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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 ($\chi^2 = 0.935$). 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 underutilization (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.

1. 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).

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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 1500 ft/min in excess of the climb rate of many single engine piston aircraft (Baker and Lamb, 1989; Federal Aviation Administration, 1997, 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, 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 (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. 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, windshear, 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 ≤ 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,