Occupant Injury Severity in General Aviation Accidents Involving Excessive Landing Airspeed

Douglas D. Boyd

BACKGROUND: Of all phases of flight operations, accidents during landings are the most frequent. Of these, poor speed management during landing has ramifications for injury severity since: 1) impact forces increase as a square of forward velocity; and 2) an aerodynamic stall, associated with inadequate landing speed, imparts high vertical G forces. Herein, the proportion of landing accidents involving deficient airspeed control and occupant injury severity was determined.

METHODS: General aviation landing accidents (1997–2016) were identified from the NTSB database. An accident involving high-airspeed (high-energy) was one for which the NTSB cited airplane porpoising, multiple bounces, or floating, whereas an inadequate airspeed related (low energy) mishap was one citing this term or in which an aerodynamic stall occurred. An anonymous online survey of certificated pilots was used to inform landing technique. Statistical analyses used Poisson distribution and Chi-squared tests.

RESULTS: Relative to the earliest period (1997–2001), the landing accident rate was undiminished for more recent years (2007–2016). Of 235 accidents, 38% involved high-energy, whereas 4% were inadequate airspeed-related. For the former, 17% resulted in occupants with fatal-serious injuries, twofold higher than for mishaps with no evidence of mis-speed. Of 1392 survey respondents, 73% selected a landing airspeed higher than required for an under-maximum weight airplane.

CONCLUSION: For landing accidents involving airspeed mismanagement, those related to excessive energy predominate and are associated with more severe injuries. Two mitigating strategies are advanced: 1) pilot training should discuss landing airspeed adjustment for aircraft weight; and 2) installation of inflatable restraints for reducing injury severity should be encouraged.

KEYWORDS: accident, general aviation, injury, landing.

Boyd DD. *Occupant injury severity in general aviation accidents involving excessive landing airspeed*. Aerosp Med Hum Perform. 2019; 90(4):355–361.

General aviation, comprised mainly of light (≤12,500 lb), single engine, piston-powered airplanes,[19] is defined as all civil aviation but for revenue-generating, passenger/freight transport. General aviation operations and aircraft certification are governed by a set of rules described in the Code of Federal Regulations (14 CFR Part 91 and 23).[14,15] In contrast, commercial operations involving paid passenger transport (e.g., air carriers) and corresponding aircraft certification are regulated by more restrictive rules (14 CFR Parts 121 and 25).[16,20] Partly because of these more stringent regulations, commercial travel is substantially safer than general aviation. Indeed, between 2010 and 2015, general aviation accounted for 97% of all civil aviation accidents (also referred herein to as mishaps).[6]

Landings represent the most common phase of operations for general aviation accidents.[2,11] In the United States, 30% of general aviation mishaps in 2014 were during this phase of operation, with an unchanged accident count over the prior year.[2] Similarly, 53% of German general aviation accidents in 2004 were during the approach and landing phase.[11]

Multiple causes abound as to landing mishaps. For example, poor speed control in which landing airspeed deviates from the reference landing airspeed ($V\text{-}_{Ref}$: defined as the airspeed to be achieved over the runway threshold[18,23]) can result in an undesirable outcome. Thus, landing too fast (i.e., above $V\text{-}_{Ref}$) may lead to "floating" and runway contact well past the touch-down zone.[18] Since ground roll-out distances increase by the square of the landing airspeed, the potential of a runway over-run for a high-energy landing is elevated.[8,18] Indeed, for an aircraft flown 20 kn over its appropriate landing airspeed of 70 kn, the roll-out distance is approximately doubled.[18] In such instances, obstructions (trees) or ravines past the runway departure end could

From Sugar Land, TX.

This manuscript was received for review in August 2018. It was accepted for publication in January 2019.

Address correspondence to: Douglas Boyd, Sugar Land, TX; dboyd.academic.aviation@gmail.com.

DOI: https://doi.org/10.3357/AMHP.5249.2019

generate high occupant G forces due to an abrupt termination of forward movement. Conversely, a landing airspeed below V_{-Ref} (referred to as low-energy or low-airspeed) can yield an aerodynamic stall above the runway and impose high vertical G forces on the aircraft occupants. Other landing accident causes include deficiency in the "flare" (a technique where the aircraft is transitioned to a level attitude just above the runway[4]) and poor longitudinal control after touch-down.[7]

Of the aforementioned landing accident causes, the author was particularly interested in mishaps involving poor airspeed control for several reasons related to aerospace medicine. First, since occupant impact forces in aircraft accidents vary as a function of the square of the airplane velocity,[3] a high landing airspeed could very well result in greater injury severity than those which occur at V_{-Ref}. Conversely, and as discussed above, an aerodynamic stall associated with an inadequate airspeed generates high vertical G forces and consequently occupant spinal loading and potentially paraplegic/quadriplegic outcomes.[26] This is germane since the seats in light airplanes certificated prior to 1988 (such aircraft representing the vast majority of the GA fleet[21]) have been determined to be inadequate in protecting occupants against peak vertical loads commonly encountered in survivable accidents.[26] Accordingly, the aims of the current study were twofold: 1) to determine the extent to which general aviation landing accidents by certificated pilots are related to poor airspeed management, and 2) to determine injury severity for such accidents.

METHODS

Procedure

Landing accidents were identified from a search of the downloaded NTSB Microsoft Access database (January 2018 release).[28] The database was queried for on-airport accidents occurring over the period spanning 1997–2016 involving piston engine-powered airplanes (≤12,500 lb) with tricycle landing gear operated by a certificated pilot (private pilot: PPL; commercial or commercial/certificated flight instructor-commercial: CFI; airline transport pilot: ATP) with at least 20 h in aircraft make-model (time-in-type). Only accidents in which flights were conducted under general operating flight rules (14 CFR Part 91)[14] and for personal missions were considered. To focus on landing accidents, the query included a search of the NTSB narrative cause for the terms "landing" or "runway." The study was restricted to landing accidents involving runways of up to 3000 ft in length. This distance was chosen to mitigate against the masking of higher airspeed landing accidents; a longer runway would allow for the dissipation of the excess energy, precluding a runway excursion past the departure end. Homebuilt aircraft and landing accidents in Alaska were excluded from the query strategy. Data were exported to Excel and checked for duplicates (which were deleted). Records were manually inspected and accidents unrelated to the landing phase deleted. Mishaps due to equipment malfunction culminating in a landing accident or in which the landing gear was not extended were excluded, as were those resulting from maneuvering or avoidance of wildlife or vehicles on the landing runway. Accident aircraft designed post- and pre-implementation of the more stringent crashworthiness requirements[13] in 1988 were identified from the FAA aircraft registry.[21]

High-airspeed (high-energy) landings were defined as those for which the NTSB final report cited porpoising, multiple bounces, or floating of the accident airplane.[8] Conversely, landings with inadequate airspeed (low-energy) were those cited as such or for which an aerodynamic stall occurred above the runway, again per the NTSB final report.[8] The on-speed category was used to refer to any landing accident in which there was no evidence of mis-speed per the aforementioned criteria. Injury severity was sourced from the NTSB reports and is as defined previously per the U.S. Code of Federal Regulations.[19]

To address the effect of winds on landing aircraft groundspeed, a cosine function was used to derive the head/tail wind component from reported winds per the NTSB accident report. Where gust conditions were reported, the highest gust speed was used in the calculation.

An anonymous online survey with the objective of finding out about landing technique by certificated pilots was constructed in SurveyMonkey® (www.surveymonkey.com) and pretested among four active general aviation pilots who are FAA Safety Team members. The web link to the online survey was posted to an aviation website (https://www.avweb.com/avwebflash/). Airman responses were collected over the period spanning July 15–August 15, 2018.

Statistical Analysis

A generalized linear model with Poisson distribution[12] was employed to determine whether changes in landing accident rate over the two decades were statistically significant. Annual fleet activity[19] for fixed wing, piston-powered aircraft engaged in personal missions was used as an offset (log N), with data for 2011 interpolated from 2010 and 2012. Although movement count (which would enumerate the number of landings) would have been a superior denominator, such data are not available to the knowledge of the author. Confidence intervals were at the 95% level. Proportion testing used contingency tables and a Pearson Chi-squared (2-sided) test was used to determine where there were statistical differences.[1] The contribution of individual cells in proportion tests was determined using standardized residuals (Z-scores) in post hoc testing. All statistical analyses were performed using SPSS (v. 24; IBM, New York, NY) software.

RESULTS

Since the general aviation accident rate has modestly declined over recent years,[6] the first question was whether landing accidents have also diminished. In the current study, certificated airmen operating piston engine powered light aircraft incurred 24 landing accidents/10 million flight hours for the period spanning 1997–2001 (**Fig. 1**). This rate transiently decreased

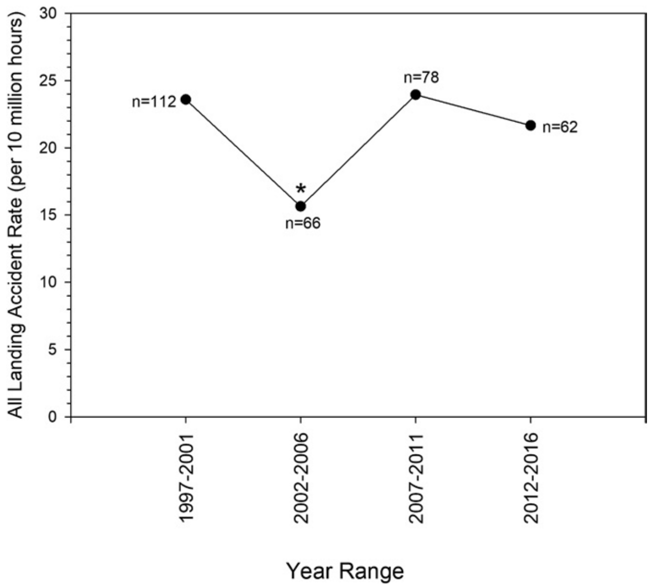

Fig. 1. Temporal landing accident rate for the period spanning 1997–2016. The landing accident rate for the indicated time periods is shown. The rate was calculated using, as denominator, the sum of annual general aviation fleet time for the specified period for piston engine-powered, light aircraft operated for personal missions. Statistical differences in the landing accident rate was tested for with a Poisson distribution using the initial period as referent. n, count; *$P = 0.008$.

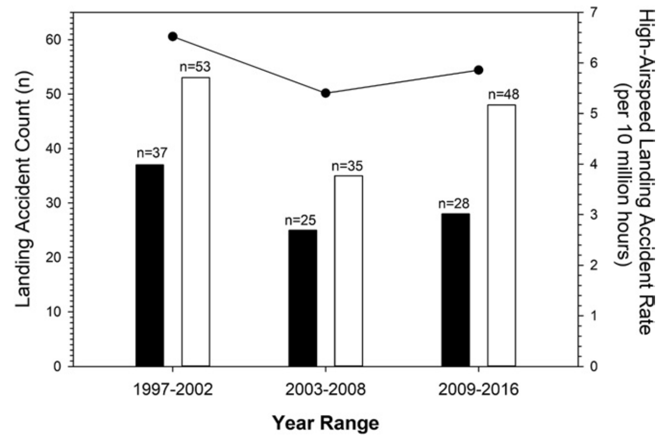

Fig. 2. The high-energy landing accident rate is unchanged over the years spanning 1997–2016. The rate of high-airspeed landing accidents for the indicated time frames, and as described in Fig. 1, is shown (line). A Poisson distribution was used to determine whether changes for the two later time periods were changed relative to the initial period. The proportion of high (black column) and on-airspeed (white column) landing accidents for the three time periods is also depicted. On-speed refers to accidents for which there was no evidence of deficient airspeed control. Proportion testing was with a Chi-squared exact 2-sided test. n, accident count.

($P = 0.008$) for the subsequent (2002–2006) period, rising thereafter. Using the initial period as referent, the landing accident rate was unchanged ($P > 0.05$) for the 2007–2011 and 2012–2016 periods. The undiminished landing accident rate for the most current period suggests that these types of mishaps continue to pose a challenge to general aviation safety.

From an aeromedical perspective, landing airspeed mismanagement has ramifications for injury severity. Accordingly, landing accidents were categorized based on landing airspeed. Of 318 landing accidents, 235 could be unambiguously categorized according to this parameter, with 136 showing no evidence of airspeed mismanagement. Surprisingly, 90 (38%) landing accidents involved excess energy as evidenced by aircraft floating, porpoising, and/or multiple bounces. Of the 90 mishaps related to a fast landing airspeed, 50 resulted in a runway excursion past the departure end. In contrast to the high fraction of high-energy accidents, nine (< 4%) landing mishaps were associated with an airspeed insufficiency.

Due to the preponderance of these high-energy landing mishaps, the question then posed was whether the rate/proportion of these types of accidents changed over the 20-yr study period. For increased statistical power, landing accidents, characterized by their excessive airspeed, were aggregated into three, rather than four, time periods. Indeed, over the two-decade study period (1997–2016), there was little evidence (**Fig. 2**, line) of a decline in the rate ($P = 0.760$) for this type of landing accident, with incident rate ratios (IRR) statistically unchanged for both the 2003–2008 (IRR 0.828; 95% CI, 0.499, 1.376; $P = 0.467$) and 2009–2016 (IRR 0.898; CI, 0.550, 1.468; $P = 0.669$) periods. Furthermore, the proportion of landing accidents related to excessive airspeed (Fig. 2 column) was also unchanged ($P = 0.818$).

As mentioned above, landing mishaps involving high-energy were by far the most frequent of the mis-speed landing accidents. Thus, injury severity for this type of landing mishap and for accidents in which there was no evidence of airspeed mismanagement was compared. Landing accidents were each categorized either as none-minor or fatal-serious based on the highest injury of the involved aircraft occupant(s). For landing accidents involving excess energy, 17% ($N = 15$) resulted in occupants with fatal-serious injuries. This was more than twofold elevated ($P = 0.026$) over landing accidents in which there was no evidence of deficient airspeed management ($N = 9$, 7%). For landing accidents involving low-energy ($N = 9$), only one resulted in a fatal-serious outcome, although the small count makes an injury severity comparison difficult.

At the same time, landing wind conditions could introduce a confounder with respect to injury severity, with a high headwind slowing the ground-speed of landing aircraft and mitigating impact forces. To determine the contribution of landing winds, the head-tail wind component was calculated for landing accidents at aerodromes with weather-reporting systems ($N = 185$). Median head winds were 0 kn (range: −23 through +14 kn) and 4 kn (range: −30 through +23 kn) for landing accidents involving excess energy and on-speed, respectively. With a median $V_{\text{-Ref}}$ value of 66 kn for the accident aircraft [derived from aircraft pilot operating handbook (POH)/flight manuals], an additional 4 kn higher landing ground speed would translate into a 12% increase in impact force for aircraft in the excess energy category.

These findings then raised the question of whether high airspeed landing accidents were related to either airman certification level or their accrued time in aircraft make-model (time-in-type). However, the proportion of this type of landing mishap was unchanged ($P = 1.000$) for each of the three certificate levels examined: ATP 39%, commercial/CFI 41%, PPL 40%. Thus, high-energy landing accidents were not over-represented for any of these three airman certification levels. To then determine if airmen with varying time-in-type carried different risk for high-airspeed landing mishaps, the accident pilot population was rank ordered by time-in-type and divided equally into three groups: low, 20–120; medium, 121–350; high, 351–5000 h in type. Just over half (51%) of low time-in-type accident airmen were involved in high-airspeed landing accidents (**Fig. 3**), whereas this proportion diminished to 37 and 32% for the pilot cohorts with the middle and highest time-in-type, respectively. The disproportionate number of airmen with the least time-in-type in landing accidents characterized by excess energy was statistically significant ($P = 0.021$).

While these data showed that nearly 40% of accidents involved high-energy landings, it was unclear whether the technique of landing fast was restricted to the numerator population (i.e., accident pilots) or reflected a common practice for the general aviation population at large. To address this question, an anonymous online survey (**Table I**) on landing technique was constructed and disseminated to the general aviation population at large. In designing the questionnaire two specific issues in operating a light aircraft were addressed. First, anecdotally, general aviation flights undertaken for leisure are sometimes at less than the maximum certificated aircraft weight. Second, the POH/flight manual for light aircraft (≤12,500 lb) are only required to specify a single (nonshort field) final approach landing speed (V-$_{\text{Ref}}$) and this must correspond to the maximum certificated aircraft weight.[18] This means that a light airplane landing at less than maximum weight but using the POH-specified landing airspeed will likely be carrying excess energy.[18]

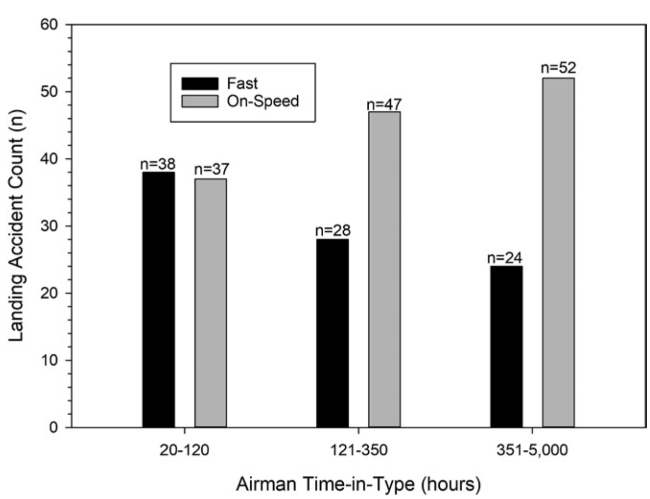

Fig. 3. Decreased proportion of high-energy landing accidents with increased airman experience in aircraft type. Accident airmen were rank-ordered by time-in-type and divided into equal thirds: lower, 20–120 h; middle, 121–350; and high, 351–5000 h. Accidents for these three levels of experienced cohorts were then categorized based on landing airspeed. On-speed is per the definition in Fig. 2's legend. A difference in proportions for accident airmen in the three different experience groups was determined using a Chi-squared 2-sided test. n, accident count.

A total of 1454 certificated airmen responded to the online survey. Of these, responses involving the following aircraft were deleted: 1) for which the flight manual specifies landing airspeed adjustment for lower than maximum weight; 2) which were experimental and therefore with no specified landing airspeed; 3) with supplemental type certificate modifications including short takeoff and landing (STOL); and 4) in which angle-of-attack indicators were installed and this instrument was used in lieu of airspeed. After elimination of these, 1392 responses (PPL, 47%; Commercial-CFI, 30%; ATP 23%) with a median time-in-type of 450 h remained. Importantly, for the question posed regarding landing the aircraft under gross maximum weight (Q5, Table I), 73% of airmen indicated that either the POH-specified final approach landing airspeed (V-$_{\text{Ref}}$), or higher, represented the targeted airspeed (**Fig. 4**). In stark contrast, only 17% of airmen adjusted their landing airspeed for the reduced landing weight. These data suggest that, under these reduced weight conditions, the majority of general aviation airmen are landing with excess energy.

DISCUSSION

The study herein reports that nearly 40% of landing accidents involving certificated airmen operating light aircraft are high-energy-related. Equally importantly, occupants in this type of landing mishap suffer higher injury severity compared with those involved in accidents for which there was no evidence of airspeed mismanagement.

These findings beg the question as to the choice of carrying excessive airspeed by the accident pilots for landing. Two reasons likely contribute. First is related to the fact that POH/flight manuals for light aircraft are only required to specify a single landing airspeed predicated on the maximum certificated weight of the airplane,[18] despite the fact that V-$_{\text{Ref}}$ decreases with landing weight.[10] Indeed, the FAA advocates lowering landing airspeed with reduced aircraft weight.[18] Considering that leisure flights are not uncommonly performed at less than the aforementioned maximum weight, an airplane landed at the POH-specified landing airspeed, will be probably carrying excess energy.[18] Unfortunately, current pilot training, be it ab initio or even for the commercial certificate, does not require any discussion (by the CFI) of adjustment of landing airspeed for reduced airplane weight under no wind gust conditions. A second equally plausible reason might reside in the reduced control authority of the flight controls at slower speed, with which pilots may be uncomfortable. Considering that runway length at most general aviation airports is typically not limiting for a light aircraft, airmen might prefer "adding a few knots" to the landing airspeed to maintain control authority. Such a habit of landing fast may in fact develop during primary training. Indeed, 30% of landing

Table I. On-line Pilot Questionnaire on Landing Technique.

QUESTION #	QUESTION	RESPONSE/CHOICE
1	What is your highest airman certificate (PPL or Comm/CFI or ATP)?	Multiple Choices: (i) PPL, (ii) Commercial and/or CFI, (iii) ATP
2	Which aircraft make/model do you fly typically?	
3	How many hours do you have in this type of aircraft?	
4	How much TOTAL time (hours) do you have (all aircraft)?	
5	Regarding landing your airplane under gross maximum weight and in NON-gusty winds, which airspeed do you try to achieve when crossing the runway threshold? Assume that runway length is not limiting	Multiple Choices: (i) final landing approach speed as published in the POH/Flight Manual; (ii) above POH final landing approach speed; (iii) POH final landing approach speed adjusted for the lower than maximum certified aircraft weight; (iv) Other (please specify)

Questions and response choices (if any) are shown. POH, pilot operating handbook, PPL, private pilot license, CFI, certificated flight instructor, ATP, airline transport pilot. Note that for Question #5, the phraseology "airspeed… when crossing the runway threshold" represents the definition of V_{-Ref}.[29]

mishaps involving primary solo students were related to excess landing airspeed.[8] Unfortunately, the recent change in airman certification standards[22] whereby the airspeed for demonstrating slow flight has been increased by 5–10 kn may further exacerbate this problem.

It is unlikely that high-energy landings are restricted to the accident pilots. Thus, in the online survey querying airmen as to landing an under maximum gross weight airplane, by far the majority of respondents indicated an adherence to, or above, the recommended POH landing airspeeds. This included 65% of ATP-holding airmen, surprisingly, since this certificate requires knowledge of weight-adjustment of landing speed.[17] The findings herein resonate with a 40-yr-old NASA study,[25] which found that the 60–80% of landings made by general aviation

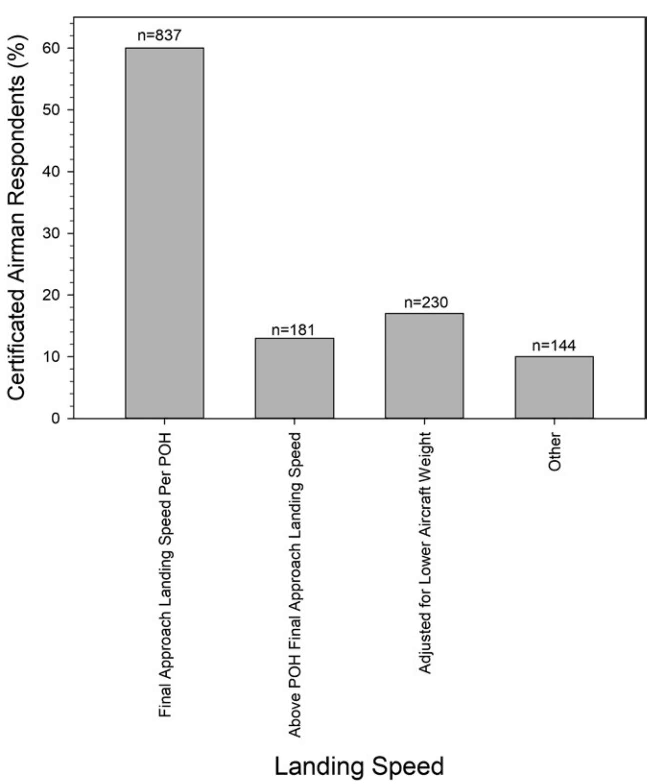

Fig. 4. Airman responses to an on-line survey on landing technique. Airman responses to Question 5 of the survey of certificated pilots were categorized based on the four choices to this question (see Table I). Other categories included ambiguous answers and not monitoring airspeed. n, respondent count.

pilots in single, piston-engine light aircraft were fast, with considerable floating during the flare. Indeed, a previous study demonstrated that landing speed of a light aircraft with a single occupant [of 182 lb per the noninstitutionalized U.S. population (age ≥16 yr)[9]] and carrying 3 h of fuel was approximately10 kn indicated airspeed lower than that specified by the POH.[8]

Injury severity increased with high-airspeed landing accidents, perhaps not surprising, since impact forces quadruple with a twofold increase in forward velocity of the aircraft.[3] However, it was possible that the data herein were skewed by the presence of accident aircraft certificated to higher crashworthiness in which dynamic load testing using an anthropomorphic test dummy was added to the certification process in 1988.[13] As reported elsewhere, these more stringent crashworthiness standards have indeed mitigated injury severity in general aviation mishaps.[5] If such aircraft were under-represented in accidents involving high energy, this could erroneously elevate injury severity for this airspeed category. However, such a scenario is unlikely since of the 235 landing accidents categorized by injury severity, only 5 (2 excess energy and 3 on-speed) such aircraft were certificated to the more stringent crashworthiness standards.

Airmen with higher time-in-type were less likely to be involved in a fast airspeed landing accident relative to those with less experience in the aircraft make-model. In contrast, the majority of survey respondents (who had substantially more time-in-type medians, 450 vs. 162 h) indicated that landing airspeed was not adjusted for a reduced airplane weight. At first glance, these observations seem at variance. One explanation that might reconcile these findings is that airmen with higher time-in-type are superior in determining the point at which a fast airspeed landing should be aborted with a go-around, thus avoiding a mishap.

This study was not without limitations. First, the accident analysis represented a retrospective study. For example, since the study comprised aircraft of different makes/models it is possible that the varying V_{SO} values (stall speed for an airplane in the landing configuration: $V\text{-}_{Ref} = 1.3 \times V_{SO}$) could skew the injury severity data if fast airspeed landing accidents were over-represented for airframes with higher V_{SO}. However, this was not the case: median V_{SO} values for both aircraft groups (involved in high-energy and on-speed landing accidents) were identical (51 kn). Second, the nature of the injuries in these high-energy landings was not investigated since such information is not recorded in the NTSB final report and warrants future studies. Third, it was unclear from the NTSB report as to whether any of the accident aircraft were equipped with inflatable restraints (air-bags: this field was only added in 2014). However, with the most current data,[19] only 3.6% of the piston engine powered light aircraft fleet is equipped with such a safety device, making this a lesser concern. Fourth, although the median head wind component for the excess energy and on-speed accident groups only differed by 4 kn, this difference may have still contributed to reduced injury severity in the latter. Fifth, the general aviation airmen online survey accrued only a fraction of the active general aviation pilot population.[20]

While the current study focused on runway landing accidents, the findings have important implications for situations where an off-field landing is required (e.g., engine failure), an important consideration since the majority (>90%) of the general aviation fleet is powered by a single, reciprocating engine.[19] An emergency landing on unimproved terrain may well lead to an abrupt stop due to obstacles and ravines and impose high peak G loads on the occupants. Thus, it is imperative for the airman to achieve touchdown at the slowest possible speed. For the pilot habitually carrying "extra airspeed" for airport landings, the consequence will likely be more severe injuries.

In conclusion, the preponderance of excess-energy landing accidents and a correspondingly higher injury severity suggests that pilot training, whether ab initio or for recurrency, should include a discussion as to the importance of adjusting landing airspeed (in nongust conditions) based on aircraft weight as espoused by the FAA[18] and others.[8,24,29] Additionally, while the minority (3.3%) of the general aviation fleet[21] with current U.S. registration conform to the more stringent crashworthiness requirements[13] (this includes newly manufactured aircraft whose designs were approved prior to implementation of these standards), aircraft owners should be encouraged to install third party inflatable restraints (air-bags), which have been demonstrated to mitigate injury severity in survivable accidents.[27]

ACKNOWLEDGMENTS

The author expresses his gratitude to *Avweb Flash* for the distribution of the pilot questionnaire online link to its aviation readers and is also very appreciative for critical insights by Sally Sims, ATP, CFI. Finally, Dr. Boyd also expresses his thanks to Dr. David Ison for input into developing the online pilot questionnaire.

Author and affiliation: Douglas Boyd, B.Sc., Ph.D., Retired, Sugar Land, TX, United States.

REFERENCES

1. Agresti A. Categorical data analysis, 3rd ed. Hoboken (NJ): Wiley; 2012.
2. AOPA Air Safety Institute. 26th Joseph T. Nall report; general aviation accidents in 2014. Frederick (MD): AOPA Air Safety Institute; 2016.
3. Banks RD, Brinkley JW, Allnutt R, Harding RM. Human responses to acceleration. In: Davis JR, Johnson R, Stepanek J, Fogarty JA, editors. Fundamentals of aerospace medicine. Philadelphia: Wolters Kluwer; 2008:83–109.
4. Benbassat D, Abramson CI. Landing flare accident reports and pilot perceptions analysis. Int J Aviat Psychol. 2002; 12(2):137–152.
5. Boyd DD. Occupant injury and fatality in general aviation aircraft for which dynamic crash testing is certification-mandated. Accid Anal Prev. 2015; 79:182–189.
6. Boyd DD. A review of general aviation safety (1984−2017). Aerosp Med Hum Perform. 2017; 88(7):657–664.
7. Boyd DD. General aviation accidents involving octogenarian airmen: implications for medical evaluation. Aerosp Med Hum Perform. 2018; 89(8):687–692.
8. Boyd DD, Dittmer P. Accident rates, phase of operations, and injury severity for solo students in pursuit of private pilot certification (1994–2013). JATE. 2016; 6(1):44–52.
9. Centers for Disease Control (CDC). National Health and Nutrition Examination Survey. [Accessed 6-1-2015]. Available from http://www.cdc.gov/nchs/nhanes/nhanes_questionnaires.htm.
10. Clancy LJ. Aerodynamics. Harlow: FT Prentice Hall; 1978.
11. Dambier M, Hinkelbein J. Analysis of 2004 German general aviation aircraft accidents according to the HFACS model. Air Med J. 2006; 25(6):265–269.
12. Dobson AJ, Barnett AG. Poisson regression and log-linear models. In: Dobson AJ, Barnett AG. An introduction to generalized linear models. Boca Raton (FL): Chapman and Hall/CRC; 2008:165–183.
13. Electronic Code of Federal Regulation. Emergency landing conditions. 2014. [Accessed 6-1-2014]. Available from http://www.ecfr.gov/cgi-bin/text-idx?SID=eb5c2484236928b8e80e743d2b5528e3&mc=true&node=pt14.1.23&rgn=div5.
14. Electronic Code of Federal Regulation. General operating and flight rules. 2015. [Accessed 1-10-2015]. Available from http://www.ecfr.gov/cgi-bin/text-idx?node=14:2.0.1.3.10.
15. Electronic Code of Federal Regulation. Airworthiness standards: normal, utility, acrobatic and commuter category airplanes. [Accessed 6-1-2017]. Available from http://www.ecfr.gov/cgi-bin/text-idx?SID=5ffea7e4489b0113fefc117f1b9fc96a&mc=true&node=pt14.1.23&rgn=div5#se14.1.23_11.
16. Electronic Code of Federal Regulation. Operating requirements: domestic, flag and supplemental operations. 2017. [Accessed 1-5-2017]. Available from http://www.ecfr.gov/cgi-bin/text-idx?node=14:2.0.1.3.10.
17. Electronic Code of Federal Regulation. Certification: pilots flight instructors, and ground instructors: knowledge. [Accessed 8-4-2018]. Available from https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=&r=PART&n=14y2.0.1.1.2#se14.2.61_1155.
18. Federal Aviation Administration. On landings. Part II. FAA-P-8740-12. Oklahoma City (OK): U.S. Department of Transportation; 2008.
19. Federal Aviation Administration. General aviation and Part 135 activity surveys. [Accessed 3-1-2018]. Available from http://www.faa.gov/data_research/aviation_data_statistics/general_aviation.
20. Federal Aviation Administration. U.S. civil airmen statistics. [Accessed 4-4-2017]. Available from https://www.faa.gov/data_research/aviation_data_statistics/civil_airmen_statistics/.
21. Federal Aviation Administration. Aircraft registry (FAA). [Accessed 3-15-2016]. Available from http://www.faa.gov/licenses_certificates/aircraft_certification/aircraft_registry/releasable_aircraft_download.
22. Federal Aviation Administration. Maneuvering during slow flight in an airplane. FAA-S-ACS-6. Washington (DC): U.S. Department of Transportation; 2016.
23. Federal Aviation Administration. Transition to jet-powered airplanes. Airplane flying handbook (FAA-H-8083-3B). Oklahoma City (OK): U.S. Department of Transportation; 2016:25–28.
24. Flight Safety Foundation. Flight Safety Digest. ALAR briefing note 8.2: the final approach speed. Alexandria (VA): Flight Safety Foundation; 2000:163–166.

25. Goode MW, O'Bryan TC, Yenni KR, Cannaday RL, Mayo MH. Landing practices of general aviation pilots in single-engine light airplanes. TN D-8283. Washington (DC): National Aeronautics and Space Administration; 1976.
26. National Transportation Safety Board. General Aviation Crashworthiness Project: Phase 3. Acceleration loads and velocity changes of survivable general aviation accidents, safety report. SR-85/02. Washington (DC): National Safety Transportation Board; 1985.
27. National Transportation Safety Board. Airbag performance in general aviation restraint systems, safety report. SS-11/01, Appendix B. Washington (DC): National Transportation Safety Board; 2011.
28. National Transportation Safety Board. NTSB accident database. [Accessed 1-5-2018]. Available from http://app.ntsb.gov/avdata/Access/.
29. Saini M. Flying by the numbers. A precise approach to landing. FAA Safety Briefing. Washington (DC): FAA; 2010:11–14.