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General aviation accidents related to exceedance of airplane weight/center of gravity limits

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ABSTRACT

Background: Obesity, affects a third of the US population and its corollary occupant weight adversely impacts safe flight operations. Increased aircraft weight results in longer takeoff/landing distances, degraded climb gradients and airframe failure may occur in turbulence. In this study, the rate, temporal changes, and lethality of accidents in piston-powered, general aviation aircraft related to exceeding the maximum aircraft weight/center of gravity (CG) limits were determined.
Methods: Nation-wide person body mass were from the National Health and Nutrition Examination Survey. The NTSB database was used to identify accidents related to operation of aircraft outside of their weight/CG envelope. Statistical analyses employed *T*-tests, proportion tests and a Poisson distribution.
Results: While the average body mass climbed steadily ($p < 0.001$) between 1999 and 2014 the rate of accidents related to exceedance of the weight/CG limits did not change ($p = 0.072$). However, 57% were fatal, higher ($p < 0.001$) than the 21% for mishaps attributed to other causes/factors. The majority (77%) of accidents were due to an overloaded aircraft operating within its CG limits. As to the phase of flight, accidents during takeoff and those occurring enroute carried the lowest (50%) and highest (85%) proportion of fatal accidents respectively.
Conclusion: While the rate of general aviation accidents related to operating an aircraft outside of its weight/CG envelope has not increased over the past 15 years, these types of accidents carry a high risk of fatality. Airmen should be educated as to such risks and to dispel the notion held by some that flights may be safely conducted with an overloaded aircraft within its CG limits.

1. Introduction

Obesity (body mass index of ≥30 kg/m^2, Krueger et al., 2014) is at epidemic proportions in the United States affecting a third of the population (Center for Disease Control (CDC), 2015a; Flegal et al., 2012). Occupant weight, as a corollary of obesity, is germane to safe flight operations (FAA, 2007) especially for general aviation (all civilian aviation apart from operations involving paid passenger transport) where usable payloads are modest. Indeed, the limited usable loads for general aviation (even more restrictive for light sport aircraft, Pagan et al., 2006) is best exemplified by the four seat Cessna Skyhawk (the most popular single engine aircraft manufactured, which fully fueled, is limited to 600 lbs for occupants and cargo (Cessna, 2015). For safe flight operations, airplane loading should not exceed the maximum certified weight specifications and be within the center of gravity (CG) limits, data documented by the manufacturer (Federal Aviation Administration (FAA), 2007) as part of aircraft certification.

Increased aircraft weight, whether attributed to the occupants, accompanying cargo or both, adversely affects aircraft performance in a variety of flight parameters. For example, longer takeoff and landing distances are evident for a heavier aircraft and climb gradients are degraded (FAA, 2007, 2008). The consequence of such decreased performance could be a runway excursion (of particular concern when the runway is followed by descending terrain or water) or the inability to clear rising terrain in the flight path. Moreover, airframe failure may occur under turbulent flight conditions where the aircraft is loaded beyond its maximum certified weight or outside of its CG limits (FAA, 2007). Importantly, the aforementioned weight-dependent performance degradation is further exacerbated by a performance penalty associated with an aging aircraft. As of 2014, the average age of the general aviation, single engine aircraft exceeds 30 years (General Aviation

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Manufacturers Association, 2014). Performance of aging aircraft often diminishes from that stated in the pilot operating handbook/flight manual largely due to airframe deterioration (causing parasitic drag), weight gain (e.g., addition of after-market products, detritus) and reduced engine performance (Airbus, 2002; FAA, 2007). Finally, exceeding the CG limits of an aircraft may make recovery from an aerodynamic stall impossible due to loss of elevator control authority (FAA, 2007).

A final emerging concern is the recent proliferation of non-FAA approved software applications for aircraft weight–CG determinations. These allow for an expedient determination of aircraft weight and CG location in a non-arduous manner compared with a standard loading graph provided in the pilot operating handbook/flight manual. However, these applications utilize a generic aircraft not taking into account modifications (e.g., new avionics, air-conditioner, residual wiring) which alters usable loads/CG limits for the end user.

Currently, there is little peer-reviewed published research on general aviation accidents related to exceeding the allowable certified weight and/or the CG limits. The comprehensive Joseph T. Nall Report (Kenny, 2015) (hereafter referred to as the Nall Report) provides data for only weight-related general aviation accidents which occurred during the takeoff/climb phase of flight and for which density altitude was a factor. Moreover, the high obesity rates for the American population (Flegal et al., 2012) (increasing the potential for aircraft over-loading), the proliferation of non-FAA-approved weights and balance software applications, and the degraded performance associated with aircraft aging are of particular concern. Therefore, the current study was undertaken to determine: the rate, temporal changes, and lethality of accidents in piston-powered, general aviation aircraft related to exceeding the maximum aircraft weight/CG limits.

2. Materials and methods

2.1. Procedure

Body mass for persons age 16 years of age or older were derived from measurements made by the National Health and Nutrition Examination Survey (NHANES) (CDC, 2015b), a survey of the non-institutionalized US population. Body mass data were adjusted using the mobile exam center (MEC) exam weight to correct for over-sampling and non-response (Centers for Disease Control and Prevention, 2016). Records with null weights were deleted from the study.

The NTSB Access database (October 2015 release) was downloaded (National Transportation Safety Board, 2015) and queried for accidents in piston-powered (1–2 power plants) airplanes operating under 14CFR Part 91. The term weight was included in the query of the narrative cause field of the database. Search criteria were used to exclude accidents involving: air medical flights, aerial observation or application, airshows, flight instruction, airdrops, glider tows and flight tests. The narrative causes of the exported data were manually parsed for accidents unrelated to exceedance of aircraft weight/CG limits (e.g., crankshaft counterweight) which were subsequently deleted. To be included in the current study, either an exceedance of the maximum certified gross weight and/or the CG limits had to be cited by the NTSB report (probable cause section) as causal or a factor in the accident. Annual fleet activity for piston-powered general aviation aircraft was obtained from the General Aviation and Part 135 Activity Surveys (FAA, 2015). A fatal accident was any in which one, or more, occupants perished within 30 days of the crash as defined following 49CFR 830 (Electronic Code of Federal Regulation, 2010).

2.2. Statistical analysis

All statistical analyses were performed using SPSS (v22) software. A *p* value of <0.05 was used as cut-off for statistical significance.

An Independent Samples *T*-test was used to determine if the weighted, average nation-wide person body mass ($\geq$16 years of age) for a specific period differed from the prior period. Equal variances were not assumed when Levene's Test for Equality of Variances was statistically significant ($p < 0.05$).

A generalized linear model with Poisson distribution (log-linear) was employed to determine if the rate of accidents ascribed to exceedance of maximum weights and/or CG changed relative to the initial period (1988–1994). The natural log of the annual fleet activity for piston-powered aircraft averaged over 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 (Field, 2009). *p* values for cells in multinomial tables were derived from adjusted standardized residuals (*Z*-scores) in post-hoc testing.

3. Results

3.1. Increase in nation-wide person weight in the USA

Temporal changes in body mass data for the US population was first determined. Toward this end, NHANES data (CDC, 2015b), collected over consecutive two year periods as part of a continuous program implemented in 1999 (CDC, 2015b) were employed. The body mass of the average American steadily climbed over the NHANES continuous program (Fig. 1A). For 1999–2000, the average person body mass was 174.3 lbs increasing to 181.5 for the years 2013–2014. Across the study period, increases in body mass between consecutive periods were strongly statistically significant ($p < 0.001$).

3.2. Rate of accidents related to aircraft weight/CG limit deviations

The increasing body mass of the US population over time raised the question as to whether a parallel climb would be evident for the rate of general aviation accidents ascribed to operating the aircraft outside of its weight/CG envelope. For increased statistical power, accidents were aggregated into 5 year periods. For the initial period (1999–2003), 45 general aviation accidents (2.3/million flight hours) in piston-powered aircraft were related to exceeding the maximum certified weight and/or the CG limits (Fig. 1B). However, there was little evidence of a change over time with a comparable rate (2.4/million flight hours) for the most recent period (2009–2013). A rate analysis (Poisson distribution) indicated no change in accident rate between the first and most recent periods ($p = 0.072$).

3.3. Lethality of accidents for which transgression of weight/CG limits was causal or a factor

The prior data indicated no temporal change in the rate of accidents related to operating the aircraft outside of its weight/CG envelope. The next question posed was whether such types of accidents vary in risk of a fatal crash compared with those unrelated to weight/CG exceedance. To answer this question, the fraction of fatal accidents related to exceeding the approved weight and/or CG limits was then compared with that for mishaps ascribed to any other reason. Hereafter, the query period was extended prior