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Accident-Precipitating Factors for Crashes in Turbine-Powered General Aviation Aircraft

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ABSTRACT

General aviation (14CFR Part 91) accounts for 83% of civil aviation fatalities. While much research has focused on accident causes/pilot demographics in this aviation sector, studies to identify factors leading up to the crash (accident-precipitating factors) are few. Such information could inform on pre-emptive remedial action. With this in mind and considering the paucity of research on turbine-powered aircraft accidents the study objectives were to identify accident-precipitating factors and determine if the accident rate has changed over time for such aircraft operating under 14CFR Part 91.

The NTSB Access database was queried for accidents in airplanes (<12,501 lb) powered by 1-2 turbine engines and occurring between 1989 and 2013. We developed and utilized an accident-precipitating factor taxonomy. Statistical analyses employed logistic regression, contingency tables and a generalized linear model with Poisson distribution.

The “Checklist/Flight Manual Not Followed” was the most frequent accident-precipitating factor category and carried an excess risk (OR 2.34) for an accident with a fatal and/or serious occupant injury. This elevated risk reflected an over-representation of accidents with fatal and/or serious injury outcomes ($p<0.001$) in the “non-adherence to V Speeds” sub-category. For accidents grouped in the “Inadequate Pre-Flight Planning/Inspection/Procedure” the “inadequate weather planning” sub-category accounted ($p=0.036$) for the elevated risk (OR 2.22) of an accident involving fatal and/or serious injuries. The “Violation FARs/AIM Deviation” category was also associated with a greater risk for fatal and/or serious injury (OR 2.59) with “Descent below the MDA/failure to execute the missed approach” representing the largest sub-category. Accidents in multi-engine aircraft are more frequent than their single engine counterparts and the decline (50%) in the turbine aircraft accident rate over the study period was likely due, in part, to a 6 fold increased representation of single engine airplanes.

In conclusion, our study is the first to identify novel precursive factors for accidents involving turbine aircraft operating under 14CFR Part 91. This research highlights areas that should receive further emphasis in training/recurrency in a pre-emptive attempt to nullify candidate accident-precipitating factor(s).

KEYWORDS: general aviation accidents, accident-precipitating factors, turbine aircraft, injury severity.

1.0 INTRODUCTION

General aviation is inclusive of all civilian aviation operations apart from those involving paid passenger transport. 14CFR Part 91 represents a set of FAA regulations governing the operation of light, non-commercial aircraft under the general aviation umbrella within the United States (http://www.ecfr.gov/cgi-bin/text-idx?node=14:2.0.1.3.10). In contrast, the corresponding 14CFR Part 121 and 135 regulations, apply to airlines and air-taxi operations respectively, and are more stringent. While accidents for the airlines have dramatically declined over the last 20 years (DeJohn et al., 2013; Li and Baker, 2007), such a decrease has not been evident for general aviation although preliminary NTSB aviation data (www.ntsb.gov/news/2014/140915b.html) show a decline in the accident rate for the most recent year (2013). Nevertheless, general aviation still accounts for the overwhelming majority (83%) of civil aviation fatalities across the United States (Bazargan and Guzhva, 2011). Furthermore, accidents in this sector 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) inclusive of hospital costs, loss of pay with a fatal accident and loss of the aircraft (Sobieralski, 2013). It should be emphasized that these costs do not include litigation expenditures.

Clearly, there is a need to reduce the high accident rate evident for general aviation. In this regard, the NTSB, as part of its investigative process, assigns a probable cause to every general aviation accident, for example; controlled flight into terrain (CFIT), spatial disorientation, loss of control and pilot error (Li et al., 2001; Shkrum et al., 1996). Noteworthy, loss of control tops the NTSB 2015 “most wanted list” for general aviation (http://www.ntsb.gov-/safety-/mwl/Documents/MWL_2015_brochure.pdf). Nevertheless, it is equally important to recognize that accidents are the culmination of one, or more, precursive factor(s). In fact, across the aviation industry, including airline operations and maintenance (Rankin et al., 2000), there has been an increasing shift towards identifying precursive elements by way of programs such as the flight operational quality assurance safety program (http://www.faa.gov/about/initiatives-/atos/air_carrier/foqa/). However, for general aviation, studies of pre-accident factors have tended to focus on a limited set of variables such as weather and light conditions (Ballard et al., 2013; Bazargan and Guzhva, 2007). Rather, greater emphasis has been placed on determining: (a) the accident cause (Boyd, 2015a; Shao et al., 2014a) (b) pilot flight history/experience/demographics (Bazargan and Guzhva, 2011; Bennett and Schwirzke, 1992; Groff and Price, 2006; Li et al., 2001; Li et al., 2005; Li and Baker, 1999) and (c) post-accident circumstances (e.g. whether the accident was on or off-airport (Ballard et al., 2013; Li and Baker, 1999; Rostykus et al., 1998) or involved a post-impact fire (Ballard et al., 2013; Handel and Yackel, 2011; Li and Baker, 1999)).

General aviation is comprised mainly of piston-driven aircraft with turbine (inclusive of turboprop and turbojet) aircraft representing the minority. However, in terms of operations, annual flight hours for turboprop aircraft represent 17% of the total flight hours for the combined piston/turboprop fleet operating under Part 91 (2013 General Aviation Manufacturer's Association (GAMA) Statistical Databook). Since turbine engine aircraft represent the minority, it is not surprising that most studies on general aviation accidents either aggregate aircraft, irrespective of their type of power plant, or focus exclusively on piston-engine aircraft (Boyd, 2015a; Boyd, 2015b; Shao et al., 2014a; Shao et al., 2014b). However, caution should be exercised in using findings from such studies to inform on accidents involving gas-turbine-powered aircraft for several reasons. First, turbine-powered aircraft are able to fly at higher altitude where there is less control authority of the flight control surfaces due to the thinner air (Brown and Holt, 2012). Second, at higher altitudes, there is a greater potential for icing, high level wind shear (associated with jet stream) (http://www.faa.gov/other_visit/aviation-_industry/airline_operators-/training/media-/Appendix_3-E_-HighAlt-Operations.pdf) and hypoxia. Indeed, 14CFR§61.31 mandate that airmen flying aircraft at altitudes in excess of 25,000 feet (FL250) in pressurized aircraft receive training in the critical factors relating to safe flight operations. Finally, turbine engines have longer engine response (spool up) times compared with their piston-counterparts - an issue important for balked landings and or missed approaches.

Considering these gaps in knowledge, the objectives of our study were two-fold (a) identify the accident-precipitating (also referred herein to as accident-precursive) factors leading to fatal accidents in turbine aircraft operating under 14CFR Part 91 and (b) determine if the fatal and all accident rate for turbine aircraft operating under these regulations has changed over the past 25 years.

2.0 MATERIALS AND METHODS

2.1. Database and Query

The NTSB (2015 March release) Access database was downloaded (http://www.ntsb.gov/avdata/Access/) and queried for accidents (operating under 14CFR Part 091) involving aircraft (<12,501 lb) (airplane category) powered by 1-2 turbine engines (horsepower 250-2501) and occurring across the 1989-2013 period. Accidents for which the following type of operations were being conducted were deleted: flights involving ferry operations, flight instruction, skydiving, flight tests, public utility, aerial observation and air shows. Additionally the following types of accidents were also excluded: ground personnel handling of aircraft, a motor vehicle collision with aircraft; during taxiing, injuries external to the aircraft, preliminary accident reports, stationary aircraft, illegal/criminal flights, aerobatics, aerial applications, accidents outside of the U.S. for which a NTSB report was not issued, and where there was lack of agreement by NTSB members as to the final report.

Data were exported to Excel and, where applicable, de-duplicated in that program. This strategy returned 551 accidents. 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). Serious injuries were defined as per NTSB Form 6120.1 (http://www.ntsb.gov/doclib/forms/6120_1web_nopwx.pdf). Minor injuries are defined as any injury that does not meet the criteria for another injury category per the aforementioned NTSB form 6120. Of 551 accidents, 313 involved accidents for which occupants sustained no and/or minor injuries while 238 involved occupants who sustained fatal and/or serious injuries.

2.2 Taxonomy

We initially considered using the Human Factors and Classification System (HFACS) (Shappell and Wiegmann, 2001) for our analysis. However, this application is best suited to enterprises that have a strong organizational component such as Part 135 or Part 121 operations. Moreover, HFACS requires review of the primary unpublished data for which we had no access to. Accordingly we developed our own taxonomy based on an analysis of the NTSB synopsis and factual report corresponding to approximately 100 records. Accident-precipitating factors included, but were not limited to, the subset of contributing factors that temporally preceded the accident cited by the NTSB in its current synopsis. In this way, a schema of 17 individual or grouped accident-precipitating factors was developed by the co-authors (both subject matter experts). All 551 accidents were subsequently classified per the aforementioned taxonomy. Disagreements as to the assignment of a particular accident-precipitating factor or category for an event were discussed until consensus was reached.

2.3 Statistics

All statistical analyses were performed using the SPSS (version 22) software package. Multi-variable logistic regression was used to identify accident-precipitating factors for crashes with fatal and/or serious injury outcomes. Backward elimination, based on a likelihood ratio test, was first used to eliminate non-contributing variables ($p>0.05$) to produce the most parsimonious model but still satisfying the criterion of 10 or more events per variable (Peduzzi et al., 1996). A check for the biasing effect of collinearity in the reduced, multi-variable model revealed variance inflation factor values of less than 10 mitigating this concern (Myers, 1990).

Contingency tables employed Pearson Chi-Square to determine if there was an overall difference in proportions. P values for cells in multinomial tables were derived from adjusted standardized residuals (Z-scores) in post-hoc testing.

To determine if accident rates differed from the earliest period (1989-1993), a generalized linear model with Poisson Distribution was employed adjusting for differences in annual turbine fleet flight times for 14CFR Part 91 operations. Sources of fleet activity were:

for post-1999, the FAA (https://www.faa.gov/data_research/-aviation_data_statistics/general_aviation/) and the 1989-1999 period, GAMA Statistical Guides (http://www.gama.-aero/media-center/industry-facts-and-statistics/statistical-databook-and-industry-outlook).

3.0 RESULTS

3.1 Accident-Precipitating Factor Categories.

The NTSB Access database was queried for accidents in aircraft (<12,501 lb) powered by 1-2 turbine engines and operating under 14CFR Part 91 rules for the period spanning 1989-2013. This search returned 551 accidents of which 87% involved turbo-prop; the remaining were comprised of turbojet-powered aircraft. Of the 551 accidents 313 and 238 involved no/minor injuries and fatal/serious injuries respectively. Based on an analysis of the NTSB synopsis and factual report for approximately 100 records, a total of 17 accident-precipitating factor/categories were derived (Table 1) and used subsequently to categorize all 551 crashes.

We then sought to identify which of these accident-precipitating factors/categories carried an increased risk for an accident with a fatal and/or serious injury outcome. As a first step in this direction, all 17 accident-precipitating factors/categories were subjected to backward elimination (based on a likelihood ratio test) in logistic regression to eliminate non-contributing variables (Field, 2009) ($p>0.05$). Using this approach, 11 accident-precipitating factor/categories meeting this criterion were selected (Table 2). This reduced model was used to quantify the increased risk (odds ratio or OR) of each variable for an accident with fatal and/or serious injury outcome (Table 2) while adjusting for the effects of the other variables. The reduced model predicted 74.8% correct compared with an overall percentage of 56.8% by chance.

The “Checklist/Flight Manual Not Followed”, was the most frequent accident-precipitating factor category (n=132) and carried an elevated risk (OR 2.34) for an accident with a fatal and/or serious occupant injury. For accidents grouped in the “Inadequate Pre-

Flight Planning/Inspection/Procedure" or "Violation FARs/AIM Deviation" categories, occupants were also at greater risk for fatal and/or serious injury (OR 2.22 and 2.59 respectively). While the "Lack of Experience/Systems Knowledge" and "Air Traffic Control/Flight Service Station Deficiency" categories were implicated in fewer accidents, nevertheless they also carried an increased risk of a fatal/and or serious injury outcome (OR 5.01 and 6.24 respectively).

3.2 Sub-Classification of Accident-Precipitating Factor Categories.

Due to the breadth of some of the accident-precursive factor categories, we sub-classified three that carried an elevated risk of an accident with a fatal and/or serious injury outcome: (a) Checklist/Flight Manual Not Followed" (b) "Inadequate Pre-Flight Planning/Inspection/Procedure" and (c) FARs Violation/AIM Deviation. Note that the sum of accidents across the sub-categories (Figures 1-3) is less than that cited for the corresponding parent category (Table 2) as sub-groups with few accidents were excluded from the former.

Regarding the "Checklist/Flight Manual Not Followed" category (OR 2.34), four sub-groups were identified (Figure 1). Of these, the "non-adherence to V Speeds" was the most prevalent sub-category (n=51). Accidents in this sub-group contributed significantly (p<0.001) to the increased risk (OR 2.34) of accidents involving fatal and/or seriously injured occupants for the parent category ("Checklist/Flight Manual Not Followed'). Conversely, and perhaps not surprisingly, accidents grouped in the "landing gear non-extension/premature retraction" sub-category carried a disproportionate fraction (p<0.001) of occupants sustaining no and/or minor injuries.

The "Inadequate Pre-Flight Planning/Inspection/Procedure category" (OR 2.22) was also sub-grouped (Figure 2). For both the "Fuel-Related" and the "Aircraft Pre-flight Condition" sub-categories, accidents were evenly divided between those in which occupants incurred fatal and/or serious injuries and those for which occupants sustained no and/or minor injuries. On the other hand, post-hoc analysis of the sub-categories indicated that the elevated risk of a fatal and/or serious injury outcome of the parent category was largely accounted for by “inadequate weather planning” (p=0.036). This sub-category was associated with a more than 3 fold increase in accidents with fatal and/or serious injury outcomes.

We also sub-classified the FARs Violation/AIM Deviation (OR 2.59) category (Figure 3). The “Descent below the MDA/failure to execute the missed approach” represented the largest sub-category of accidents (n=27) the majority (78%) of which resulted in fatal and/or serious injuries. Not surprisingly, as this problem is well recognized in general aviation (Kenny, 2012), flight from visual to instrument meteorological conditions constituted the second most common sub-category and again most (91%) of these accidents yielded fatal and/or serious injuries. In contrast, the overwhelming number (7 of 8) accidents grouped as “failure to comply with scheduled Inspections/AD/SB,” involved no and/or minor injuries.

3.3 Other Accident-Precipitating Factors.

Several other accident-precursive factor categories were also associated with an elevated risk for an accident involving fatal and/or serious injuries (Table 2). “Lack Experience/Systems Knowledge,” an accident-precipitating factor category for 26 accidents carried an Odds Ratio of 5.01 for a fatal and/or serious injury outcome. Similarly, deficiencies on the part of Air Traffic Control or the Flight Service Station was cited as an accident-precursive factor for only 14 accidents but nevertheless carried a high risk of an accident with fatal and/or serious injuries (OR 6.24). Half of the accidents in this category involved the lack of enroute advisories on adverse weather (convective or icing) or low-terrain alerts. Pilot Physical/Drug Impairment/Incapacitation (OR 25.07) was also infrequent (n=14) and only 4 of these accidents were due to pilot incapacitation similar to the 1% rate (Li and Baker, 2007) reported elsewhere. Not surprisingly (Bazargan and Guzhva, 2007; Li and Baker, 1999), instrument meteorological conditions/convective weather (OR 5.28) and deficient lighting conditions (OR 3.89) both carried an excess risk of an accident with fatal and/or serious occupant injury.

On the other hand, the “Contaminated Runway” (OR 0.10), “Pilot Skill Deficiency” (0.30) and “Aircraft Malfunction” (OR 0.49) categories all showed reduced risk of an accident with a fatal and/or serious injury outcome. Alternatively stated, these accident-precipitating factor categories were associated with an elevated chance for an outcome with no and/or minor occupant injury. The findings with the first two accident-precursive factors were not unexpected since accidents involving the landing and take-off roll rarely carry fatal injuries (Kenny, 2012) and because we defined “Pilot Skill Deficiency” in context of this phase of flight (see Table 1). The “Aircraft Malfunction” category comprised 127 events with landing gear/brake system representing the largest subgroup (n=35) none of which culminated in fatal and/or serious outcomes. Loss of engine power contributed 30 events with only a minority (n= 10) resulting in fatal and/or serious injuries. These data parallel the general aviation fleet, independent of powerplant, showing that the vast majority of accidents involving a malfunction are non-fatal (Kenny, 2012).

3.4 Temporal Change in Turbine-Powered Aircraft Accident Rate and the Fraction of Accidents with Fatal/Serious Injuries.

We then determined if accident rates in turbine aircraft operating under 14CFR Part 91 rules have changed over the 1989-2013 period of the current study. Indeed, adjusting for the variations in annual turbine fleet activity conducted under 14CFR Part 91, a steady decline in the accident rate was evident over the 25 year period (Figure 4-line graph). Specifically, the accident rate for the 1989-1993 period was 4.3 (per million flight hours), but declined by over 50% for the most recent (2009-2013) period. A generalized linear model with Poisson distribution revealed that the difference between the first (1989-1993) and last (2009-2013) periods was statistically significant ($p<0.001$).

In contrast, the fraction of accidents corresponding to fatal and/or serious occupant injury outcome was largely unchanged between the 1980-1993 (49%) and 1999-2003 (48%) periods after which a decline was evident. For the most recent period (2009-2013) 29.7% of accidents resulted in fatal and/or serious occupant injury. Post-hoc analysis indicated that for the most recent time period the reduced fraction of accidents with fatal and/or serious injury was statistically significant ($p=0.005$).

3.5 Temporal Decrease in the Fraction of Accidents in Twin-Engine Turbine Aircraft.

We were curious as to the reason(s) underlying the decrease in all and fatal/serious accident rates. Since we, and others (Boyd, 2015a; Kenny, 2012), have previously reported both a higher all accident and fatal accident rate for multi-engine aircraft (albeit piston-powered aircraft) we hypothesized that the aforementioned decrease may reflect a shift in the proportion of accident aircraft from a twin to single engine configuration over time. Indeed this proved to be the case (Figure 6). The percentage of accidents in single engine turbine aircraft operating under 14CFR Part 91 steadily increased from 7% for the 1989-1993 time frame to 46% for the most recent period (2009-2013). A Chi-Square test showed that this shift in the overall distribution of twin/single engine aircraft accidents was statistically significant (Pearson Chi-Square $p<0.001$). We entertained the notion that the increased representation of single engine aircraft accidents over time had the consequence of a lower stall speed and hence a lesser impact force on occupants in an accident (impact force is a function of the square of velocity (Freitas, 2014)). However our data (not shown) indicated no statistical difference in stall speeds (V_{SO}) across the time periods.

4.0 CONCLUSIONS

Although there has been an increased focus on identifying accident-precursive events for airline operations ((http://www.faa.gov/about/initiatives/atos-/air_carrier/foqa/) and (Rankin et al., 2000)) there has been little corresponding effort for the general aviation sector. Herein, in a study of crashes involving turbine-powered aircraft operating under 14CFR part 91 we have identified several novel accident-precipitating factors associated with fatal and/or serious injury outcomes.

“Non-adherence to V speeds” was the most frequent accident-precipitating factor within the “Checklist/Flight Manual Not Followed“ category and carried the highest fraction of accidents with a fatal and/or serious injury outcome. Operating at an inappropriate airspeed could be due to either (a) intended/inadvertent deviation from published values or (b) not recognizing that many of these specified values vary under a range of loading/configuration and/or ambient conditions (e.g. increased bank angle results in an increased stall speed).

However, NTSB reports lack data that would allow us to determine which of these two scenarios were applicable to the airman involved in a particular accident.

The limitations of V speeds and importantly pilot knowledge (or lack thereof) on this topic deserve discussion. In context of aerodynamic stalls, V speeds are surrogates for angle of attack and stalls can occur at any speed. Installation of angle of attack indicators, as advocated by the NTSB (http://www.ntsb.gov/safety-/mwl/Pages/mwl7_2015.aspx), is one strategy that should mitigate accidents caused by aerodynamic stalls. For operations in turbulence, while reducing speed to prevent over-stress of the airframe is well recognized, again, the target speed to be achieved warrants comment. A common practice, at least for light aircraft (<12,500 lbs), is to reduce airspeed to maneuvering speed (V_A) a value specified in the flight manual (only a subset of aircraft flight manuals reference a turbulence-penetration speed -V_B). However this approach is fraught with limitations since (a) airspeed fluctuates in turbulence (Schiff, 2001) and any attempt to achieve V_A will result in an over-speed condition and (b) V_A decreases with lower aircraft weight and flight manuals may specify only that speed corresponding to maximum weight. Equally important for flight in turbulence, adherence to the appropriate V speed may still not protect against structural failure in the event of simultaneous control inputs in different axes (http://www.faa.gov/regulations_policies/-handbooks_manuals/aviation/pilot_handbook/media/PHAK-Errata-Sheet.pdf). Another V speed meriting discussion is minimum controllable speed (V_{MC}) in the event of engine failure in a multi-engine aircraft. Airmen need to be particularly cognizant as to the offsets of the published V_{MC} values by aircraft weight, ambient conditions and flap/landing gear configuration. This is of particular importance since, too often, accidents in multi-engine aircraft occur as a consequence of poor single engine procedures inclusive of inappropriate speed selection (Boyd, 2015a). Taken together, discussions with pilots should include greater emphasis on the importance of appropriate V speed selection corresponding to a phase of flight but nevertheless, the limitations of such speeds (especially in context of aerodynamic stalls) and finally the fact that published values are rarely constant.

Adverse weather (instrument meteorological conditions or convective activity) is a well-documented risk factor for fatal general aviation accidents (Bazargan and Guzhva, 2007; Li and Baker, 1999). Moreover, pilots are more likely to continue a planned flight without diverting or returning to the departure airport after the mid-way point of the trip (Batt and O'Hare, 2005; O'Hare and Owen, 2002) a phenomenon referred to as “plan continuation bias.” Thus, pre-departure weather planning can be crucial for a successful flight outcome. However, the disproportionate number of accidents with fatal and/or serious injury outcomes involving inadequate weather planning (no evidence of an official weather briefing) argues that a subset of airmen operating turbine-powered aircraft are placing insufficient emphasis on such planning. Of course we cannot exclude the possibility that some of these pilots did receive weather information from sources other than official FAA sources (Flight Service Station or the internet-based DUATS). Nevertheless, these findings would argue for the importance of comprehensive pre-flight planning in context of weather evaluation. That said, weather can change rapidly and current conditions may deviate from those forecast. In this regard, a long well-recognized problem plaguing general aviation (Kenny, 2012) is the continued flight from visual to instrument meteorological conditions also evidenced in our study. Typically such events are fatal- in our study 90% of accidents in which this accident-precipitating factor was cited involved fatal and/or seriously injured occupants. Interestingly of the 11 accidents, the pilots for all but one of the aircraft were instrument-certified. This finding suggests that in the face of deteriorating weather airmen should be strongly encouraged to request an enroute clearance.

We found that the largest number of accidents in the “FAR Violation/AIM Deviation” category was attributed to a “Descent below MDA/failure to execute the Missed” the majority (78%) of which resulted in fatal and/or serious injuries. This problem may be rooted in two different causes. First, turbine aircraft are often faster than piston-powered aircraft comparable in terms of passenger capacity. Second, turbine engines are characterized by longer response (spool up) times compared with piston-powered aircraft (Brown and Holt, 2012). Thus, decision-making as to whether to break off an approach in degraded visibility has to be expeditious even more so for turbine aircraft requiring only one pilot. Moreover, current regulations allow airmen operating under 14CFR Part 91 to do a “look see” even if the current broadcast visibility is below minimums. Taken together, due consideration should be given to modifying the regulations for turbine operators operating under 14CFR Part 91 to prohibit instrument approaches when the automated weather broadcast indicates below minimums. Indeed, for operations conducted under 14CFR Part 135/121 an instrument approach cannot be commenced under such weather conditions.

As an accident-precursive factor, “Deficiencies on part of Air Traffic Control or the Flight Service Station” were rare (n=14) but nevertheless carried a high risk of a fatal and/or serious injury outcome. Half of the accidents in this category involved the lack of enroute advisories on adverse weather (convective or icing) or low-terrain alerts. We speculate that the growing presence of on-board data-linked weather and terrain-alerting systems may prove efficacious in nullifying this accident-precursive factor in the future.

We were initially surprised that pilot fatigue was not identified as a candidate accident-precipitating factor. That said, it is likely that the role of fatigue is grossly underestimated for several reasons. First, 14CFR Part 91 operations lack regulations pertaining to pilot rest unlike 14CFR Part 121 where rest requirements are mandatory. Airmen operating under 14CFR Part 91 must therefore exercise self-discipline and should be made aware of technologies available for monitoring sleep. Further, in a non-fatal accident investigation pilots are unlikely to admit fatigue as a factor for fear of punitive action by aviation authorities and/or civil litigation.

The finding of a steady decline in the accident rate of turbine-powered aircraft over the 25 year period was surprising and in contrast to an unchanged rate for the aggregated general aviation fleet (Kenny, 2012). One possible explanation for the decline is that aviation safety in this sector is improving. Alternatively, the reduction in fatal accident rate for turbine-powered aircraft operating under 14CFR Part 91 may be related, in part, to an increasing proportion of single engine accident aircraft over time. Certainly, based on prior studies with piston aircraft (Kenny, 2012), both the all-accident and fatal accident rates for multi-engine aircraft is higher than the corresponding rate for single engine aircraft. Our data are consistent with the latter notion which clearly demonstrated an increased representation of single engine turbine aircraft over the study period. Nevertheless, we recognize that other co-variates, not captured in the present study, could also contribute to the decline in the accident rate reported herein.

Notwithstanding our findings, our study had limitations. First and foremost, this was a retrospective study. Also, assigning an accident-precipitating factor or category to an accident was not always clear-cut. Another limitation is that we made the assumption that the increased fraction of accidents in single turbine engine aircraft evident over time reflects a proportionate increase in fleet activity by these aircraft. Also, we recognize that a low number of events, especially where accident-precipitating factor categories were sub-classified, would have resulted in a loss of statistical power. Finally, since the FAA lacked fleet flight time for the 2011 year, denominator data for the 2009-2013 period represents an average of these years with the exclusion of the corresponding data for 2011.

In conclusion, our study is the first to identify novel precursive factors for accidents involving turbine aircraft operating under 14CFR Part 91. Our findings point to areas that should receive increased emphasis in training/recurrency in a pre-emptive attempt to nullify the effect of candidate accident-precipitating factor(s). Increased attention should be given by airmen to adherence to checklists/flight manuals and in particular recommended V speeds, their limitations and the need to adjust for modifying variables. In a similar vein, airmen should exercise greater diligence in pre-flight weather planning especially when convective weather and instrument meteorological conditions are forecast. Further, with typically higher aircraft speeds and longer engine spool up times (Brown and Holt, 2012) (a) airmen should receive training as to decision-making with reference to decision height for instrument approaches under minimum weather conditions and (b) aviation authorities should consider whether conducting approaches under conditions below broadcast minimums should be prohibited for turbine operations.

5.0 LEGENDS

FIGURES

Figure 1. Sub-Classification of Non-Adherence to Checklist/Flight Manual Category.

The number of accidents (n) is specified above each column.

Figure 2. Inadequate Pre-Flight Planning/Inspection/Procedure Sub-Categorization.

Accidents in the “Inadequate Pre-Flight Planning/Inspection/Procedure” category (Table 2) was sub-grouped. The number of accidents (n) is indicated above each column.

Figure 3. Sub-Classification of the FARs Violation/AIM Deviation Category.

The number of accidents (n) is indicated above each column. Abbreviations: MDA, minimum descent altitude; AD, airworthiness directive; SB, service bulletin.

Figure 4. Temporal change in Turbine-Powered Aircraft Accident Rates and the Fraction of Accidents with Fatal/Serious Injuries.

Accidents (n) for turbine-powered aircraft for the indicated time period were normalized to turbine fleet activity operating under 14CFR Part 91 for the corresponding period and depicted as accident rate (line graph). The bar graph represents the fraction of accidents with fatal and/or serious injuries for the indicated period is shown. A fraction of 0.4 means that of 40% of the accidents for the specified time period involved occupants with fatal/and or serious injuries. The number (n) of accidents with fatal and/or serious injury outcomes is included above each column.

Figure 5. Accidents of Turbine-Powered Aircraft Segregated by Single and Twin-Engine Configuration.

The number (n) of accidents by turbine-powered aircraft operating under 14CFR Part 91 separated by single and twin-engine aircraft for the indicated time period is shown.

TABLES

Table 1. Taxonomy and Explanation of Accident-Precipitating Factor Categories.

Abbreviations: Wx-weather, FBO, fixed base operator; FARs, federal aviation regulations; AIM, Airman Information Manual; FOD, foreign object damage; ATC, air traffic control; FSS, flight service station; IFR, instrument flight rules.

Table 2. Risk Assessment of the Accident-Precipitating Factors for a Crash with a Fatal and/or Serious Injury Outcome.

Variables from Table 1, which in backward elimination using Log Likelihood ratio test reached a statistical level of ($p<0.05$), were then analysed by logistic regression for risk of an accident with a fatal and/or serious injury outcome.

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Figure 1

Figure 1

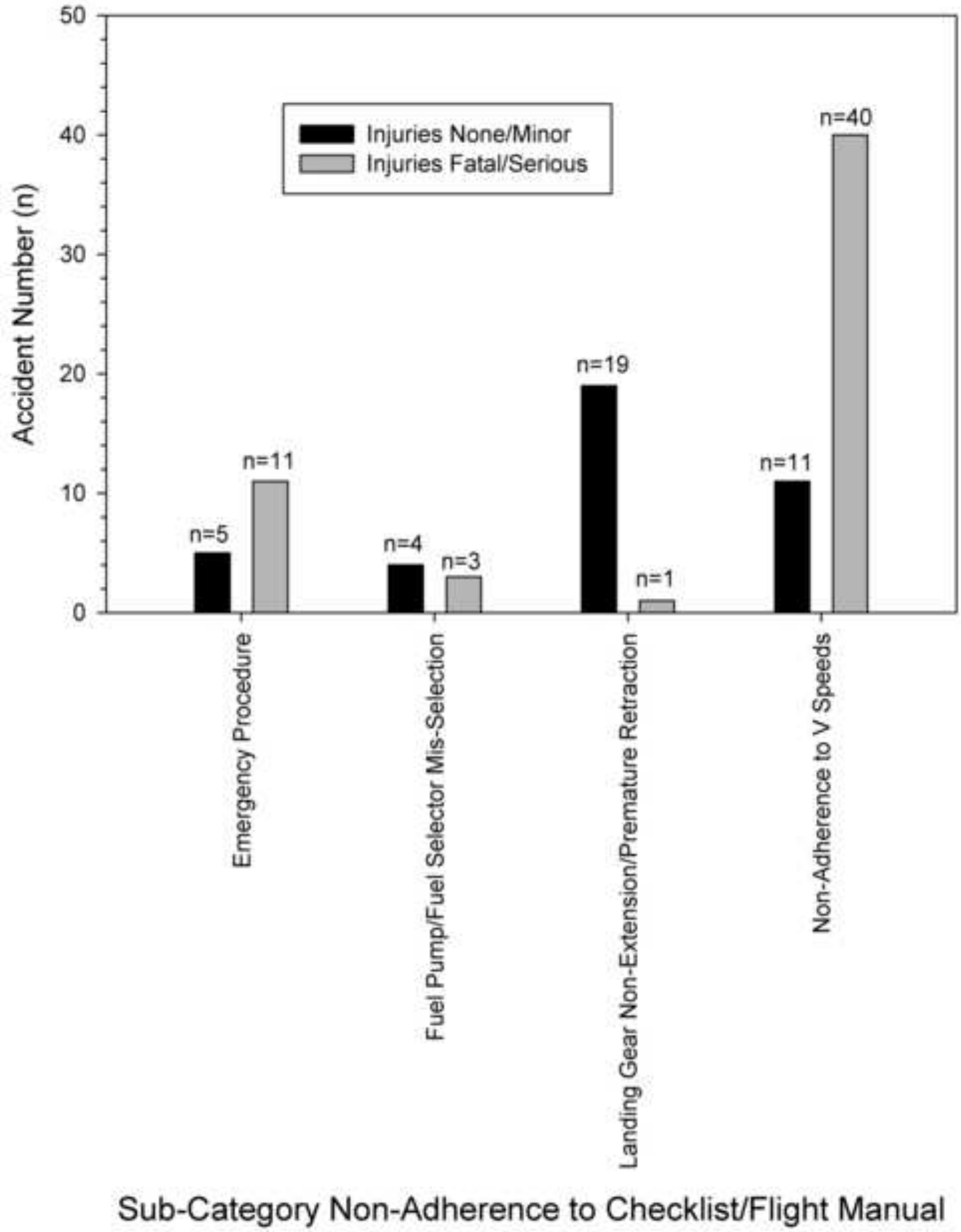

Figure 2

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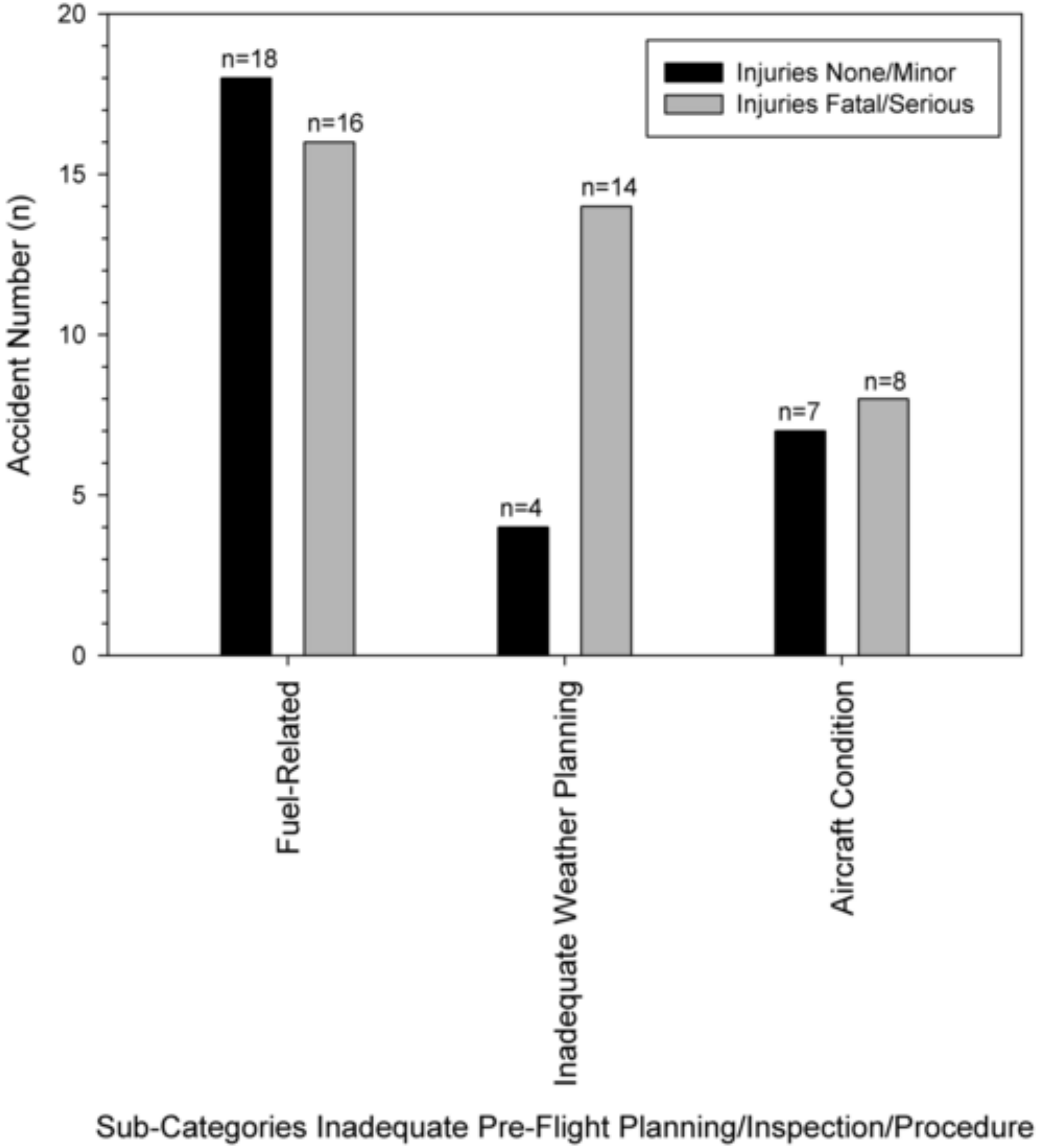

Figure 3

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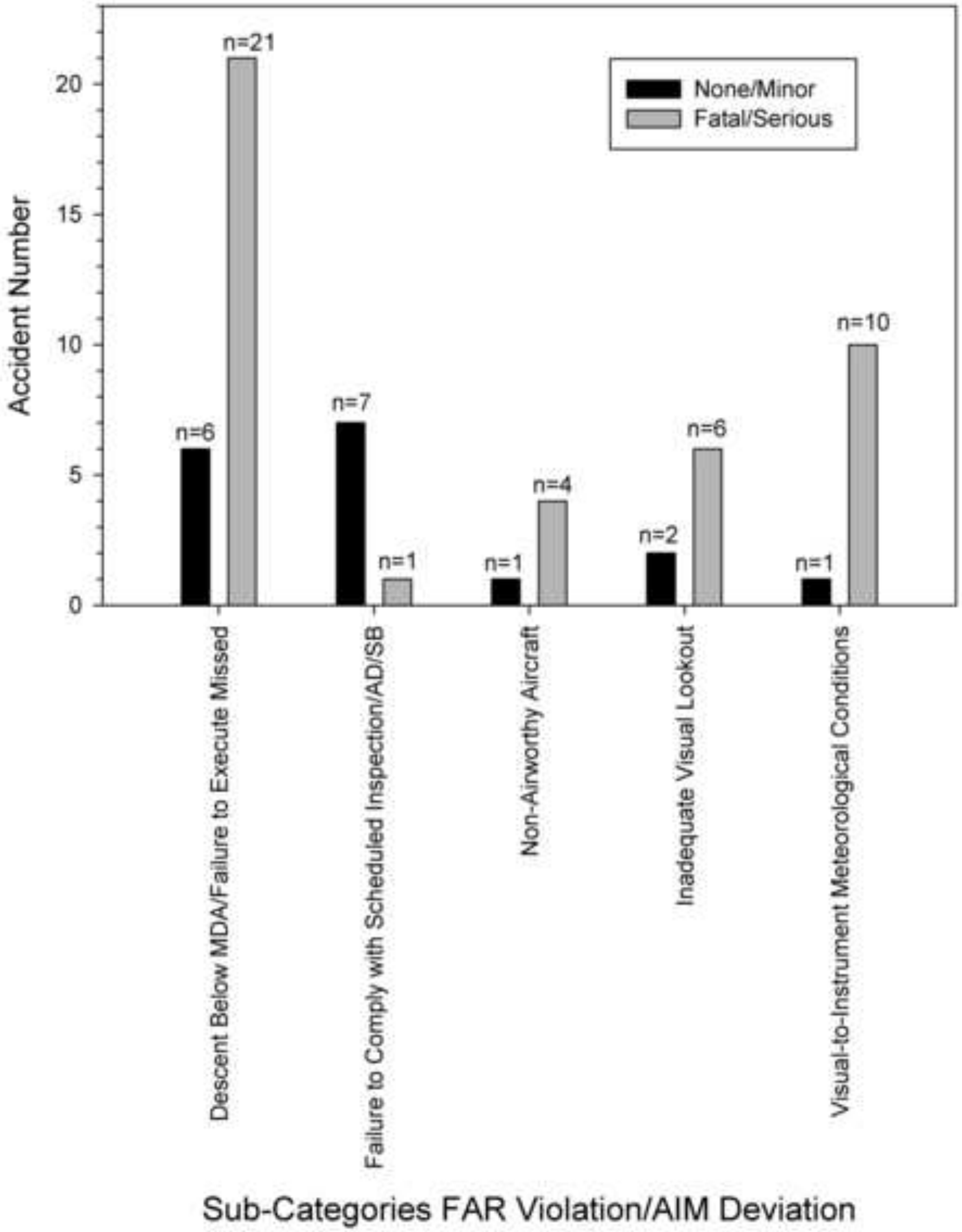

Figure 4

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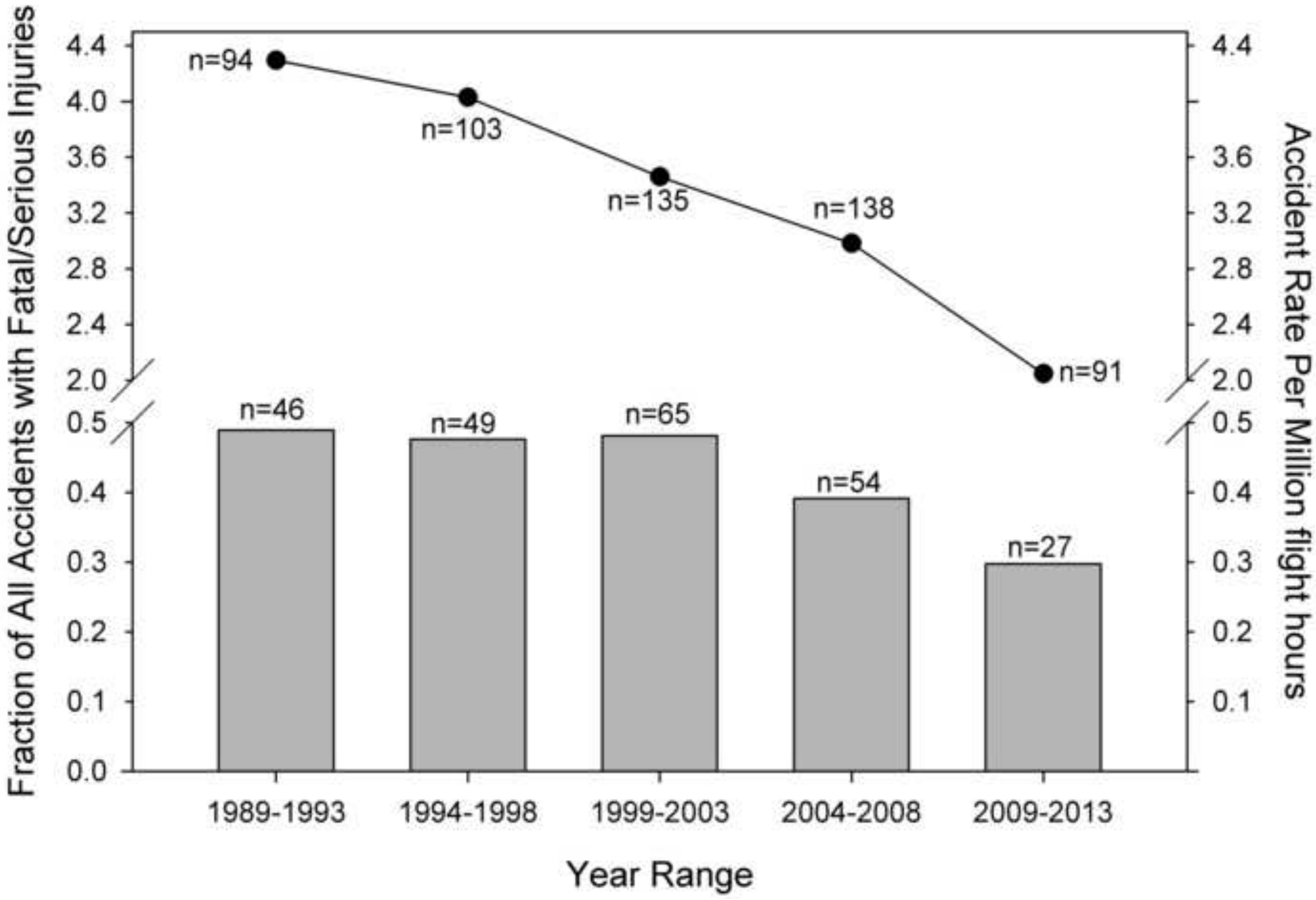

Figure 5

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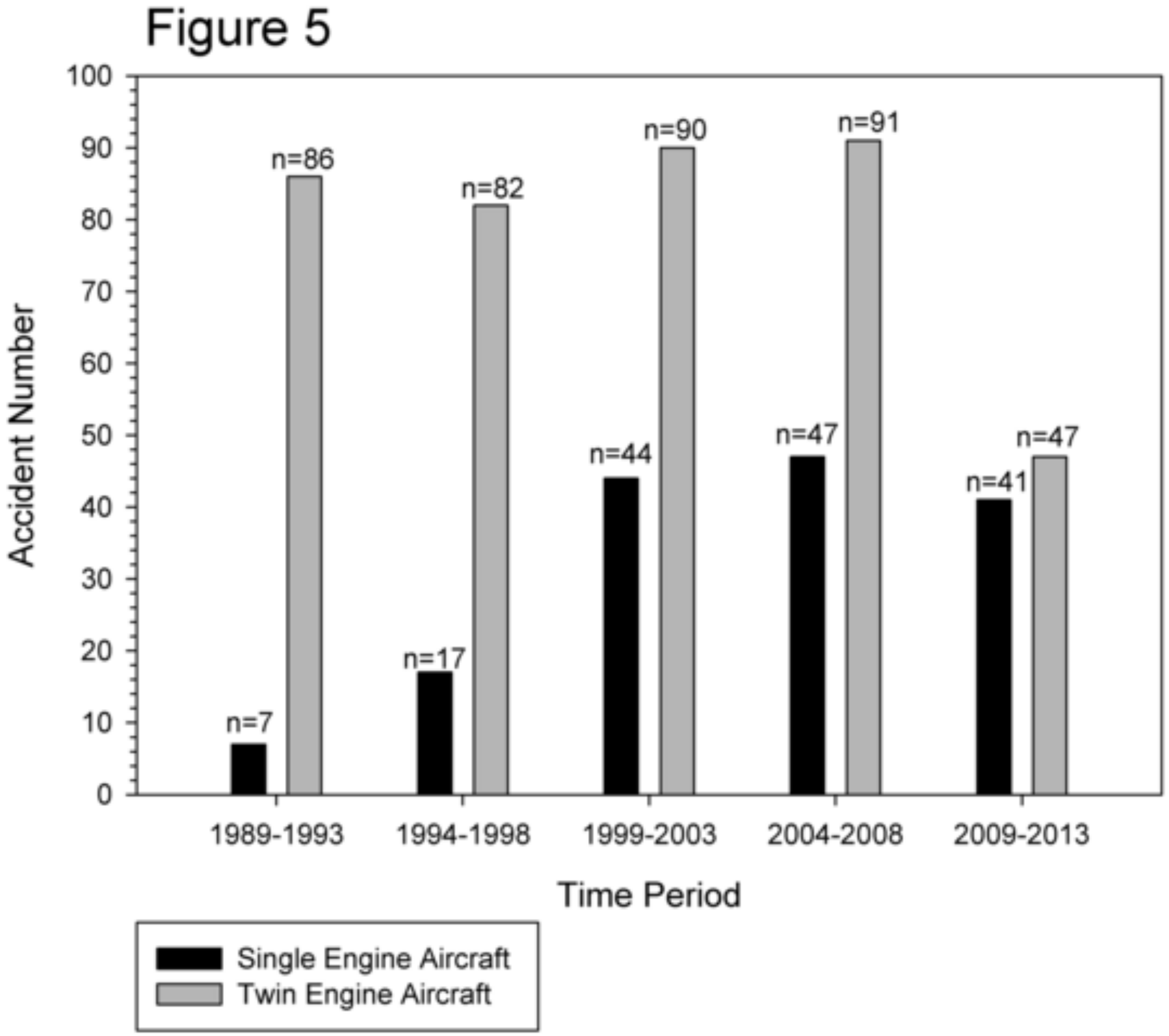

Table 1

ACCIDENT-PRECIPITATING FACTOR CATEGORY	ACCIDENT-PRECIPITATING FACTOR/ CATEGORY	EXPLANATION
1	Checklist/Flight Manual Not Followed	self-explanatory and includes non-adherence to V speeds
2	Contaminated Runway	Runway contaminated with water, snow or ice
3	WX/Aircraft Icing/Frost/Snow	Weather conditions included icing, frost or snow or aircraft was contaminated by these elements
4	Improper/inadequate maintenance/Inadequate Inspection	improper or inadequate maintenance or inadequate Inspection by maintenance facility
5	Inadequate Inflight Planning/Decision Making	Inadequate inflight planning or inadequate decision making by pilot
6	Inadequate Pre-flight Planning/Inspection/Procedure	Failure to undertake comprehensive pre-flight planning or aircraft pre-flight inspection or a procedure associated with the latter
7	Instrument meteorological conditions or Convective Weather	instrument meteorological conditions or thunderstorms
8	Deficient Lighting	ambient lighting that is anything but daylight
9	Deficiency by Operator/Owner/FBO	deficiency on part of the operator or owner or fixed base operator
10	Violation Federal Airman Regulations (FARs)/Airman Information Manual (AIM) Deviation	Inclusive of: a descent below minimum altitude of an instrument procedure, weather below minimums than those prescribed in the approach chart, continued flight from visual to instrument meteorological conditions in the absence of an IFR flight plan, flight into known icing, outdated aeronautical charts, pilot flying was non-instrument certified pilot, aircraft was modified in an unapproved fashion, non-compliance with an airworthiness directive or service bulletin, under visual conditions an aircraft did not give right of way to converging aircraft, aircraft was unairworthy
11	Diverted Attention	Pilot was distracted
12	Malfunction (includes FOD)	Aircraft malfunction including damage caused by foreign object
13	Lack Experience/Systems Knowledge	Lack of experience or lack of systems knowledge on part of the pilot for the accident aircraft
14	Fatigue	crew member fatigue
15	ATC/FSS Deficiency	Deficiency on part of Air Traffic Control or the Flight Service Station
16	Pilot Physical/Drug Impairment/Incapacitation	Pilot impairment physically or by medications or pilot incapacitation
17	Pilot Skill Deficiency	Pilot skill in context of hand/foot-eye coordination in context of landing or take-offs

Table 2

					95% Confidence Intervals	
Accident Precipitating Factor/Category	**n**	**Wald**	**p Value**	**Odds Ratio**	**Lower**	**Upper**
Checklist/Flight Manual Not Followed	132	13.97	<0.001	2.34	1.48	3.69
Contaminated Runway	22	8.39	0.004	0.10	0.02	0.48
Inadequate Pre-flight Planning/Inspection/Procedure	68	7.13	0.008	2.22	1.24	3.98
Instrument meterological conditions or Convective Weather	90	27.12	<0.001	5.28	2.82	9.88
Deficient Lighting	50	11.91	0.001	3.89	1.80	8.43
Violation FARs/AIM deviation	64	6.96	0.008	2.59	1.28	5.24
Malfunction	127	7.54	0.006	0.49	0.30	0.82
Lack Experience/Systems Knowledge	26	9.63	0.002	5.01	1.81	13.87
Air Traffic Control/Flight Service Station Deficiency	14	4.92	0.026	6.24	1.24	31.43
Pilot Physical/Drug Impairment/Incapacitation	14	9.26	0.002	25.07	3.15	199.74
Pilot Skill Deficiency	39	5.23	0.022	0.30	0.11	0.84