011-2012) time frame.

The fatal accident rate was then determined over the decade. Across all time periods, there was a non-statistically significant linear trend ($p=0.084$). Fatal accident rates were also compared with the earliest time period (2002-2004). For this period, 39% (46/116) of accidents in twin engine aircraft operating under 14CFR Part 91 were fatal (Figure 1 line graph). However, compared with the 2002-2004 time frame, the fatal accident rates for the subsequent time periods were non-significant as determined using a Chi Square Test.

3.2 Accident Cause Distribution.

The causes of non-fatal accidents (Figure 2) was then determined using NTSB data. Surprisingly, the largest percentage (36%) of accidents (86/229) were ascribed to malfunctions of which 84 could be sub-categorized. Nearly half of the malfunctions (n=37) related to the landing gear or a brake system failure. Failure of landing gear/brake system for 3 of the 37 non-fatal accidents may have been secondary to a hard landing. Loss of engine power and failure of the fuel system accounted for 26% (22/84) and 11% (9/84) of malfunctions respectively. Errors during the landing and takeoff phases of flight accounted for nearly one quarter (58/229) of non-fatal accidents while 14.4% (33/229) of accidents were ascribed to fuel exhaustion/contamination/mismanagement.

Accident causes for fatal accidents were then determined across all lighting conditions but separating accidents by instrument and visual conditions (Table 1). The sum of the percentage of accident causes per weather category equals a value of 100. The highest percentage (28%) of fatal accidents (13/47) for operations in degraded visibility were due to instrument approach deficiencies; although unsurprisingly under visual conditions no accidents were attributed to this cause. Similar to non-fatal accidents, the greatest percentage (27%) of fatal accidents under visual conditions was attributed to a malfunction (27/101) involving an engine(s), instrument panel, flight control surfaces, fuel system or a cabin heater. Of 35 accidents in visual and instrument conditions combined, 25 were attributed to a loss of power in one, or in a few cases, both engines. Importantly, the NTSB cited a failure to follow single engine procedures as a contributing factor in the majority (20) of accidents related to loss of engine power. The percentage of accidents due to this cause was lower under instrument weather conditions (17% or 8/47 accidents), and a Fisher's Exact Test indicated that this difference was indeed statistically significant ($p<0.01$). Failure to maintain control/spatial disorientation accounted for 13% (13/101) of fatal accidents and was unchanged (15% or 7/47 accidents) by degraded visibility ($p=0.53$). Similarly, between 12-15% of fatal accidents (12/101 and 7/47 accidents under visual and instrument conditions respectively) were attributed to failure to maintain obstacle/terrain clearance. Perhaps not surprising, and in contrast to the data for non-fatal accidents (Figure 2), a much higher (2-5X) percentage of fatal crashes was ascribed to aerodynamic stalls. Accidents related to fuel (exhaustion/contamination-/mismanagement) accounted for 12 (12/101) and 6% (3/47) of fatal crashes under visual and instrument weather conditions respectively although this difference was not statistically significant ($p=0.36$).

3.3 Lethality of Accidents.

The lethality of accidents was then determined as a function of accident cause and degraded visibility (Table 2). Although the numbers were small, encountering convective weather (thunderstorms), leading to in-flight break-up in some cases, was the most lethal with all occupants sustaining fatal injuries irrespective of visibility conditions. Similarly, accidents due to a failure to maintain control/spatial disorientation carried a 93% (14/15) and 78% (7/9) lethality rate under visual and instrument weather conditions respectively. Interestingly, fuel-related accidents and crashes attributed to a malfunction both carried a lower lethality rate than the aforementioned causes. For fuel-related accidents, 29% (12/42) and 50% (3/6) of occupants were fatally injured for operations conducted in visual and instrument conditions respectively although this difference was not statistically significant ($p=0.36$). In contrast, for accidents due to malfunctions, a lower percentage of occupants fatally injured was evident for operations conducted under visual (25% or 27/108) compared with those under instrument (67% or 8/12) conditions ($p <0.01$).

3.4 Fatal Accident Causes at Night.

A prior study reported an increased risk of fatality for general aviation operations conducted at night [14]. With this in mind, the author sought to identify the most frequent accident causes at night. Although the total number of fatal accidents at night was relatively small (n=33) and precluded a statistical comparison with accidents during daylight, failure to maintain obstacle/terrain clearance was the most prevalent cause leading to 36% (12/33) of crashes (Figure 3). Not surprisingly, there were few such accidents during the day. At night, of twelve accidents attributed to this cause, the majority (75%) were not operating under an instrument flight plan. Aerodynamic stall/failure to maintain control and instrument approach deficiencies accounted for 27 (9/33) and 30% (10/33) of fatal accidents at night respectively.

3.5 Risk Factors for Fatal Flights.

Risk factors for a fatal accident were then determined. Of 377 accidents only 186 were complete for the 12 parameters of interest (listed in Table 3). Of the complete cases, there were 60 and 126 fatalities and non-fatalities respectively equating to a value of five events per variable (60/12) far fewer than the recommended minimum value of 10 [21]. This necessitated a two-step approach (uni-variable and then multi-variable analysis) as described in the Methods.

In the uni-variable analysis (Table 3), advanced pilot certification (comparing either commercial or airline transport pilot (ATP) certification with private license) was not associated with a diminished risk for a fatal crash. Likewise the addition of an instrument certificate did not carry a lower risk for a fatal accident outcome. Note that the population cohort (n=375) used for the analysis of benefit of the IFR-add on is larger (n=372) than the group used to determine the benefits of advanced certification (commercial, ATP). The reason for this discrepancy is the censoring of records for aviators holding military and foreign certificates from the latter analysis. Regarding aircraft aerodynamics, landing speed is a function of its weight and it is well recognized that the impact force imposed on the occupant(s) is a square of the forward velocity of the aircraft [8]. Since this study included aircraft with a broad maximum certified weight range (3,000-8000 lbs.) this parameter could be associated with an elevated fatality rate. However logistic regression revealed an unchanged risk (with confidence intervals crossing unity) for a fatal flight as a function of maximum certified weight.

Five parameters were identified as risk factors from the uni-variable analysis: instrument weather conditions, light conditions, whether the accident was on, or off, the airport, occurrence of a post-impact fire and a flight distance over 300 nm. Note that for this analysis 323 complete records were available for analysis (197 and 126 non-fatal and fatal respectively). The number of events per variable was therefore 25 (126/5) and well in excess of a value of 10 suggested for logistic regression [21].

Degraded visibility, night, off-airport landings and a post-impact fire all contributed to a robust multi-variable model (Chi Square 168.735, $p<0.001$) with a predictive value of 82% compared with 61% for the null model. However, flight distance over 300 nm did not improve the strength of the model. As in the uni-variable analysis, operations conducted at night showed an elevated risk for a fatal outcome (OR 3.68)-Table 4. Additionally, in the multi-variable analysis the data also showed an increased risk of a fatal accident for an off airport landing (OR 14.81) and a post-impact fire (OR 7.24). These findings are in line with previous studies [11,14,22], which aggregated single and multi-engine airplanes, showing a strong association between a fatal accident and either an off airport landing [14,22] or a post-impact fire [11,14]. A check for the biasing effect of collinearity in the multi-variable model revealed variance inflation factor values of less than 10 mitigating this concern [18].

4.0 DISCUSSION

To the author's knowledge this is the first study to exclusively report on accident causes in twin, piston engine powered airplanes for operations conducted under 14CFR Part 91. Most studies [10,14,19,29] on general aviation accidents aggregate single and multi-engine aircraft despite the fact that the flight profile for these aircraft differ substantially. Twin engine aircraft typically fly faster, longer distances, at higher altitudes and carry an increased fuel load. Equally important, as a consequence of their increased weight, landing speeds are higher which translates into a higher kinetic energy transferred to the occupants on a crash landing. Thus not surprisingly, the lethality rate of multi-engine aircraft are higher than for their single engine counterparts [13].

The high percentage of fatal accidents attributed to a malfunction irrespective of visibility conditions (22% average for both weather conditions) was surprising. This proportion was substantially higher than the 4% cited in a prior publication focused on accidents occurring during instrument approaches [5]. However, the latter study included air taxi operations conducted under the more stringent 14CFR Part 135 rules and was restricted to a single phase of flight: two factors that likely contribute to a lower rate. The percentage of fatal twin engine aircraft accidents attributed to the malfunction category was also slightly higher than the 17% reported by the 2010 Nall report on general aviation for that year [13].

What was particularly disconcerting in this study was the number of fatal accidents involving a loss of engine power. While arguably two engines provide an additional level of redundancy in the event of an inoperative engine, adherence to single engine procedures is of paramount importance. Unfortunately, a failure to follow single engine procedures as, cited by the NTSB, was a contributing factor in the majority of the accidents related to loss of engine power.

Regarding the 100% lethality of accidents due to convective weather, common practice is to teach aviators flying light aircraft (inclusive of single and multi-engine airplanes) to decrease airspeed to maneuvering airspeed (V_A) to avoid airframe stresses that may cause structural failure. However thunderstorms are characterized by strong updrafts and downdrafts which may cause airspeed fluctuations of 15-25 knots thereby exceeding V_A. A pilot attempting to maintain V_A will exceed this speed with an increased possibility of airframe failure (http://www.faa.gov/regulations_policies/handbooks_manuals-/aviation/pilot_handbook/media/PHAK-Errata-Sheet.pdf Items # 19 & 20).

Interestingly, examination of the accident cause profile revealed some key differences between twin and single engine powered aircraft the latter which the author reported on previously [25]. Aerodynamic stalls contributed to a lower percentage (14 compared with 22%) of fatal crashes in twin engine aircraft operating in visual conditions compared with single engine powered aircraft. Likewise, failure to maintain control/spatial disorientation was cited more frequently (25 and 15% respectively) as a fatal accident cause under degraded visibility in single engine aircraft [25]. In contrast, the percentage of accidents caused by instrument approach deficiencies in reduced visibility was similar for both single and twin engine aircraft (30 and 28% respectively). This latter finding is not surprising and reflects a continued concern by general aviation pilots as to the problem of maintaining instrument currency [28]. Notwithstanding these observations, a key difference between both studies was the pilot population; exclusively private pilots for the single engine aircraft cohort in contrast to a mixed population of aviators with advanced certification (the majority constituted by commercial or ATP pilots) in the current study. This difference could very well contribute to the lower level of aerodynamic stalls as a commercial license requires pilots to maintain control of the aircraft under conditions approaching a stall to a higher standard than aviators tested for the private pilot certificate (US Department of Transportation documents FAA-S-8081-12C and FAA-S8081-14B respectively). Moreover, earlier studies had reported a reduced involvement of ATP pilots in general aviation accidents [23] as well as fewer pilot errors [16]. On the other hand the logistic regression showed little evidence of a risk reduction for a fatal accident with advanced certification arguing against this possibility at least with respect to twin engine aircraft. As to the concordance of accidents caused by instrument approach deficiency this may reflect the very high percentage of IFR-certified aviators in both studies; 100% for a prior report by the author of single engine aircraft [25] and over 85% for the current study on twin engine aircraft.

That advancing age did not represent a risk factor for a fatal accident in the current investigation was somewhat surprising as aging is associated with diminished cognitive function. Indeed, prior publications [4,14] have cited advancing age as a risk factor for a fatal outcome. However, for the study by Li and Baker [14] the elevated risk was modest (Odds Ratio= 1.7) with a lower confidence interval of 1.0. Similarly, Bazargan and Guzhva [4] reported a small elevated risk (OR 1.21) with advancing age comparing aviators 60 years and older with a reference group of pilots spanning the ages of 30-39 years.

The current study demonstrated that instrument and lighting conditions, an off-airport accident as well as a fire were all risk factors for a fatal accident in twin engine aircraft operating under 14CFR Part 91. It will be very interesting in future studies to determine if these aforementioned risk factors are identical for fatal accidents in single-engine aircraft.

The study had a number of limitations. First and foremost this study was retrospective. Second, in some instances the number of events attributed to a particular accident cause was small especially for the analysis of night accidents. Finally, there may have been risk factors that were not captured in this research. For example, recent flight experience times are often absent from the NTSB report and precluded an analysis of this co-variate in the logistic regression analysis. Also, accident aircraft were likely equipped with a wide range of avionics from the traditional analog displays through to the current electronic flight displays a factor that was not addressed in this study. The latter systems demand an increased cognitive function and maintaining proficiency is more difficult compared with the traditional analog instrumentation [20].

In conclusion, this study emphasizes training areas that should be given priority in regard to pilots flying twin-engine aircraft. First and foremost, increased emphasis should be given to single engine procedures upon loss of power in one engine. Second, the high proportion of fatal accidents in instrument weather conditions and at night due to instrument approach deficiency and loss of control/spatial disorientation argues for increased training in these areas. The recent advent of affordable full motion FAA-approved flight simulators provides a means of achieving this objective. Third, pilots should be made aware of appropriate speed selection for turbulence penetration in inadvertent penetration of convective weather. Finally, for night operations under visual conditions general aviation pilots should be encouraged to conduct flights in accordance with instrument flight rules towards diminishing the proportion of accidents attributed to failure to maintain obstacle/terrain clearance.

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6.0 LEGENDS

Figure 1. Temporal Change in Twin-Engine Accident Rate.

The change in all (fatal and non-fatal combined) accident rate (bar graph) normalized to FAA data for twin engine aircraft used for personal or business purpose for the indicated time period. n=accident number (fatal and non-fatal combined). The line graph depicts the percentage of all accidents that were fatal for the corresponding time period. P values indicate the statistical level relative to the first time period (2002-2004).

Figure 2. Distribution of Causes of Non-Fatal Accidents.

The distribution of accident cause is shown where the sum of all non-fatal accidents equals 100. Accident cause was per the NTSB final report. FMOTC, failure to maintain obstacle/terrain clearance; Fuel, fuel exhaustion/contamination/mismanagement; landing/takeoff- errors in the landing/takeoff phase. Other –failure to maintain control, icing (structural, carburetor), instrument approach deficiencies, overfilling fuel tank, windshear, mid-air collision, undetermined. n-number of accidents.

Figure 3. Comparison of Fatal Accident Causes at Night and Day.

The distribution of accident causes at night and day is depicted where the sum of fatal accidents equals 100 for each of the two lighting conditions. Accident cause was per the NTSB final report and abbreviations as per Figure 2. Other –checklist incomplete, exceed aircraft maximum design limits, icing, landing/takeoff errors, pilot incapacitation, undetermined. n-number of accidents.

Table 1. Distribution of Fatal Accident Causes.

Visual conditions were defined as a vertical visibility ≥3000 feet and horizontal visibility ≥3 statute miles. For instrument flight conditions these values were <3000 feet and/or <3 miles respectively. Accident cause was per the NTSB final report. FMC/SD, failure to maintain control/spatial disorientation; FMOTC, failure to maintain obstacle/terrain clearance; Fuel, fuel exhaustion/contamination/mismanagement; Other – mid-air collision, improper starting procedure, undetermined. N-number of fatal accidents, (%) percentage of accidents in that category for the indicated weather condition. ND-not done.

Table 2. Occupants Fatally Injured per Accident.

The number and percentage of occupants fatally injured is shown as a function of accident cause and weather conditions. Visual and instrument weather conditions were defined as per Table 1. N= number of airplane occupants fatally injured for a given accident cause. Convective WX, thunderstorms; FMC/SD, failure to maintain control/spatial disorientation; FMOTC, failure to maintain obstacle/terrain clearance; Fuel, fuel exhaustion/contamination/mismanagement;

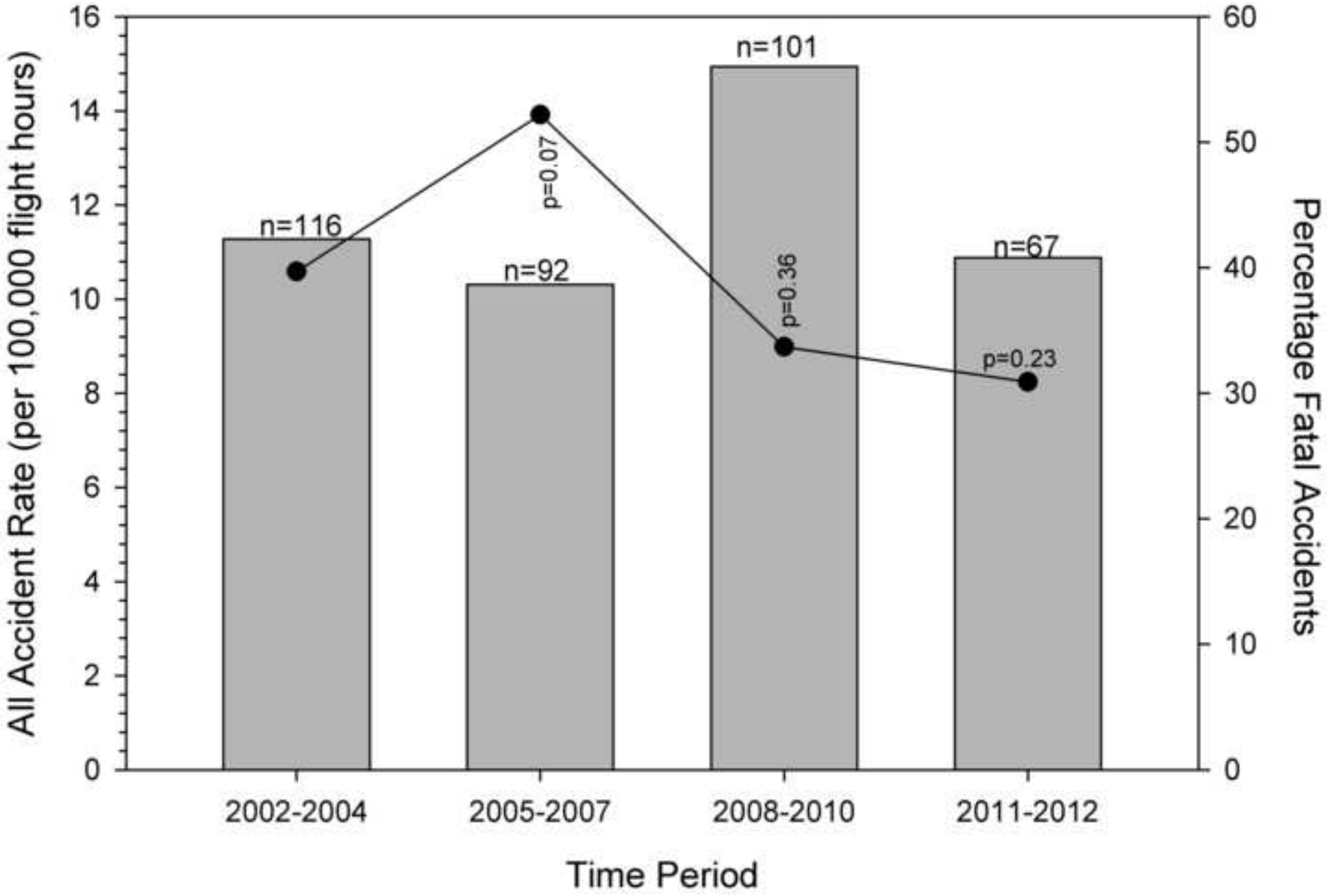
Table 3. Uni-variable analysis of Pilot Demographics Certification, Flight History and Aircraft Characteristics as Risk Factors for a Fatal Flight.

Logistical regression of putative risk factors associated with a fatal accident. N- number of accidents (fatal, non-fatal combined) in analysis. ATP, airline transport pilot. Visual and instrument conditions were defined as per Table 1. Only those aviators with IFR certification in the airplane category were included as IFR-certified. Ref, referent.

Table 4. Multi-variable analysis of Risk Factors for a Fatal Flight.

Multi-variable logistical analysis of risk factors for a fatal accident selected from uni-variable analysis. N=323 accidents (fatal, non-fatal combined) in analysis. Visual and instrument conditions were defined as per Table 1. Ref, referent.

Figure 1



All Accident Rate (per 100,000 flight hours)
0
2
4
6
8
10
12
14
16
Percentage Fatal Accidents
0
10
20
30
40
50
60
n=116
n=92
n=101
n=67
p=0.07
p=0.36
p=0.23
2002-2004
2005-2007
2008-2010
2011-2012
Time Period

Figure 2

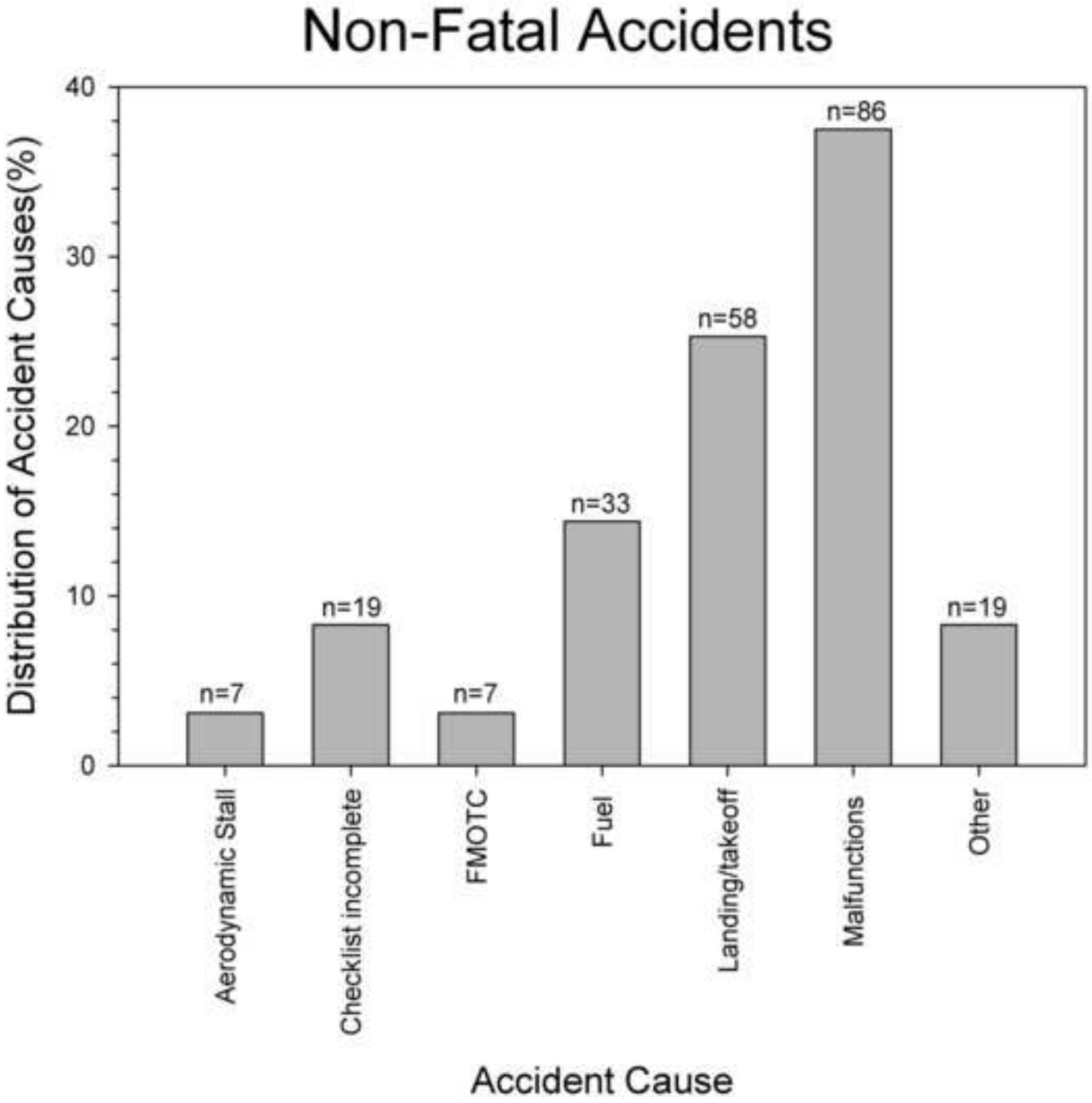

Non-Fatal Accidents
Distribution of Accident Causes(%)
0
10
20
30
40
n=7
n=19
n=7
n=33
n=58
n=86
n=19
Aerodynamic Stall
Checklist incomplete
FMOTC
Fuel
Landing/takeoff
Malfunctions
Other
Accident Cause

Figure 3
Click here to download high resolution image

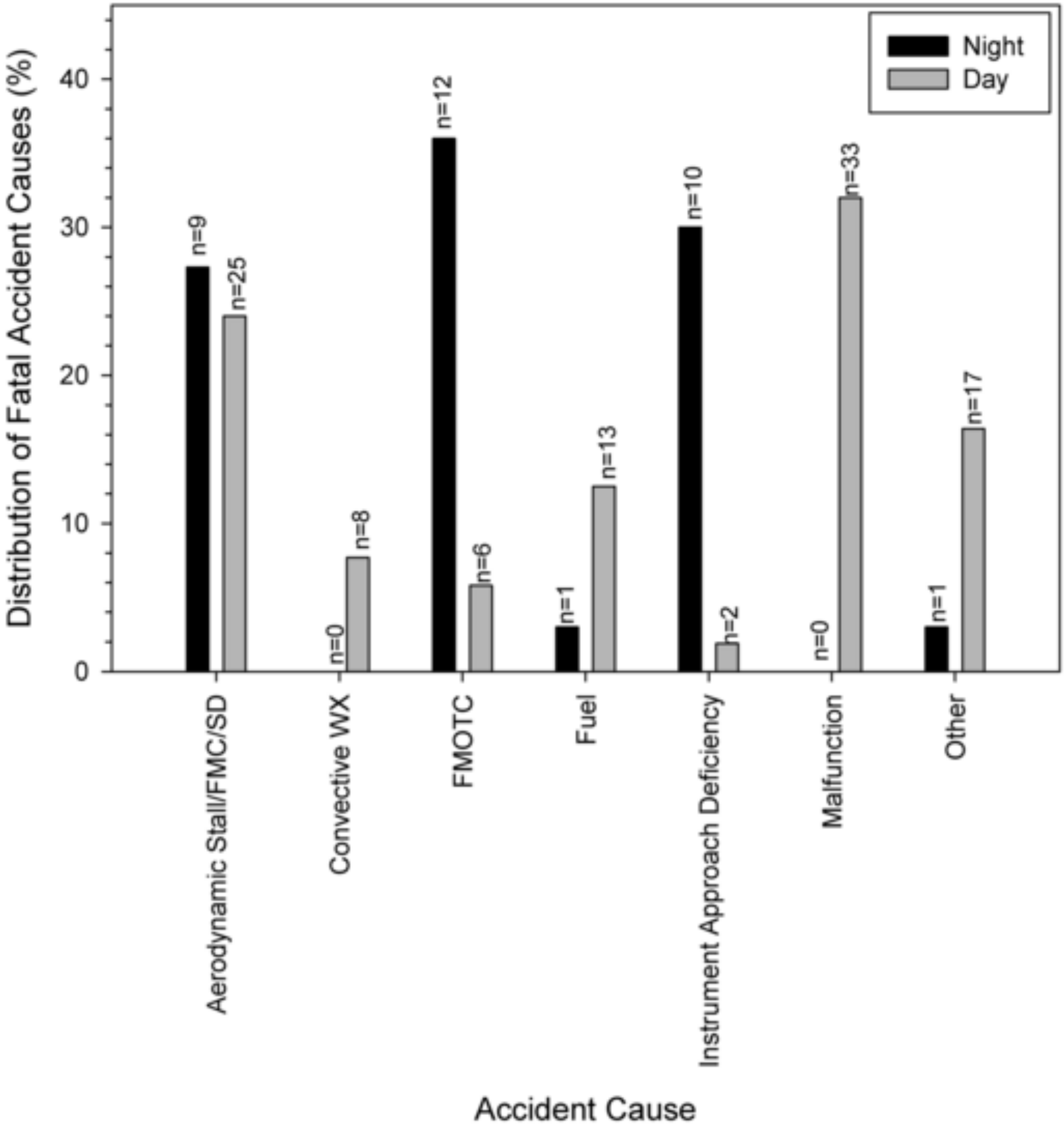
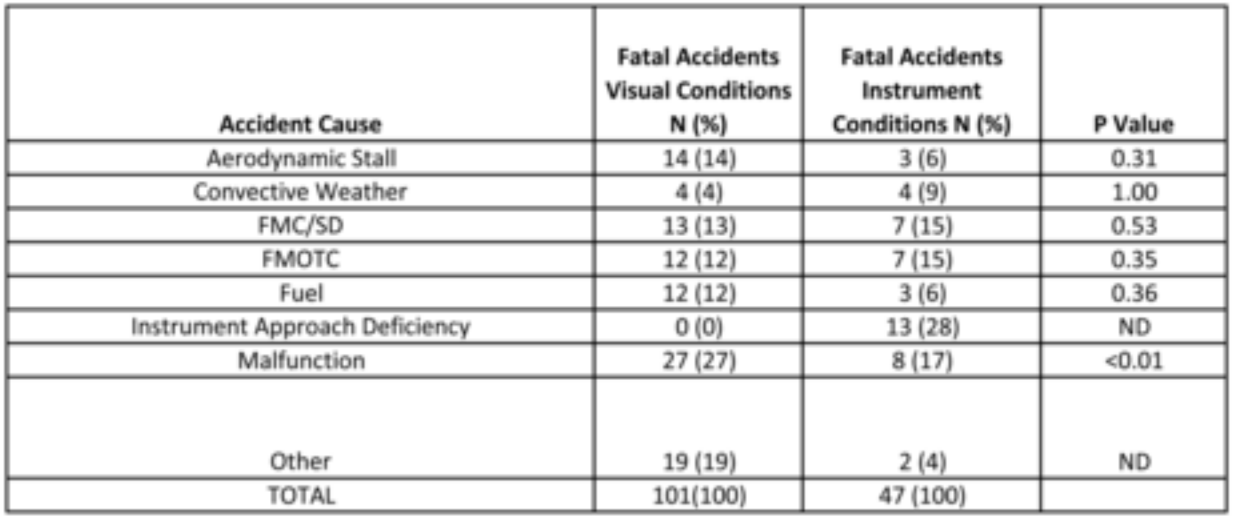
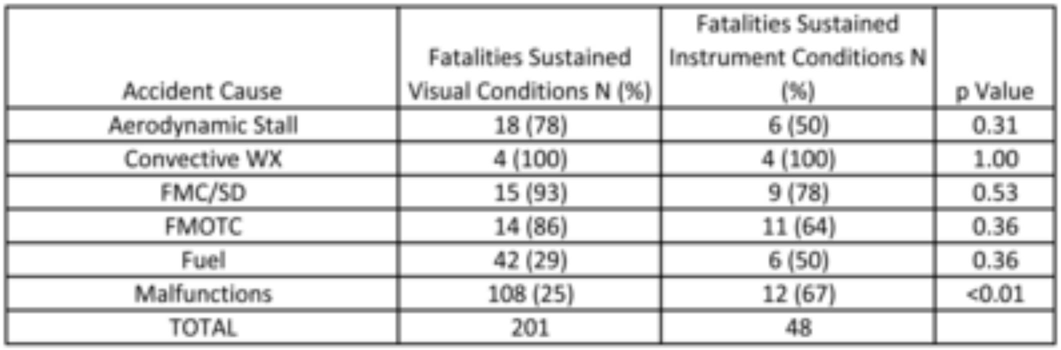


Table 1



Accident Cause	Fatal Accidents Visual Conditions N (%)	Fatal Accidents Instrument Conditions N (%)	P Value
Aerodynamic Stall	14 (14)	3 (6)	0.31
Convective Weather	4 (4)	4 (9)	1.00
FMC/SD	13 (13)	7 (15)	0.53
FMOTC	12 (12)	7 (15)	0.35
Fuel	12 (12)	3 (6)	0.36
Instrument Approach Deficiency	0 (0)	13 (28)	ND
Malfunction	27 (27)	8 (17)	<0.01
Other	19 (19)	2 (4)	ND
TOTAL	101(100)	47 (100)	

Table 2

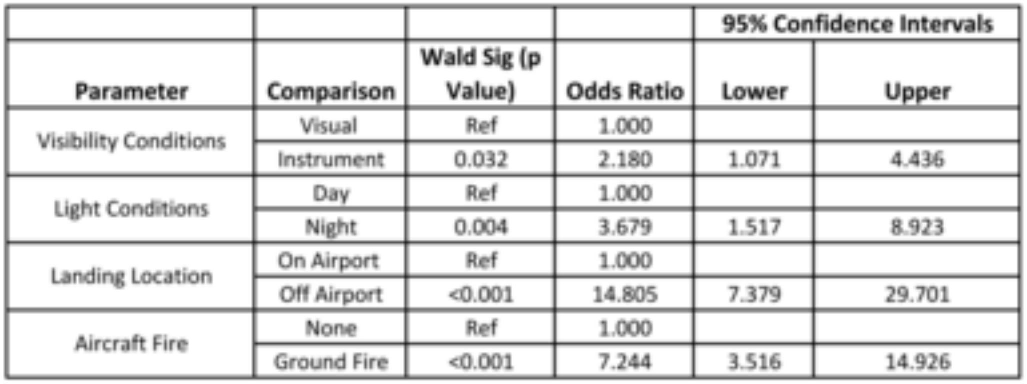


Accident Cause	Fatalities Sustained Visual Conditions N (%)	Fatalities Sustained Instrument Conditions N (%)	p Value
Aerodynamic Stall	18 (78)	6 (50)	0.31
Convective WX	4 (100)	4 (100)	1.00
FMC/SD	15 (93)	9 (78)	0.53
FMOTC	14 (86)	11 (64)	0.36
Fuel	42 (29)	6 (50)	0.36
Malfunctions	108 (25)	12 (67)	<0.01
TOTAL	201	48	

Table 3

					95% Confidence Intervals	
Parameter	N	Comparison	Wald Sig (p Value)	Odds Ratio	Lower	Upper
Pilot Age (Years)	309	20-39	Ref	1.000		
		40+	0.427	1.290	0.689	2.414
		40-59	0.634	1.173	0.608	2.265
		60-79	0.260	1.497	0.742	3.021
		80+	0.695	1.350	0.301	6.061
Pilot Certification	372	Private	Ref	1.000		
		Commercial/ATP	0.586	0.889	0.483	1.356
		Commercial	0.968	0.991	0.626	1.568
		ATP	0.246	0.706	0.393	1.27
IFR Certification	375	Not Certified	Ref	1.000		
		Certified	0.482	1.241	0.680	2.264
Second Pilot	368	Yes	Ref	1.000		
		No	0.482	1.314	0.614	2.814
Visibility Conditions	376	Visual	Ref	1.000		
		Instrument	<0.001	3.324	1.965	5.622
Pilot Total Flight Time (hours)	375	<1,000	Ref	1.000		
		1,000+	0.667	0.902	0.553	1.469
		1,000-2,499	0.713	1.112	0.633	1.951
		2,500-3,999	0.791	1.097	0.554	2.171
		4,000-8,999	0.123	0.473	0.283	1.163
		9,000+	0.404	0.746	0.374	1.486
Pilot Flight Time Make/Model (hours)	289	0-249	Ref	1.000		
		250+	0.099	0.642	0.379	1.088
		250-499	0.989	0.995	0.491	2.016
		500-749	0.465	0.722	0.301	1.729
		750-999	0.227	0.451	0.124	1.640
		1000+	0.029	0.376	0.156	0.904
Light Conditions	374	Day	Ref	1.000		
		Dawn/Dusk/Night	<0.001	4.252	2.401	7.529
		Dawn/Dusk	0.230	2.092	0.639	6.449
		Night	0.000	5.141	2.703	9.779
Accident Flight Distance (nm)	338	0-299	Ref	1.000		
		300+	0.002	2.14	1.33	3.443
		300-599	0.025	1.823	1.076	3.087
		600+	0.004	3.511	1.486	8.296
Aircraft Max Certified Weight (lbs)	377	3,000-3,999	Ref	1.000		
		4,000+	0.165	1.529	0.839	2.784
		4,000-4,999	0.432	1.333	0.641	2.731
		5,000-5,999	0.179	1.574	0.812	3.051
		6,000-6,999	0.091	1.852	0.906	3.784
		7,000+	0.618	1.244	0.527	2.937
Landing Location	367	On Airport Landing	Ref	1.000		
		Off Airport Landing	<0.001	18.560	10.356	33.263
Aircraft Fire	373	None	Ref	1.000		
		Ground Fire	<0.001	7.633	4.412	13.206

Table 4



				95% Confidence Intervals	
Parameter	**Comparison**	**Wald Sig (p Value)**	**Odds Ratio**	**Lower**	**Upper**
Visibility Conditions	Visual	Ref	1.000		
	Instrument	0.032	2.180	1.071	4.436
Light Conditions	Day	Ref	1.000		
	Night	0.004	3.679	1.517	8.923
Landing Location	On Airport	Ref	1.000		
	Off Airport	<0.001	14.805	7.379	29.701
Aircraft Fire	None	Ref	1.000		
	Ground Fire	<0.001	7.244	3.516	14.926