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Rates and Causes of Accidents for General Aviation Aircraft Operating in a Mountainous and High Elevation Terrain Environment

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ABSTRACT

Background: Flying over mountainous and/or high elevation terrain is challenging due to rapidly changeable visibility, gusty/rotor winds and downdrafts and the necessity of terrain avoidance. Herein, general aviation accident rates and mishap cause/factors were determined (2001-2014) for a geographical region characterized by such terrain.

Methods: Accidents in single piston engine-powered aircraft for states west of the US continental divide characterized by mountainous terrain and/or high elevation (MEHET) were identified from the NTSB database. MEHET-related-mishaps were defined as satisfying any one, or more, criteria (controlled flight into terrain/obstacles (CFIT), downdrafts, mountain obscuration, wind-shear, gusting winds, whiteout, instrument meteorological conditions; density altitude, dust-devil) cited as factors/causal in the NTSB report. Statistics employed Poisson distribution and contingency tables.

Results: Although the MEHET-related accident rate declined ($p<0.001$) 57% across the study period, the high proportion of fatal accidents showed little (40-43%) diminution (χ^2 =0.935). CFIT and wind gusts/shear were the most frequent accident cause/factor categories. For CFIT accidents, half occurred in degraded visibility with only 9% operating under instrument flight rules (IFR) and the majority (85%) involving non-turbo-charged engine-powered aircraft. For wind-gust/shear-related accidents, 44% occurred with a cross-wind exceeding the maximum demonstrated aircraft component. Accidents which should have been survivable but which nevertheless resulted in a fatal outcome were characterized by poor accessibility (60%) and shoulder harness under-utilization (41%).

Conclusion: Despite a declining MEHET-related accident rate, these mishaps still carry an elevated risk of a fatal outcome. Airmen should be encouraged to operate in this environment utilizing turbo-charged-powered airplanes and flying under IFR to assure terrain clearance.

Keywords: general aviation accident, accident; mountain accidents; fatal accident; general aviation; survivability.

1.0 INTRODUCTION

General aviation (14CFR Part 91) includes all civilian aviation operations except those involving revenue-based passenger transportation (Electronic Code of Federal Regulation, 2015) such as air carriers. Although accident rates for the airlines have dramatically declined over the last several decades (DeJohn et al., 2013), only a modest decrease has been witnessed for general aviation (Li and Baker, 2007). In fact, general aviation accounts for the overwhelming majority (96% for 2014, up from 94% for the period spanning 2002-2005) of civil aviation fatalities in the United States (Li and Baker, 2007; National Transportation Safety Board, 2015). Such accidents also carry a substantial financial burden estimated at $1.6-4.6 billion annually to individuals and institutions affected when taking into account hospital costs, loss of pay with a fatal accident, loss of the aircraft and accident investigation costs (Sobieralski, 2013).

General aviation safety in the United States is heavily influenced by the geographical region (Kearney and Li, 2000). Prior studies have demonstrated that states characterized by mountainous terrain and high elevation, carry a higher accident rate than those (15.3 and 8.5 accidents per 100,000 flight hours, respectively) featuring low lying, relatively flat terrain (Dobson and Campbell, 2014; Kearney and Li, 2000). The fatal accident rate is also greater; a study published over 25 years ago (Baker and Lamb, 1989) reported a 68% increase in fatal general aviation accidents in the Colorado Rockies relative to the rest of the state (Baker and Lamb, 1989). A subsequent study mirrored these findings again showing an elevated fatality rate for accidents in mountainous terrain (Grabowski et al., 2002).

A plethora of factors likely contribute to the higher accident rate and the disproportionate increase in fatal mishaps. Flying over mountainous and/or high elevation terrain carries its challenges most relating to the weather. Severe, localized, gusty winds and mountain waves (Federal Aviation Administration, 1997), at variance with the synoptic forecast, are often associated with mountainous terrain (Federal Aviation Administration, 1997; Gaffin, 2014). Also, winds blowing perpendicular to a mountain ridge can generate rotor patterns on the leeward side which may lead to aircraft upset by virtue of exceeding the roll authority of a small airplane. Along similar lines, a mountain range may create downdrafts of greater than 1,500 feet/minute in excess of the climb rate of many single engine piston aircraft (Baker and Lamb, 1989; Federal Aviation Administration, 1997; Federal Aviation Administration, 1999). Regarding visibility, mountain weather can be highly changeable with rapid onset of degraded visibility (Colorado State University, 2016). It should be emphasized that some of these weather conditions are not restricted to the immediate mountain environment. Mountain waves, for example, can propagate 70-100 nm downwind of the ridge (Federal Aviation Administration, 1975; Federal Aviation Administration, 1997; Gaffin, 2014). Finally, the climb performance of normally-aspirated (i.e. non turbo-charged) piston engine-powered aircraft diminishes with altitude (Federal Aviation Administration, 1999) potentially leading to accidents in areas with elevated terrain where the aircraft is unable to clear rising terrain (Baker and Lamb, 1989).

Notwithstanding the landmark study by Baker and Lamb (Baker and Lamb, 1989), which focused on accidents occurring between 1964 and 1987, technology has advanced considerably in the interim. Many general aviation aircraft are currently equipped with on-board satellite-broadcast weather and terrain-alerting systems (Federal Aviation Administration, 2010) and, to a lesser extent, synthetic vision (Wilson, 2016), systems unavailable at the time of the aforementioned study. Additionally, the modernization of the National Weather Service (Committee on the Assessment of the National Weather Service's Modernization Program, 2012) has resulted in the installation of automated weather reporting systems in mountain passes (Committee on the Assessment of the National Weather Service's Modernization Program, 2012; Spitzmiller, 2015), locations where winds are accelerated due to a Venturi effect (Federal Aviation Administration, 1999). Finally, in addition to the advent of mountain flying classes in 1990 (http://coloradopilots.org/mtnfly_class.asp), flight instruction has undergone a transformation with current emphasis on *scenario-based training* (Federal Aviation Administration, 2016). With these considerations in mind, the objective of the current study was to determine the trends in all/fatal general aviation accident rates related to mountain environment/high elevation terrain (MEHET) and mishap causes/factors for the period spanning 2001-2014.

2.0 MATERIALS AND METHODS

2.1 Procedure

The NTSB Access database (June 2016 release) was downloaded (National Transportation Safety Board, 2015) and queried for accidents in airplanes of 12,500 pounds weight or less with a single piston-powered engine (>150 horse power) and operating under 14 CFR Part 91 (Electronic Code of Federal Regulation, 2015) regulations with the purpose of a personal or business flight. The query was limited to accidents spanning the 2001-2014 period (unless indicated otherwise) occurring in states (UT, NM, NV, ID, OR, CO, WY, CA, AZ, WA) characterized by their high elevation and/or mountainous terrain per a topographical map (www.mapresources.com) of the contiguous states of the USA. Fleet activity for the aforementioned states and avionics equipage was obtained from the annually-conducted General Aviation and Part 135 Activity Survey (Federal Aviation Administration, 2010). Data for 2011 were interpolated from 2010 and 2012 fleet activities. Accidents related to a mechanical failure, pilot incapacitation, suicide, passenger injury external to the aircraft, primary students, non-certified airmen, taxiing or standing aircraft, or for which aerobatics were performed were all excluded from the study. Fatal outcome was determined per the NTSB report (Federal Aviation Administration, 2015b; National Transportation Safety Board, 2015).

Accidents were deemed MEHET-related by satisfying any single or combination of the following criteria: controlled flight into terrain or man-made obstacles (CFIT), downdrafts, mountain obscuration, wind-shear, gusting winds, whiteout, instrument meteorological conditions; density altitude, dust-devil (indicative of wind conditions) (Baker and Lamb, 1989; Colorado State University, 2016; Federal Aviation Administration, 1997; Federal Aviation Administration, 1999; Gaffin, 2014; Sinclair, 1969). The NTSB probable cause and/or factual report were manually inspected for these criteria.

For analysis of survivable/non-survivable accidents only off-airport mishaps were considered. A non-survivable accident included any involving either CFIT, loss of control, spatial disorientation, airframe structural failure, a mid-air collision, an aerodynamic stall (NOT stall/mush), or a nose-low attitude in crash. A survivable accident was operationally defined as any other than one identified as non-survivable per the aforementioned criteria. Accident site location was either via latitude/longitude coordinates or textual data (distance/bearing from a major city or landmark) provided in the NTSB factual report. The straight-line distance of the accident site to a rescue facility (typically a fire department) was determined using Google Earth (https://www.google.com/earth/). The following accidents were excluded from the analysis of survivable accidents: an aircraft struck by lightning but which landed without further incident, one which ditched into a body of water or for which its aircraft parachute was deployed. Survivability for each accident was determined by the study authors with an inter-independent rater assessment indicating a high degree of agreement (Cohen kappa=0.960). Rater disagreement was subsequently resolved by discussion between assessors.

Accident site accessibility was categorized as follows: highly accessible (<5 nm from rescue station or with immediate road access, or in an area with <1/3 forestation or with an elevation ratio 1.00-1.05); accessible (>5 and <10 nm from a rescue facility or proximal to a road or in an area with 1/3-2/3 forestation or with an elevation ratio of 1.06-1.10); poorly accessible (>10 nm from rescue services or not served by a road or in densely (>2/3 coverage) wooded area or with an elevation ratio of >1.10). Elevation ratio was determined through the use of the equation y/((a+b)/2), where "a" and "b" were the elevations of the accident site and nearest rescue facility respectively, and "y" was the highest point of elevation along the most direct path between location a and location b.

Accident causes or factors contributing to the accident were as cited in the NTSB probable cause.

2.2 Statistical and Trigonometrical Analyses

A generalized linear model with Poisson distribution (log-linear) was employed to determine if a change in the rate of accidents was statistically significant. The natural log of the annual fleet activity for piston-powered aircraft for the aforementioned states summed for the indicated period was used as an offset. Contingency tables employed Pearson Chi-Square (2-sided test) to determine where there were statistical differences in proportions. If the expected minimum count was less than five the Fisher's Exact Test was used instead (Agresti, 2012; Field, 2009). P values for cells in multinomial tables were derived from adjusted standardized residuals (Z-scores) in post-hoc testing. All statistical analyses were performed using SPSS (v23) software. A p value of $\leq$0.05 was used as cut-off for statistical significance.

For determination of head and crosswind speed, the runway used and reported airports winds for the accident flight were obtained from the NTSB factual report and sine/cosine functions used to compute head and cross-wind components. Where gusting conditions prevailed, the highest wind gust was used.

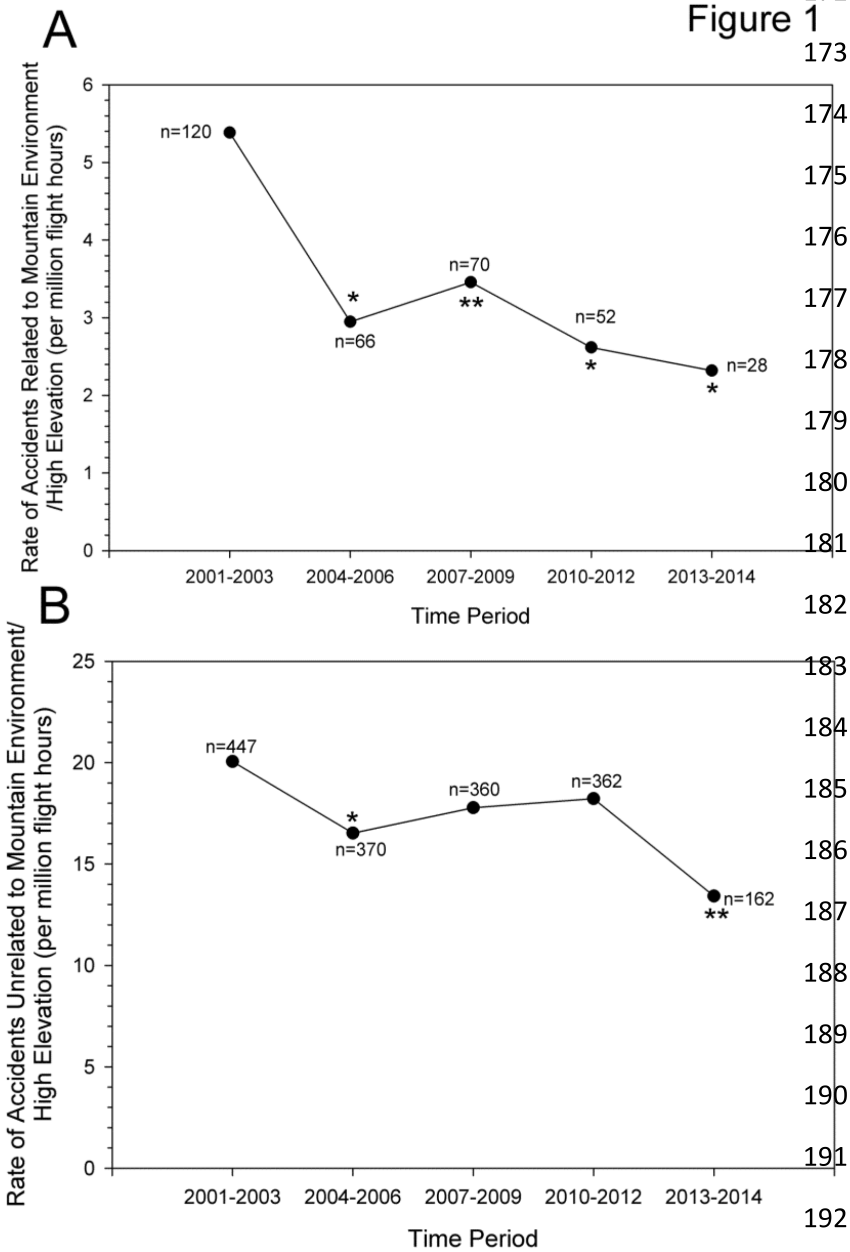
3.0 RESULTS

3.1 Temporal rates for MEHET-related or MEHET-unrelated accidents.

Although past studies have reported high general aviation accident and fatality rates in mountainous regions (Baker and Lamb, 1989; Grabowski et al., 2002), these investigations were conducted in an era prior to the advent of portable and/or panel-installed weather, terrain alerting technologies (Federal Aviation Administration, 2015b; Wilson, 2016) now common in light aircraft

(Federal Aviation Administration, 2010). In addition, the number of automated weather reporting systems in mountainous regions has increased and flight instruction strategies have evolved to *scenario-based* training. With this in mind, we first determined the rate of accidents in states west of the continental divide characterized by their mountainous and/or high elevation over the period spanning 2001-2014. Accidents were categorized as MEHET-related or non-MEHET-related as described in the Methods. Interestingly the MEHET-related accident rate declined (Figure 1A) by 57% ($p<0.001$) between the initial (2001-2003) and the most recent period (2013-2014). Poisson rate analysis indicated that relative to the initial period, all subsequent periods showed a statistically significant reduction in the MEHET-related accident rate.

Figure 1

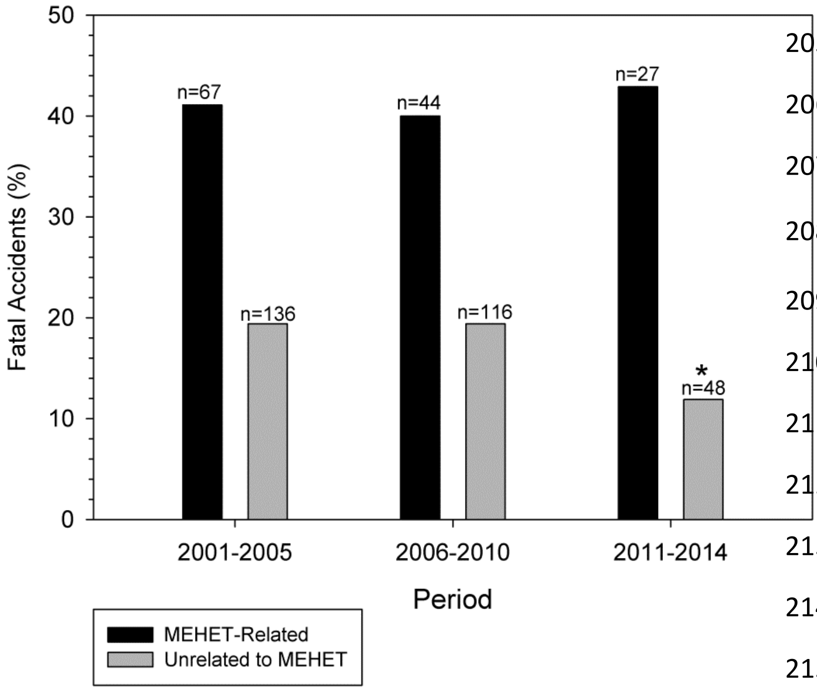


For comparative purpose, non-MEHET-related accident rates were determined over the corresponding period (Figure 1B). A more modest decline (33%), in comparison with the MEHET-related accident rate (57%), was evident over the entire period ($p<0.001$). Also, for the non-MEHET-related mishaps, only the 2004-2006 (p=0.006) and final periods (2013-2014), were decreased statistically (p<0.001) relative to the reference period (2001-2003).

3.2 The high fraction of fatal MEHET-related accidents does not change over the study period.

With the dramatic reduction in MEHET-related accident rates, we also tested whether the fraction of fatal accidents showed a parallel diminution. For increased statistical power, accidents were aggregated into three separate time periods. Fatal MEHET-related accidents accounted for 41% of all mishaps (Figure 2) for the earliest period (2001-2005). Unfortunately, this proportion showed little change (χ^2 =0.935) over time with 43% of accidents having a fatal outcome for the most recent period (2011-2014).

Figure 2



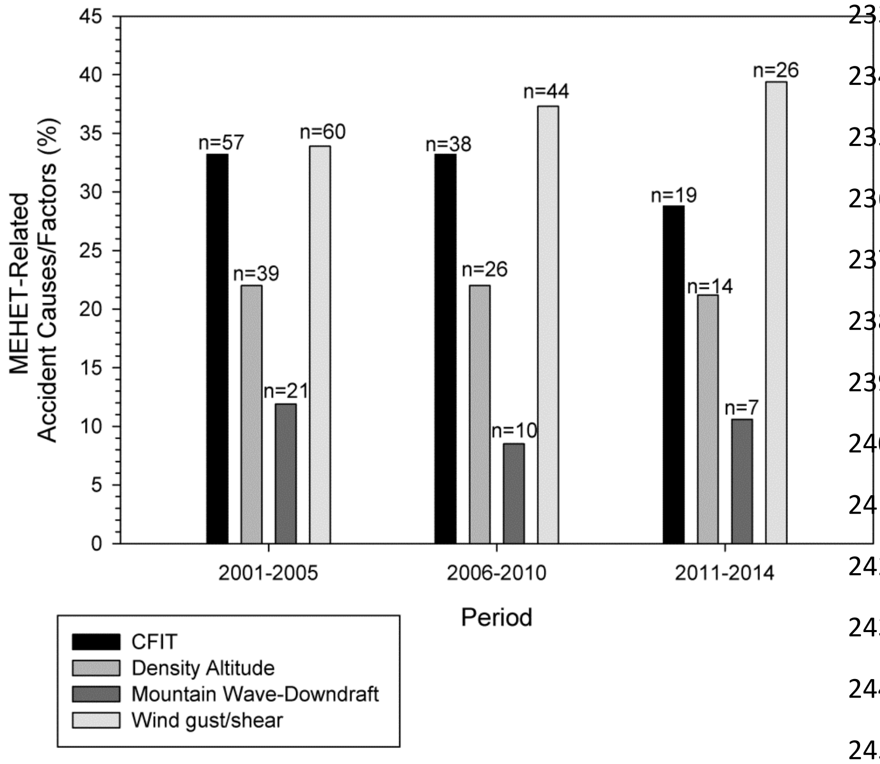
Non-MEHET-related accidents carried a lower risk for a fatal accident (12-20%) compared with MEHET-related mishaps (40-43%) across all time periods (Figure 2). Moreover, non-MEHET-related accidents showed a further reduction in the fraction of fatal mishaps for the most recent period. Thus, for this group, there was a disproportionate decrease in fatal accidents over the period spanning 2011-2014 referencing the initial (2001-2005) period (χ^2<0.001).

3.3. Causes and temporal changes in MEHET-related accidents.

Accident causes/factors for MEHET-related accidents were then determined. Figure 3 depicts the four most frequent causes/factors cited in the NTSB report. Of these cause/factor categories, the percentage of mishaps related to mountain waves-downdrafts was lowest for all time periods. In contrast, CFIT and wind gust/shear were the most prevalent cause/factor categories for MEHET-related accidents (Figure 3). Importantly, the proportion of mishaps related to CFIT or wind gust/shear remained unchanged over the study period (χ^2 =0.962).

Perhaps not surprisingly, the overwhelming majority (>80%) of MEHET-related accidents caused by CFIT were fatal (Figure 4). Also, while mishaps related to mountain wave/downdrafts were infrequent (see Figure 3), 37% ended in a fatal outcome (Figure 4). Conversely, although a high proportion of MEHET-related accidents were wind gust/shear-related (per Figure 3), very few of these accidents were lethal (Figure 4).

Figure 3



3.4 Flight Conditions, Engine type and Flight Planning for MEHET-related CFIT mishaps

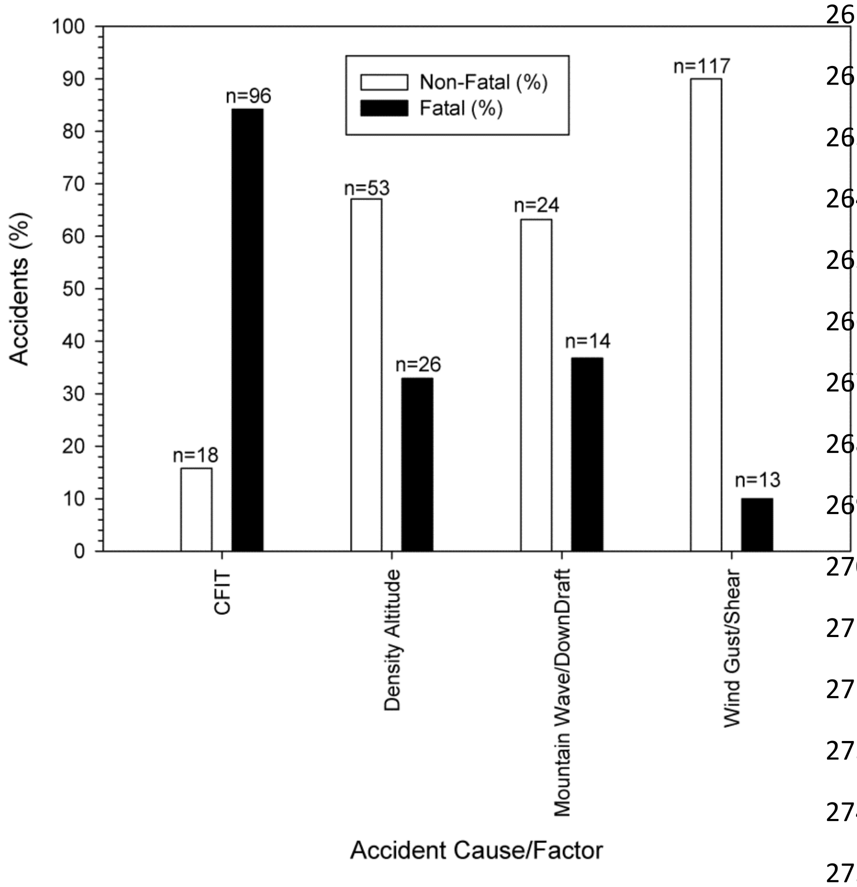
Considering the high frequency of CFIT accidents, coupled with their elevated risk of a fatal outcome, flight conditions, type of flight plan, pilot instrument certification and whether the aircraft engine was turbo-charged were then determined for accident flights. The latter parameter was of particular interest for the following reason: climb performance and service ceilings are diminished for airplanes with normally-aspirated powerplants compared with their turbo-charged-powered equivalents (Federal Aviation Administration, 2004). Indeed, general aviation accidents in mountains regions were previously ascribed, in part, to the inability of the aircraft to out-climb rising terrain (Baker and Lamb, 1989).

The majority (64%-sum of % occurring in lighting other than daylight and reduced visibility (IMC)) of accidents (Table 1) occurred under compromised visibility. Surprisingly, despite the fact that the majority (75%) of accident flights were cross-country (i.e. >50 nm per 14CFR61.1(b)(3)(ii)) and were in degraded visibility, only 9% of accidents flights were operating under instrument flight rules

(Table 1) although 58% of airmen were IFR-certified in airplanes. Only 13% of the aircraft were turbo-charged piston engine-powered surprising considering the high elevation of the accident site (median = 5,557 ft. MSL) which would necessitate an even higher altitude selection for flight operations.

3.5. On-airport accidents related to gusting cross-winds.

Figure 4



Adverse wind conditions (gusts, shear) are a common occurrence in mountainous regions (Federal Aviation Administration, 1997; Gaffin, 2014) and was the leading cause for MEHET-related accidents (see Figure 3). Aircraft are most vulnerable to changes in wind direction and/or speed during the landing and take-off phases due to their low altitude and a flying speed close to the aerodynamic stall speed. These challenges are further amplified with gusting winds perpendicular to the runway (referred to as a cross-wind) in use (van Es et al. 2001). Bearing these factors in mind, gusting cross-wind conditions were determined for on-airport MEHET-related accidents. Of 117 on-airport accidents in the wind-gust/shear category, 38% (n=45) showed a runway cross-wind component at the time of the mishap. Somewhat surprisingly, nearly half (44%) of wind-gust/shear-related accidents with a cross-wind component occurred with flights exceeding the maximum demonstrated cross-wind component specified for the aircraft (Table 2).

3.6 Survivable accidents with fatal outcomes.

For off-airport accidents, mountainous terrain can pose a hazard to occupant survival due to the limited availability of relatively flat terrain, suitable for a controlled crash, and poor accessibility to rescue personnel. Thus, we were interested in identifying factors associated with a fatal accident which, by various operational criteria (as described in the Methods section), should otherwise have been survivable. The accident cohort studied included both MEHET-related and non-MEHET-related mishaps.

Table 1 (CFIT)

	Parameter	**Value**
Flight Conditions	VMC- Daylight N, (%))	40 (36)
	VMC-Other than Daylight N (%)	16 (14)
	IMC (All Lighting Conditions) N (%)	56 (50)
Flight Plan	None N (%)	89 (78)
	IFR N (%)	10 (9)
	VFR N (%)	14 (12)
	Unknown N (%)	1 (1)
Planned Flight Distance N=110	Median (nm)	125
	Q1 (nm)	60
	Q3 (nm)	317
	Flights ≥ 50 nm (%)	75%
Accident Site Elevation (ft. MSL) N=113	Median	5,557
	Q1	3,600
	Q3	7,633
	Range	110-, 12,300
Engine Type	Normally Aspirated N (%)	99 (87)
	Turbo-charged N (%)	15 (13)

Of 516 accidents deemed survivable by operational criteria, 6% nevertheless resulted in a fatal outcome (Table 3). Site accessibility to first responders in terms of distance to the nearest rescue facility, forestation and mountainous terrain is of particular importance in terms of potential delays associated with either or a combination of these measures. Over half (60%) of accidents were in poorly accessible sites. For occupant survival, there is also strong evidence as to the benefit of a restraint system to prevent blunt force trauma the most important hazard threatening an occupant's survival (Guohua and Baker, 1997). However, 11% and 41% of occupants involved in such fatal accidents were not utilizing installed lapbelts or shoulder harnesses respectively (Table 3). Finally, post-accident fires are well recognized as carrying a high risk of a fatal outcome (Li and Baker, 1999). Indeed, over a third of fatal accidents, which could otherwise have been survivable, incurred a post-crash conflagration.

Table 2 Cross-wind Accidents

		Accidents (n)	Accidents (%)
Wind Gust (kts)	10-19	19	42
	20-29	19	42
	>29	7	16
Head/Tail Wind Gust Speed (kts)	0-10	17	38
	11-20	18	40
	>20	10	22
Cross-wind Gust Speed (kts)	0-8	7	16
	9-17	28	62
	>17	10	22
Exceeded cross-wind Limits	Yes	20	44
	No	21	47
	Aircraft crosswind data Not Available	4	9

4.0 DISCUSSION

We report herein a steady decline, over the past 14 years, in the MEHET-related accident rate for a geographical region of the United States characterized by its mountainous and high elevation terrain. Unfortunately, the proportion of these accidents, which are fatal, remains unchanged over the corresponding period. CFIT represents the most frequent cause/factor for MEHET-related fatal accidents and of these the overwhelming majority are in normally aspirated engine-powered aircraft whose climb rate and service ceiling are inferior to corresponding aircraft with turbocharged powerplants.

Multiple reasons likely have contributed to the impressive decrease in MEHET-related accident rate. For example, rapid advances in technology have translated into nearly half of the general aviation fleet being equipped with a global-positioning system moving map (Federal Aviation Administration, 2010) and the proliferation of affordable, portable units means that in all likelihood, this equipage is even higher. Importantly, and germane to operations in mountainous terrain these systems often display data-linked weather and terrain. That said, the applicability of this argument is speculative as it is based on avionics data for the general aviation fleet rather than the accident aircraft for which such information is rarely available in the NTSB report. Deployment of automated weather reporting systems in mountain passes (Committee on the Assessment of the National Weather Service's Modernization Program, 2012; Spitzmiller, 2015) has probably also culminated in the diminution in MEHET-related mishap rate as flight routes chosen by general aviation airmen may involve traversing mountain passes (due to the inability of normally aspirated piston-powered aircraft to climb to an altitude greater than surrounding terrain). Lastly, the transition of flight training (including recurrency requirements) to *scenario-based* instruction may have also yielded gains in safety (Federal Aviation Administration, 2016). Thus, for airmen based in geographical areas characterized by their mountains and/or high elevation terrain additional emphasis would be placed

Table 3			
Non-Fatal Survivable Accidents (n=486)			
Survivable Accidents Resulting in Fatality (n=30)	Accident Site Accessibility	Poorly Accessible n (%)	18 (60)
		Accessible n (%)	6 (20)
		Highly Accessible n (%)	6 (20
	Shoulder Harness	Evaluable (n)	27
		Utilized (n)	16
		% Utilized	59
	Seatbelts	Evaluable (n)	27
		Utilized (n)	24
		% Utilized	89
	Post-Crash Fire	Evaluable (n)	30
		n	11
		%	37

on weather phenomenon/degraded aircraft performance adversely affecting flight safety.

Although the MEHET-related accident (inclusive of fatal and non-fatal mishaps) rate declined, unfortunately the fraction of fatal accidents (>40%) remained stubbornly high across the study period. These findings are resonant with an earlier report (Baker and Lamb, 1989). Equally important, the fraction of fatal accidents is well above that for non-MEHET-related mishaps and higher than that (~20%) for single engine-piston powered aircraft operating across the breadth of the USA (Li and Baker, 2007; Neuhaus et al., 2010; Wiegmann and Taneja, 2003). The over-representation of fatal accidents reflects, in a large part, the high proportion of CFIT accidents. Not surprisingly, these types of mishaps are often fatal due to high impact forces imparted to the occupants (Freitas, 2014). Over half of such accidents occurred in limited visibility with the minority operating under instrument flight rules. This begs the question as to why the overwhelming majority of airmen operated without an IFR flight plan considering most (75%) accident flights were cross-country, in weather known to be highly changeable (Colorado State University, 2016) and that the majority of airmen were IFR-certified. One possibility is that the service ceiling for normally aspirated-powered aircraft (which by far represented the majority of accident airplanes) was below the minimum enroute altitudes or minimum obstacle clearance altitude required for IFR operations. Consequently, this would lead to selection of a route between mountains and hence an increased risk of CFIT especially in degraded visibility.

The survivability of accidents merits discussion. The majority of accidents were in remote locations with poor accessibility to first responders. Although we lack data on time to rescue and types of injuries it is nevertheless probable that some of the occupants who perished could have been saved had first aid been rendered in a more expedient manner. A prerequisite for rescue personnel reaching the accident site is that the location must first be determined. In remote areas this will likely depend on activation of the emergency locator transmitter (ELT). Although there is a paucity of data on the type of ELT for the accident flights (per the NTSB accident report) it is noteworthy that as of 2014 only 22% of United States general aviation aircraft were equipped with 406 MHz-transmitting ELTs which are superior to 121.5-broacasting units (installed on 76% of general aviation aircraft) in their accuracy, and their higher rate of activation in an accident (Federal Aviation Administration, 2015b). Indeed, search and rescue crews are able to access the accident site, on average, six hours faster for aircraft equipped with the former type of ELT (NOAA, 2016). Also regarding survivability, for nearly half of these accidents, occupants were not utilizing their shoulder harnesses raising the question as to why some occupants chose to forgo use of this part of the restraint system despite the known protection against a serious or fatal injury (National Transportation Safety Board, 2011). One possibility is the increasing body mass of the American public at large with 35% of Americans currently defined as obese ($\geq$30 kg/m^2) (Boyd, 2016; Center for Disease Control (CDC), 2015; Flegal et al., 2012). It is possible that an increasing girth may either preclude utilization of the shoulder harness or render discomfort to the occupant. Another possibility is that for restraint systems comprised of separate lapbelt and shoulder harness the latter unintentionally disengaged.

Based on aircraft registration, 15% of fatal accidents involved airmen resident in the *flatland* states (data not shown) less than that (38%) reported in a prior study (Baker and Lamb, 1989). Such pilots may be unfamiliar with the vagaries of mountain weather and aircraft underperformance at high elevation. The decline may be related to general aviation airmen operating closer to their home base (possibly due to financial constraints) or reflect the different capture areas used in the two studies (Aspen for the former versus 10 states for the current investigation).

Our study was not without limitations. First, it was a retrospective study. Second, the population at risk (denominator) data represented fleet activity for the indicated states. However, portions of some of these states (CA, WA) are not characterized by mountainous or high elevation terrain. Another limitation was the criteria used to identify MEHET-related mishaps which, in some instances, may have identified accidents unrelated to the mountain environment or high elevation terrain. Finally, in regard to accidents operationally defined as survivable, it was unclear whether a fatal outcome for those involving a post-impact fire was a consequence of a living individual unable to egress prior to the conflagration of the aircraft, or who was killed by blunt force trauma upon impact.

In conclusion, despite a declining rate of MEHET-related accidents over the past 14 years, these mishaps still carry a high risk of a fatal outcome largely due to CFIT. Flight safety in mountainous terrain/high elevation would likely benefit from airmen being encouraged to utilize (a) aircraft powered by turbo-charged engine (capable of higher service ceilings and climb performance) and (b) the IFR infrastructure which assures terrain clearance. As to survivable accidents, a discussion with airmen as to the benefits of shoulder harness utilization is warranted in training/recurrency considering their proven benefit in injury prevention (Guohua and Baker, 1997). Additionally, consideration should be given to the development of crash-resistant fuel tanks for general aviation aircraft which have improved survival in rotorcraft mishaps involving a post-impact fire (Federal Aviation Administration, 2015a). Finally, adopting Dutch Civil Aviation Authority practices in setting the manufacturers' demonstrated cross-wind component as a legal limit (van Es et al., 2001) may very well mitigate the number of cross-wind-related accidents.

5.0 Funding

This research did not receive any specific grant from funding agencies in the public, commercial or non-for-profit sectors.

6.0 LEGENDS

FIGURES

Figure 1. Temporal Change in the Rate of MEHET-related or un-related Accidents.

Accident rates for states (UT, NM, NV, ID, OR, CO, WY, CA, AZ, WA) characterized by their high elevation and/or mountainous terrain were categorized into those related (PANEL A) or unrelated (PANEL B) to MEHET. Rates are expressed per million flight hours for the aggregated fleet activity across the corresponding states. A Poisson rate analysis was used to determine statistical significance relative to the initial period; Panel A, *, $p<0.001$; **, $p=0.003$. Panel B, *, $p=0.006$; **, $p<0.001$. n, number of accidents for the specified period.

Figure 2. Temporal Change in Fatal Accident rate for MEHET-related and non-related Mishaps.

Per the accident cohort specified in Figure 1, the percentage of fatal accidents for the indicated time period is depicted. n, number of accidents. Contingency table analysis was performed separately for MEHET-related and unrelated accidents to determine if the proportion of fatal accidents between periods was changed. *, $p=0.003$ for non-MEHET accidents.

Figure 3. Longitudinal Analysis of Accident Causes/Factors for MEHET-related Mishaps.

The proportion of accidents related to the four most common causes/factors is shown for the specified periods. Each accident may have multiple cause/factors per the NTSB report and may thus be represented in different categories for any one time period. CFIT, controlled flight into terrain or obstacles. The wind gust/shear category includes mishaps related to dust-devils. A 2X4 contingency table was used to determine if the proportion of accident cause/factors changed between the three periods. n, number of accidents.

Figure 4. Relationship between Accident Causes/Factors and Fatal Outcome for MEHET-related Mishaps.

MEHET-related accidents were categorized by cause/factors per the Figure 3 legend and expressed as the percentage with a fatal or non-fatal injury outcome. n, number of accidents.

TABLES

Table 1. Flight Conditions, Engine type and Flight Planning for MEHET-related CFIT mishaps.

Flight conditions and flight planning are shown for CFIT accidents related to the mountain environment or high elevation terrain. Accident site elevation was per the NTSB factual report or Google Earth determination in the absence of the former. Flight distance was determined using the

AOPA Flight Planner (https://www.aopa.org/flightplanner/). Engine type was determined from the engine manufacturer's website. N (%), number and percentage of accidents respectively. Q, quartile.

Table 2. Gust Wind Conditions and Exceedance of the Demonstrated Aircraft Cross-Wind Component for MEHET-related accidents.

MEHET-related on-airport accidents for which gusting wind conditions were prevailing at the time of the accident are shown. Computation of head and cross-wind components was using sine and cosine mathematical functions. The demonstrated maximum cross-wind speed for aircraft were determined from a variety of online aviation sources including pilot operating handbooks. Of 45 accidents with a head/tail wind component, only one occurred with a tail-wind. Accidents in which gust data were unavailable were excluded from the analysis. n, accident count.

Table 3. Off-Airport Accidents Operationally Defined as Survivable but which had a Fatal Outcome.

Off-airport accidents (MEHET-related and un-related) were categorized by operational criteria (per the Methods) as survivable or non-survivable. Accident site accessibility was defined as highly accessible (<5 nm from rescue station or with immediate road access, or in an area with <1/3 forestation or with an elevation ratio 1.00-1.05); accessible (>5 and <10 nm from a rescue facility or proximal to a road or in an area with 1/3-2/3 forestation or with an elevation ratio of 1.06-1.10); poorly accessible (>10 nm from rescue services or not served by a road or in densely (>2/3 coverage) wooded area or with an elevation ratio of >1.10). Seatbelt=lapbelt. n, number of accidents; Q, quartile.

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